FIG. 2

USER-WEARABLE UNIT - 12

MOTION DETECTION UNIT - 36

INPUT/OUTPUT UNIT - 38

BATTERY - 32

CONTROL UNIT - 30

HAPTIC FEEDBACK MECHANISM - 34

RF TRANSCEIVER - 29

RF ANTENNA - 28

GRIP SENSOR - 40
FIG. 3

MANAGEMENT MODULE - 115

RF TRANSCEIVER - 42

FIRST RF ANTENNA - 18
SECOND RF ANTENNA - 22
THIRD RF ANTENNA - 26
transmitting an RF interrogation signal(s) from RF antennas - 52

transmitting RF response signals from a user-wearable unit worn in proximity to a user's hand in response to reception of the radio frequency interrogation signal(s) by the user-wearable unit - 54

generating arrival time signals indicative of arrival times of the RF response signals at the RF antennas - 56

processing the arrival time signals by a management module to track location of the user-wearable unit relative to inventory bins configured to store inventory items - 58

identifying, by the management module, an inventory bin based on proximity of the user-wearable unit to the identified inventory bin - 60

monitoring performance of the inventory system task based on the identified inventory bin - 62

FIG. 8
controlling operation of a haptic feedback mechanism, by the management module, included in the user-wearable unit to communicate a haptic feedback to the user indicating that the identified inventory bin matches a designated inventory bin associated with the inventory system task - 64

controlling operation of a haptic feedback mechanism, by the management module, included in the user-wearable unit to communicate a haptic feedback to the user indicating that the identified inventory bin does not match a designated inventory bin associated with the inventory system task - 66

controlling operation of a haptic feedback mechanism, by the management module, included in the user-wearable unit to communicate a haptic feedback to the user indicating that an inventory item held by the user has been identified by the management module - 68

controlling operation of a haptic feedback mechanism, by the management module, included in the user-wearable unit to communicate a haptic feedback to the user indicating that an inventory item held by the user has not been identified by the management module - 70

controlling operation of a haptic feedback mechanism, by the management module, included in the user-wearable unit to communicate a haptic feedback to the user guiding the user to a designated inventory bin associated with the inventory system task - 72

FIG. 9
tracking motion of the user-wearable unit via a motion detection unit included in the user-wearable unit - 74

transmitting a signal from the user-wearable unit indicative of a command input by the user generated by moving the user-wearable unit in a predetermined manner, the command input relating to the accomplishment of the inventory system task by the user - 76

FIG. 10
tracking motion of the user-wearable unit via a motion detection unit included in the user-wearable unit - 76

processing, by a processor included in the user-wearable unit, output of the motion detection unit to detect a command input by the user - 80

transmitting a signal indicative of the command input from the user-wearable unit - 82

processing, by the management module, the command input as part of monitoring performance of the inventory system task - 84

FIG. 11
FIG. 13
WRIST BAND HAPTIC FEEDBACK SYSTEM

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is related to and incorporates by reference for all purposes the full disclosure of co-pending U.S. patent application Ser. No. 15/083,083, filed Mar. 28, 2016, entitled “ULTRASONIC BRACELET AND RECEIVER FOR DETECTING POSITION IN 2D PLANE”.

BACKGROUND

Modern inventory systems, such as those in mail order warehouses, supply chain distribution centers, airport luggage systems, and custom-order manufacturing facilities, face significant challenges in responding to requests for inventory items. As inventory systems grow, the challenges of simultaneously completing a large number of packing, storing, and other inventory-related tasks become non-trivial.

In many inventory systems, an incoming inventory item is typically stored into an inventory bin so as to be quickly retrievable in response to an order for the inventory item. An inventory management system typically stores the identification and location of the inventory bin in which the inventory item is stored for use in locating and processing the inventory item in response to an order for the inventory item. For example, an inventory system worker can pick up the incoming inventory item and place the inventory item into the inventory bin. To keep track of where the inventory item is stored, it is important to efficiently and accurately identify the inventory bin into which the inventory item is placed. Existing approaches for keeping track of where inventory items are stored, however, may require the inventory system worker to perform time consuming acts beyond placing the inventory item into an inventory bin and retrieving the inventory item from the inventory bin, such as pushing a button associated with the inventory bin or scanning a barcode associated with the inventory bin. And while the inventory system worker may be required to perform less time consuming tasks when a computer vision system is used to track placement of the inventory item, such a computer vision system may be computationally intensive and expensive. Accordingly, improved approaches for keeping track of where an inventory item is stored are of interest.

BRIEF DESCRIPTION OF THE DRAWINGS

Various embodiments in accordance with the present disclosure will be described with reference to the drawings, in which:

FIG. 1 illustrates a radio frequency (RF) tracking system configured to monitor performance of an inventory system task, in accordance with many embodiments;

FIG. 2 is a simplified schematic diagram illustrating a user-wearable unit of an RF tracking system configured to monitor performance of an inventory system task, in accordance with many embodiments;

FIG. 3 is a simplified schematic diagram illustrating components of an RF tracking system configured to monitor performance of an inventory system task, in accordance with many embodiments;

FIG. 4 through FIG. 6 schematically illustrate an approach for determining the location of a user-wearable unit based on time of flight of interrogation signals from and back to respective RF antennas, in accordance with many embodiments;

FIG. 7 schematically illustrates an alternate approach for determining the location of a user-wearable unit based on time of flight of an interrogation signal from a single RF antenna and resulting RF response signals back to three RF antennas, in accordance with many embodiments;

FIG. 8 is a simplified schematic diagram of acts of a computer implemented method of monitoring performance of an inventory system task, in accordance with many embodiments;

FIG. 9 is a simplified schematic diagram of acts involving haptic feedbacks that can be accomplished in the method of FIG. 8, in accordance with many embodiments;

FIG. 10 is a simplified schematic diagram of acts involving generating a user input via a user motion that can be accomplished in the method of FIG. 8, in accordance with many embodiments;

FIG. 11 is a simplified schematic diagram of acts involving generating a user input via a user motion that can be accomplished in the method of FIG. 8, in accordance with many embodiments;

FIG. 12 illustrates components of an inventory system in which an RF tracking system configured to monitor performance of an inventory system task can be implemented, in accordance with many embodiments;

FIG. 13 illustrates components of an example management module that can be employed in the inventory system shown in FIG. 12;

FIGS. 14 and 15 illustrate an example mobile drive unit that can be employed in the inventory system shown in FIG. 12;

FIG. 16 illustrates an example inventory holder that can be utilized in the inventory system shown in FIG. 12; and

FIG. 17 illustrates an environment in which various embodiments can be implemented.

DETAILED DESCRIPTION

In the following description, various embodiments will be described. For purposes of explanation, specific configurations and details are set forth in order to provide a thorough understanding of the embodiments. However, it will also be apparent to one skilled in the art that the embodiments may be practiced without the specific details. Furthermore, well-known features may be omitted or simplified in order not to obscure the embodiment being described.

Inventory management systems are provided that include a radio frequency (RF) based tracking system that tracks movement of one or more hands of an inventory system worker to monitor performance of inventory tasks. The RF based tracking system can include one or more user-wearable units (e.g., one or more wristbands) that are tracked via RF signals to accurately identify their location in an applicable 3D space, thereby providing real time tracking information of the inventory system worker's hand(s) that can be used to improve efficiency of the inventory management system.

A user-wearable unit can be worn on one or both wrists of an inventory system worker who retrieves inventory items from storage locations (e.g., inventory bins, either fixed or movable) and/or places inventory items into storage locations. For example, when placing an inventory item into a storage location, the item can be retrieved by the worker from a transport container. When the item is taken out of the transport container, the item can be identified (e.g., via bar
scan or optical means). The item may be automatically assigned a volume optimized location ("storage cell") to be stored within a designated storage volume (mobile or fixed). The identified storage cell can be conveyed to the associate who then moves the item to the intended storage cell. Movement of the item can be tracked via tracking the location of the user-wearable unit(s), thereby tracking the movement of the worker's hands that are moving the item. The user-wearable unit(s) can be tracked via low power RF link monitoring from a suitable number of antennas. The tracked location of the user-wearable unit(s) is compared with known locations of inventory cells to identify the inventory cell into which the worker places the item or from which the worker retrieves the item. The identified inventory cell can be recorded as the new location of the item and/or can be compared with a system designated inventory cell for the item. If the identified inventory cell does not match a system designated inventory cell, a suitable haptic feedback can be delivered to the worker to alert the worker to a possible incorrect item placement or retrieval. In many embodiments, the worker can override the inventory system. For example, the worker can twist the worker's left wrist, thereby twisting a user-wearable wristband worn thereon, to generate an input command to the inventory system to override the system designated inventory cell and accept the worker's placement of the item via the workers right hand (tracked by a user-wearable wristband on the worker's right hand) into a storage cell selected by the worker. The RF based tracking system can also be operated in a mode in which the worker places items into storage cells selected by the worker, thereby allowing the worker to optimize placement of the items and the placement of the items to be automatically tracked by the inventory system.

Turning now to the drawing figures in which like reference numerals refer to like elements in the various drawing figures, FIG. 1 illustrates a RF based tracking system 10 configured to monitor performance of an inventory system task in accordance with many embodiments. The RF tracking system 10 includes one or more user-wearable units 12 (e.g., wrist bands in the illustrated embodiment) that are worn in proximity to one or both hands of an inventory system worker 14. The tracking system 10 tracks the location of the user-wearable unit(s) 12 via at least one of a first RF interrogation signal 16 emitted by a first RF antenna 18, a second RF interrogation signal 20 emitted by a second RF antenna 22 and a third RF interrogation signal 24 emitted by a third RF antenna 26. Each of the user-wearable units 12 is configured to transmit a first RF response signal in response to reception of the first RF interrogation signal 16 by the user-wearable unit 12, transmit a second RF response signal in response to reception of the second RF interrogation signal 20 by the user-wearable unit 12 and transmit a third RF response signal in response to reception of the third RF interrogation signal 24 by the user-wearable unit 12. The location of each of the user-wearable units 12 can be calculated based on known locations of the RF antennas 18, 22, 26 and respective time of flights of the respective RF signals between each of the RF antennas 18, 22, 26 and each of the user-wearable units 12 using known approaches.

In many embodiments, the location of each of the user-wearable units 12 is tracked, thereby tracking the location of the left hand and/or the right hand of the worker 14. In many embodiments, the RF tracking system 10 tracks the locations of the workers left hand and/or right hand to monitor performance of an inventory task assigned to the worker 14, such as placing an inventory item 13 into an inventory bin 19, retrieving an inventory item 13 from an inventory bin 19, placing an inventory item 13 into an inventory tote 15 or retrieving an inventory item 13 from an inventory tote 15. In many embodiments, the inventory system task is accomplished within an inventory workspace 170. In the embodiment illustrated in FIG. 1, the RF tracking system 10 is configured to track the left hand and/or the right hand of the worker 14 relative to inventory bins of a portable inventory holder 23. The portable inventory holder 23 has a plurality of separate inventory bins 19. In many embodiments, the inventory holder 23 is movable within an inventory facility via a suitable mobile drive unit 20, such as any of the mobile drive units described herein. In the illustrated embodiment, the RF antennas 18, 22, 26 are not mounted to the inventory holder 23. Instead, in the illustrated embodiment, the RF antennas 18, 22, 26 are mounted in known locations separate from the inventory holder 23. The inventory holder 23 is controllably placed relative to the RF antennas 18, 22, 26 within a suitable positional tolerance (e.g., within three-quarters of an inch). By placing the inventory holder 23 relative to the RF antennas 18, 22, 26 within a suitable positional tolerance, each of the inventory bins 19 is thereby placed relative to the RF antennas 18, 22, 26 within a suitable positional tolerance. The resulting time sequence of locations of the user-wearable units 12 is compared to known locations of the inventory bins 19 to detect when the user-wearable unit(s) 12 comes within a suitable proximity of any particular inventory bin 19 corresponding to an interaction between the worker 14 and the particular inventory bin 19.

In many embodiments, the RF tracking system 10 is used to automatically monitor performance of inventory tasks assigned to the inventory worker 14. For example, the inventory worker 14 can be instructed to place an inventory item into a system designated one of the inventory bins 19, such as into inventory bin (C2). Because the inventory holder 23 is positioned to a known position relative to the RF antennas 18, 22, 26, the RF tracking system 10 can track the location of the worker's 14 left hand and/or right hand relative to the inventory bins 19, including relative to the designated inventory bin (C2). The tracked locations can be continually compared to known locations of the inventory bins 19 to detect when the tracked locations come within a designated distance or within a designated volume corresponding to any of the inventory bins 19, including corresponding to the designated inventory bin (C2). If such a qualifying proximity is detected, the corresponding inventory bin can be identified and compared to the designated inventory bin (C2) into which the inventory item should be placed per instructions to the worker 14. If the identified inventory bin matches the designated inventory bin (C2), the RF tracking system 10 can be configured to proceed based on the assumption that the inventory item has been placed into the designated inventory bin (C2). For example, by proceeding based on the assumption that the inventory item has been placed in the designated inventory bin (C2), it may be possible to proceed without the worker 14 performing an action that confirms that the inventory item was placed into the designated bin (C2), such as via scanning of an identification tag for the designated inventory bin (C2). By automatically tracking performance of the assigned inventory task, the RF tracking system 10 can be used to reduce or eliminate actions performed by the worker 14 to confirm performance of an assigned inventory task. In a similar manner, the RF tracking system 10 can be used to monitor performance of an inventory task in which the worker 14 is instructed to retrieve an inventory item from a designated one of the inventory bins 19.
In many embodiments, the RF tracking system 10 is configured to provide feedback to the worker 14 based on the tracked position(s) of the worker’s left hand and/or right hand. For example, each of the user-wearable units 12 can include a haptic feedback mechanism that is controlled to provide suitable haptic feedback to the worker 14 that indicates whether the worker 14 is interacting with the designated inventory bin (C2) or another of the inventory bins 19 different from the system designated inventory bin (C2). Any suitable communication means can be used to transmit a signal to the respective user-wearable unit 12 indicative of whether the worker 14 is interacting with the designated inventory bin (C2) or not. For example, user-wearable unit(s) 12 can include a communication unit (e.g., a Wi-Fi transceiver) to receive a signal indicative of whether the worker 14 is interacting with the designated inventory bin (C2) or another of the inventory bins 19. If a signal is received by the user-wearable unit 12 that the worker 14 is interacting with the designated inventory bin (C2), the user-wearable unit 12 can control the haptic feedback mechanism to provide a confirmatory haptic feedback to the worker 14. If a signal is received by the user-wearable unit 12 that the worker 14 is interacting with an inventory bin 19 other than the designated inventory bin (C2), the user-wearable unit 12 can control the haptic feedback mechanism to provide a haptic feedback to the worker 14 indicating that the worker 14 is interacting with an inventory bin 19 other than the designated inventory bin (C2).

The RF tracking system 10 can also be configured to provide guidance feedback to the worker 14 based on the tracked positions of the user-wearable unit 12. For example, a guidance signal can be transmitted to the user-wearable unit 12 indicating one or more directions in which the worker 14 should move the worker’s respective hand to interact with the designated inventory bin (C2). The user-wearable unit 12 can be configured to control a suitable communication means to communicate to the worker 14 one or more directions to move the worker’s respective hand to interact with the designated inventory bin (C2). For example, the user-wearable unit 12 can include light-emitting diodes (LEDs) (e.g., distributed along an upper surface of the unit 12 and/or along a lower surface of the unit 12) that can be selectively activated based on the orientation of the unit 12 (which can be determined by processing output from the motion detection unit 36, for example, output from an accelerometer indicative of orientation of the unit 12 relative to vertical) to communicate to the worker 14 one or more directions to move the worker’s respective hand to interact with the designated inventory bin (C2). The LEDs can have any suitable distribution, shape, and/or color. For example, any suitable number of the LEDs can be shaped to display a directional arrow and activated to indicate the corresponding direction for the worker 14 to move the worker’s respective hand to interact with the designated inventory bin (C2). As another example, the haptic feedback mechanism 34 can be configured to provide haptic feedback, which can be based on the orientation of the unit 12, to communicate to the worker 14 one or more directions to move the worker’s respective hand to interact with the designated inventory bin (C2). As another example, the unit 12 can include a display screen on which guidance can be presented (e.g., a direction arrow) to communicate to the worker 14 one or more directions to move the worker’s respective hand to interact with the designated inventory bin (C2).

The RF tracking system 10 can also be configured to transmit any suitable data from the user-wearable unit 12. For example, the user-wearable unit 12 can be configured to embed data into one or more of the RF response signals to communicate any suitable attribute of the user-wearable unit 12, such as, for example, identification of the worker 14, indication of whether the user-wearable unit 12 is worn on the left hand or the right hand of the worker 14, a charge state of the user-wearable unit 12, an operational status (e.g., any existing faults) of the user-wearable unit 12 or a duration of use of the user-wearable unit 12. Alternatively, any other suitable communication approach can be used to communicate any suitable attribute of the user-wearable unit 12, including via Wi-Fi transmission.

FIG. 2 is a simplified schematic diagram illustrating an embodiment of the user-wearable unit 12. In the illustrated embodiment, the user-wearable unit 12 includes an RF antenna 28, an RF transceiver 29, a control unit 30, a power source (e.g., battery) 32, a haptic feedback mechanism 34, a motion detection unit 36 and an input/output unit 38. The control unit 30 is operatively connected to the RF transceiver 28, the battery 32, the haptic feedback mechanism 34, the motion detection unit 36, and the input/output unit 38. The control unit 30 can include any suitable electronic components including, but not limited to, a processor, memory, and/or equivalent electronic circuits.

The control unit 30 can detect reception of the RF interrogation signals 16, 20, 24 via the RF antenna 28 and control the RF transceiver 29 to transmit the RF response signals in response to the reception of the RF interrogation signals 16, 20, 24. The control unit 30 can be configured to embed data into the RF response signals indicative of any suitable attribute of the user-wearable unit 12 such as a unique identifier that can be used to identify the worker 14 and/or what hand of the worker 14 on which the user-wearable unit 12 is worn, a charge state of the user-wearable unit 12, an operational status (e.g., any existing faults) of the user-wearable unit 12 or a duration of use of the user-wearable unit 12.

In many embodiments, the control unit 30 controls operation of the haptic feedback mechanism 34 to provide haptic feedback to the worker 14 indicative of whether the worker is interacting with the designated inventory bin (C2) or an inventory bin 19 other than the designated inventory bin (C2). The control unit 30 can receive an input indicating that the worker 14 is interacting with an inventory bin 19 (i.e., the position of the user-wearable unit 12 is within a designated proximity of an inventory bin 19) and whether the identified inventory bin 19 with which the worker 14 is interacting corresponds to the designated inventory bin (C2) or an inventory bin 19 other than the designated inventory bin (C2). For example, the input can be transmitted to the input/output unit 38 (which can include a suitable communication unit such as a wireless transceiver).

In many embodiments, the user-wearable unit 12 includes a motion detection unit 36 configured to generate data that can be processed to track orientation of the user-wearable unit 12. The motion detection unit 36 can include any suitable orientation data generating device, such as a gyroscope chip configured to track orientation of the user-wearable unit 12 or an accelerometer chip configured to track translational and/or rotational accelerations of the user-wearable unit 12. By tracking motion of the user-wearable unit 12, the output from the motion detection unit 36 can be processed to detect input commands generated by the worker 14 by moving the user-wearable unit 12 in recognizable motions corresponding to respective input commands. For example, the input commands can be generated by any variety or combination of motions, e.g.,
The RF tracking system 10 can include a user-worn grip sensor 40 that outputs a signal indicative of whether the inventory worker 14 is holding an inventory item. The grip sensor 40 can be supported in any suitable way. For example, the grip sensor 40 can be mounted to a glove worn by the inventory worker 14. The grip sensor 40 can have any suitable configuration. For example, the grip sensor 40 can include one or more pressure sensors on the fingertips and/or palms, one or more pressure sensors or strain gauges on wristbands, one or more proximity sensors, or any suitable combination of the foregoing items. In many embodiments, the control unit 30 receives an output signal generated by the grip sensor 40. The user-wearable unit 12 can transmit a signal indicative of the output of the grip sensor 40 so that the RF tracking system 10 can process the tracked locations of the user-wearable unit(s) 12 in combination with the output from the grip sensor 40 to detect when an inventory item is placed into the identified inventory bin or retrieved from the identified inventory bin.

FIG. 3 is a simplified schematic diagram illustrating additional components of the RF tracking system 10, in accordance with many embodiments. The additional illustrated components include the first RF antenna 18, the second RF antenna 22, the third RF antenna 26, an RF transceiver 42, and a management module 115. The RF transceiver 42 is operatively coupled with each of the RF antennas 18, 22, 26 and outputs signals to the RF antennas 18, 22, 26 that are converted by the RF antennas 18, 22, 26 into the RF interrogation signals 16, 20, 24. The management module 115 is operatively coupled with the RF transceiver 42 and controls timing of the RF interrogation signals 16, 20, 24. The RF antennas 18, 22, 26 receive the RF response signals and output corresponding signals to the RF transceiver 42, which outputs one or more signals to the management module 115 indicative of the timing of the receipt of the RF response signals by the RF antennas 18, 22, 26.

In many embodiments, the management module 115 processes the respective time of flights of the RF interrogation signals 16, 20, 24 and the respective RF response signals to determine and track location of the user-wearable unit(s) 12. For example, the management module 115 can store data defining respective spatial regions corresponding to each of the inventory bins 19 and evaluate the determined locations of the user-wearable unit(s) 12 to assess whether the determined location is located within any of the respective spatial regions. If the determined location is found to be within any of the respective spatial regions, the management module 115 can be configured to determine that the worker 14 is interacting with the inventory bin 19 corresponding to the respective spatial region. In many embodiments, the management module 115 is configured to evaluate whether the identified inventory bin 19 matches the designated inventory bin (C2), or matches an inventory bin 19 other than the designated inventory bin (C2). In many embodiments, the management module 115 is configured to communicate with the user-wearable unit(s) 12 via a suitable communication mechanism such as those described herein, to indicate, upon occurrence, that the worker 14 is interacting with the designated inventory bin (C2) and, upon occurrence, that the worker 14 is interacting with an inventory bin 19 other than the designated inventory bin (C2).

FIG. 4 through FIG. 6 schematically illustrate an approach for determining the location of a user-wearable unit based on time of flight of interrogation signals from and back to respective RF antennas, in accordance with many embodiments. FIG. 4 depicts a first RF interrogation signal 16 transmitted from the first RF antenna 18 at a first time point (t1). The first RF interrogation signal 16 is thereafter received by the user-wearable unit 12, which transmits a first RF response signal 17 in response to the reception of the first RF interrogation signal 16. The first RF response signal 17 is then received by the first RF antenna 18 at a second time point (t2). The time period between the first time point (t1) and the second time point (t2) is used to determine a first distance (d1) between the first RF antenna 18 and the user-wearable unit 12 (e.g., via a lookup table). In a similar manner, FIG. 5 depicts a second RF interrogation signal 20 transmitted from the second RF antenna 22 at a third time point (t3), for example, a suitable time span after the second time point (t2). The second RF interrogation signal 20 is thereafter received by the user-wearable unit 12, which transmits a second RF response signal 21 in response to the reception of the second RF interrogation signal 20. The second RF response signal 21 is then received by the second RF antenna 22 at a fourth time point (t4). The time period between the third time point (t3) and the fourth time point (t4) is used to determine a second distance (d2) between the second RF antenna 22 and the user-wearable unit 12. In a similar manner, FIG. 6 depicts a third RF interrogation signal 24 transmitted from the third RF antenna 26 at a fifth time point (t5), for example, a suitable time span after the fourth time point (t4). The third RF interrogation signal 24 is thereafter received by the user-wearable unit 12, which transmits a third RF response signal 25 in response to the reception of the third RF interrogation signal 24. The third RF response signal 25 is then received by the third RF antenna 26 at a sixth time point (t6). The time period between the fifth time point (t5) and the sixth time point (t6) is used to determine a third distance (d3) between the third RF antenna 26 and the user-wearable unit 12. In many embodiments, the time span between the first time point (t1) and the sixth time point (t6) is sufficiently short to ensure that the user-wearable unit 12 has not moved significantly.

The three distances (d1, d2, d3) can be used to determine the location of the user-wearable unit 12 based on known locations of the RF antennas 18, 22, 26.

FIG. 7 schematically illustrates an alternate approach for determining the location of a user-wearable unit based on time of flight of an interrogation signal from a single RF antenna and resulting RF response signals back to three RF antennas, in accordance with many embodiments. At a first time point (t1), a first RF interrogation signal 16 is transmitted from the first RF antenna 18 at a first time point (t1). The first RF interrogation signal 16 is thereafter received by the user-wearable unit 12, which transmits a first RF response signal 17 in response to the reception of the first RF.
interrogation signal 16. The first RF response signal 17 is then received by the first RF antenna 18 at a second time point (t2). The time period between the first time point (t1) and the second time point (t2) is used to determine the first distance (d1) between the first RF antenna 18 and the user-wearable unit 12 (e.g., via a lookup table). The first RF response signal 17 is also received by the second RF antenna 22 at a third time point (t3). The first, second, and third time points (t1, t2, t3) can be used to determine the distance (d2) between the second RF antenna 22 and the user-wearable unit 12. The first RF response signal 17 is also received by the third RF antenna 26 at a fourth time point (t4). The first, second and fourth time points (t1, t2, t4) can be used to determine the distance (d3) between the third RF antenna 26 and the user-wearable unit 12. The three distances (d1, d2, d3) can be used to determine the location of the user-wearable unit 12 based on known locations of the RF antennas 18, 22, 26. Any suitable combination or variation of the approaches described herein (based on time of flight of one or more interrogation signals from and back to one or more RF antennas) can be employed to determine the location of the user-wearable unit 12.

FIG. 8 is a simplified schematic diagram of acts of a computer implemented method 50 of monitoring performance of an inventory system task, in accordance with many embodiments. Any suitable RF tracking system can be used to practice the method 50, such as the RF tracking system 10 described herein. The method 50 includes transmitting an RF interrogation signal(s) from RF antennas (act 52). An RF response signal(s) is transmitted from a user-wearable unit(s) worn in proximity to a user’s hand in response to reception of the RF interrogation signal(s) by the user-wearable unit(s) (act 54). One or more signals indicative of arrival times of the RF response signal(s) at the RF antennas are generated (act 56). The one or more signals are processed, by a management module, to track location of the user-wearable unit(s) relative to inventory bins configured to store inventory items (act 58). An inventory bin is identified, by the management module, based on proximity of the user-wearable unit to the identified inventory bin (act 60). Performance of the inventory task is monitored based on the identified inventory bin (act 62).

FIG. 9 is a simplified schematic diagram of acts involving haptic feedbacks that can be optionally accomplished in the method 50, in accordance with many embodiments. The optional acts include controlling operation of a haptic feedback mechanism, by the management module, included in the user-wearable unit to communicate a haptic feedback to the user indicating that the identified inventory bin matches a designated inventory bin associated with the inventory system task (act 64). The haptic feedback mechanism can be controlled by the management module to communicate a haptic feedback to the user indicating that the identified inventory bin does not match a designated inventory bin associated with the inventory system task (act 66). The haptic feedback mechanism can be controlled by the management module to communicate a haptic feedback to the user indicating that an inventory item held by the user has been identified by the management module (act 68). The haptic feedback mechanism can be controlled by the management module to communicate a haptic feedback to the user guiding the user to a designated inventory bin associated with the inventory system task (act 72).
portions of workspace 170 as parking spaces for mobile drive units 120, the scheduled recharge or replacement of mobile drive unit batteries, the storage of empty inventory holders 130, or any other operations associated with the functionality supported by inventory system 110 and its various components. Management module 115 may select components of inventory system 110 to perform these tasks and communicate appropriate commands and/or data to the selected components to facilitate completion of these operations. Although shown in FIG. 12 as a single, discrete component, management module 115 may represent multiple components and may represent or include portions of mobile drive units 120 or other elements of inventory system 110. As a result, any or all of the interaction between a particular mobile drive unit 120 and management module 115 that is described below may, in particular embodiments, represent peer-to-peer communication between that mobile drive unit 120 and one or more other mobile drive units 120.

Mobile drive units 120 move inventory holders 130 between locations within workspace 170. Mobile drive units 120 may represent any devices or components appropriate for use in inventory system 110 based on the characteristics and configuration of inventory holders 130 and/or other elements of inventory system 110. In a particular embodiment of inventory system 110, mobile drive units 120 represent independent, self-powered devices configured to freely move about workspace 170. Examples of such inventory systems are disclosed in U.S. Pat. No. 9,087,314, issued Jul. 21, 2015, titled “SYSTEM AND METHOD FOR POSITIONING A MOBILE DRIVE UNIT” and U.S. Pat. No. 8,280,547, issued on Oct. 2, 2012, titled “METHOD AND SYSTEM FOR TRANSPORTING INVENTORY ITEMS”, the entire disclosures of which are herein incorporated by reference. In alternative embodiments, mobile drive units 120 represent elements of a tracked inventory system configured to move inventory holder 130 along tracks, rails, cables, crane system, or other guidance or support elements traversing workspace 170. In such an embodiment, mobile drive units 120 may receive power and/or support through a connection to the guidance elements, such as a powered rail. Additionally, in particular embodiments of inventory system 110 mobile drive units 120 may be configured to utilize alternative conveyance equipment to move within workspace 170 and/or between separate portions of workspace 170. The contents and operation of an example embodiment of a mobile drive unit 120 are discussed further below with respect to FIGS. 14 through 16.

Additionally, mobile drive units 120 may be capable of communicating with management module 115 to receive information identifying selected inventory holders 130, transmit the locations of mobile drive units 120, or exchange any other suitable information to be used by management module 115 or mobile drive units 120 during operation. Mobile drive units 120 may communicate with management module 115 wirelessly, using wired connections between mobile drive units 120 and management module 115, and/or in any other appropriate manner. As one example, particular embodiments of mobile drive units 120 may communicate with management module 115 and/or with one another using 802.11, Bluetooth, or Infrared Data Association (IrDA) standards, or any other appropriate wireless communication protocol. As another example, in a tracked inventory system 110, tracks or other guidance elements up upon which mobile drive units 120 may freely move about workspace 170 and communicate appropriate commands and/or data to the components of inventory system 110. Furthermore, as noted above, management module 115 may include components of individual mobile drive units 120. Thus, for the purposes of this description and the claims that follow, communication between management module 115 and a particular mobile drive unit 120 may represent communication between components of a particular mobile drive unit 120. In general, mobile drive units 120 may be powered, propelled, and controlled in any manner appropriate based on the configuration and characteristics of inventory system 110.

Inventory holders 130 store inventory items. In a particular embodiment, inventory holders 130 include multiple storage bins with each storage bin capable of holding one or more types of inventory items. Inventory holders 130 are capable of being carried, rolled, and/or otherwise moved by mobile drive units 120. In particular embodiments, inventory holder 130 may provide additional propulsion to supplement that provided by mobile drive units 120 when moving inventory holder 130.

Additionally, in particular embodiments, inventory items may also hang from hooks or bars (not shown) within or on inventory holder 130. In general, inventory holder 130 may store inventory items in any appropriate manner within inventory holder 130 and/or on the external surface of inventory holder 130.

Additionally, each inventory holder 130 may include a plurality of faces, and each bin may be accessible through one or more faces of the inventory holder 130. For example, in a particular embodiment, inventory holder 130 includes four faces. In such an embodiment, bins located at a corner of two faces may be accessible through either of those two faces, while each of the other bins is accessible through an opening in one of the four faces. Mobile drive unit 120 may be configured to rotate inventory holder 130 at appropriate times to present a particular face and the bins associated with that face to an operator or other components of inventory system 110.

Inventory items represent any objects suitable for storage, retrieval, and/or processing in an automated inventory system 110. For the purposes of this description, “inventory items” may represent any one or more objects of a particular type that are stored in inventory system 110. Thus, a particular inventory holder 130 is currently “storing” a particular inventory item if the inventory holder 130 currently holds one or more units of that type. As one example, inventory system 110 may represent a mail order warehouse facility, and inventory items may represent merchandise stored in the warehouse facility. During operation, mobile drive units 120 may retrieve inventory holders 130 containing one or more inventory items requested in an order to be packed for delivery to a customer or inventory holders 130 carrying pallets containing aggregated collections of inventory items for shipment. Moreover, in particular embodiments of inventory system 110, boxes containing completed orders may themselves represent inventory items.

In particular embodiments, inventory system 110 may also include one or more inventory stations 150. Inventory stations 150 represent locations designated for the completion of particular tasks involving inventory items. Such tasks may include the removal of inventory items from inventory holders 130, the introduction of inventory items into inventory holders 130, the counting of inventory items in inventory holders 130, the decomposition of inventory items (e.g., from pallet- or case-sized groups to individual inventory items), the consolidation of inventory items between inventory holders 130, and/or the processing or handling of inventory items in any other suitable manner. In particular embodiments, inventory stations 150 may just represent the physical locations where a particular task involving inven-
management of mobile drive units

tration, an embodiment of inventory system

movement of mobile drive units

tors of inventory stations

ory items can be completed within workspace

with the corresponding task and/or any other appropriate 50

replenishment, and counting of inventory items and/or the 100

workspace

nents of the inventory system

workspace

ates. In sorne embodiments, workspace 170 includes multi-

tuple floors, and some combination of ramps, elevators, conveyors, and/or other devices are provided to facilitate move-

ment of mobile drive units 120 and/or other components of the inventory system 110 between the multiple floors. Although FIG. 12 shows, for the purposes of illustration, an embodiment of inventory system 110 in which workspace 170 includes a fixed, predetermined, and finite physical space, particular embodiments of inventory system 110 may include mobile drive units 120 and inventory holders 130 that are configured to operate within a workspace 170 that is of variable dimensions and/or an arbitrary geometry. While FIG. 12 illustrates a particular embodiment of inventory system 110 in which workspace 170 is entirely enclosed in a building, alternative embodiments may utilize workspaces 170 in which some or all of the workspace 170 is located outdoors, within a vehicle (such as a cargo ship), or otherwise unconstrained by any fixed structure.

In operation, management module 115 selects appropriate components to complete particular tasks and transmits task assignments 118 to the selected components to trigger completion of the relevant tasks. Each task assignment 118 defines one or more tasks to be completed by a particular component. These tasks may relate to the retrieval, storage, replenishment, and counting of inventory items and/or the management of mobile drive units 120, inventory holders 130, inventory stations 150 and other components of inventory system 110. Depending on the component and the task to be completed, a particular task assignment 118 may identify locations, components, and/or actions associated with the corresponding task and/or any other appropriate information to be used by the relevant component in completing the assigned task.

In particular embodiments, management module 115 generates task assignments 118 based, in part, on inventory requests that management module 115 receives from other components of inventory system 110 and/or from external components in communication with management module 115. These inventory requests identify particular operations to be completed involving inventory items stored or to be stored within inventory system 110 and may represent communication of any suitable form. For example, in particular embodiments, an inventory request may represent a shipping order specifying particular inventory items that have been purchased by a customer and that are to be retrieved from inventory system 110 for shipment to the customer. Management module 115 may also generate task assignments 118 independently of such inventory requests, as part of the overall management and maintenance of inventory system 110. For example, management module 115 may generate task assignments 118 in response to the occurrence of a particular event (e.g., in response to a mobile drive unit 120 requesting a space to park), according to a predetermined schedule (e.g., as part of a daily start-up routine), or at any appropriate time based on the configuration and characteristics of inventory system 110. After generating one or more task assignments 118, management module 115 transmits the generated task assignments 118 to appropriate components for completion of the corresponding task. The relevant components then execute their assigned tasks.

With respect to mobile drive units 120 specifically, management module 115 may, in particular embodiments, communicate task assignments 118 to selected mobile drive units 120 that identify one or more destinations for the selected mobile drive units 120. Management module 115 may select a mobile drive unit 120 to assign the relevant task based on the location or state of the selected mobile drive unit 120, an indication that the selected mobile drive unit 120 has completed a previously-assigned task, a predetermined schedule, and/or any other suitable consideration. These destinations may be associated with an inventory request the management module 115 is executing or a management objective the management module 115 is attempting to fulfill. For example, the task assignment may define the location of an inventory holder 130 to be retrieved, an inventory station 170 to be visited, a storage location where the mobile drive unit 120 should park until receiving another task, or a location associated with any other task appropriate based on the configuration, characteristics, and/or state of inventory system 110, as a whole, or individual components of inventory system 110. For example, in particular embodiments, such decisions may be based on the popularity of particular inventory items, the stuffing of a particular inventory station 150, the tasks currently assigned to a particular mobile drive unit 120, and/or any other appropriate considerations.

As part of completing these tasks mobile drive units 120 may dock with and transport inventory holders 130 within workspace 170. Mobile drive units 120 may dock with inventory holders 130 by connecting to, lifting, and/or otherwise interacting with inventory holders 130 in any other suitable manner so that, when docked, mobile drive units 120 are coupled to and/or support inventory holders 130 and can move inventory holders 130 within workspace 170. While the description below focuses on particular embodiments of mobile drive unit 120 and inventory holder 130 that are configured to dock in a particular manner, alternative embodiments of mobile drive unit 120 and inventory holder 130 may be configured to dock in any manner suitable to allow mobile drive unit 120 to move inventory holder 130 within workspace 170. Additionally, as noted below, in particular embodiments, mobile drive units 120 represent all or portions of inventory holders 130. In such embodiments, mobile drive units 120 may not dock with inventory holders 130 before transporting inventory holders 130 and/or mobile drive units 120 may each remain continually docked with a particular inventory holder 130.

While the appropriate components of inventory system 110 complete assigned tasks, management module 115 may interact with the relevant components to ensure the efficient use of space, equipment, manpower, and other resources available to inventory system 110. As one specific example of such interaction, management module 115 is responsible, in particular embodiments, for planning the paths mobile drive units 120 take when moving within workspace 170 and...
for allocating use of a particular portion of workspace 170 to a particular mobile drive unit 120 for purposes of completing an assigned task. In such embodiments, mobile drive units 120 may, in response to being assigned a task, request a path to a particular destination associated with the task. Moreover, while the description below focuses on one or more embodiments in which mobile drive unit 120 requests paths from management module 115, mobile drive unit 120 may, in alternative embodiments, generate its own paths.

Components of inventory system 110 may provide information to management module 115 regarding their current state, other components of inventory system 110 with which they are interacting, and/or other conditions relevant to the operation of inventory system 110. This may allow management module 115 to utilize feedback from the relevant components to update algorithm parameters, adjust policies, or otherwise modify its decision-making to respond to changes in operating conditions or the occurrence of particular events.

In addition, while management module 115 may be configured to manage various aspects of the operation of the components of inventory system 110, in particular embodiments, the components themselves may also be responsible for decision-making relating to certain aspects of their operation, thereby reducing the processing load on management module 115.

Thus, based on its knowledge of the location, current state, and/or other characteristics of the various components of inventory system 110 and an awareness of all the tasks currently being completed, management module 115 can generate tasks, allot usage of system resources, and otherwise direct the completion of tasks by the individual components in a manner that optimizes operation from a system-wide perspective. Moreover, by relying on a combination of both centralized, system-wide management and localized, component-specific decision-making, particular embodiments of inventory system 110 may be able to support a number of techniques for efficiently executing various aspects of the operation of inventory system 110. As a result, particular embodiments of management module 115 may, by implementing one or more management techniques described below, enhance the efficiency of inventory system 110 and/or provide other operational benefits.

FIG. 13 illustrates in greater detail the components of a particular embodiment of management module 115. As shown, the example embodiment includes a resource scheduling module 192, a route planning module 194, a segment reservation module 196, an inventory module 197, a communication interface module 198, a processor 190, and a memory 191. Management module 115 may represent a single component, multiple components located at a central location within inventory system 110, or multiple components distributed throughout inventory system 110. For example, management module 115 may represent components of one or more mobile drive units 120 that are capable of communicating information between the mobile drive units 120 and coordinating the movement of mobile drive units 120 within workspace 170. In general, management module 115 may include any appropriate combination of hardware and/or software suitable to provide the described functionality.

Processor 190 is operable to execute instructions associated with the functionality provided by management module 115. Processor 190 may comprise one or more general purpose computers, dedicated microprocessors, or other processing devices capable of communicating electronic information. Examples of processor 190 include one or more application-specific integrated circuits (ASICs), field-programmable gate arrays (FPGAs), digital signal processors (DSPs) and any other suitable specific or general purpose processors.

Memory 191 stores processor instructions, inventory requests, reservation information, state information for the various components of inventory system 110 and/or any other appropriate values, parameters, or information utilized by management module 115 during operation. Memory 191 may represent any collection and arrangement of volatile or nonvolatile, local or remote devices suitable for storing data. Examples of memory 191 include, but are not limited to, random access memory (RAM) devices, read only memory (ROM) devices, magnetic storage devices, optical storage devices, or any other suitable data storage devices.

Resource scheduling module 192 processes received inventory requests and generates one or more assigned tasks to be completed by the components of inventory system 110. Resource scheduling module 192 may also select one or more appropriate components for completing the assigned tasks and, using communication interface module 198, communicate the assigned tasks to the relevant components. Additionally, resource scheduling module 192 may also be responsible for generating tasks associated with various management operations, such as prompting mobile drive units 120 to recharge batteries or have batteries replaced, instructing inactive mobile drive units 120 to park in a location outside the anticipated traffic flow or a location near the anticipated site of future tasks, and/or directing mobile drive units 120 selected for repair or maintenance to move towards a designated maintenance station.

Route planning module 194 receives route requests from mobile drive units 120. These route requests identify one or more destinations associated with a task the requesting mobile drive unit 120 is executing. In response to receiving a route request, route planning module 194 generates a path to one or more destinations identified in the route request. Route planning module 194 may implement any appropriate algorithms utilizing any appropriate parameters, factors, and/or considerations to determine the appropriate path. After generating an appropriate path, route planning module 194 transmits a route response identifying the generated path to the requesting mobile drive unit 120 using communication interface module 198.

Segment reservation module 196 receives reservation requests from mobile drive units 120 attempting to move along paths generated by route planning module 194. These reservation requests request the use of a particular portion of workspace 170 (referred to herein as a “segment”) to allow the requesting mobile drive unit 120 to avoid collisions with other mobile drive units 120 while moving across the reserved segment. In response to received reservation requests, segment reservation module 196 transmits a reservation response granting or denying the reservation request to the requesting mobile drive unit 120 using the communication interface module 198.

The inventory module 197 maintains information about the location and number of inventory items in the inventory system 110. Information can be maintained about the number of inventory items in a particular inventory holder 130, and the maintained information can include the location of those inventory items in the inventory holder 130. The inventory module 197 can also communicate with the mobile drive units 120, utilizing task assignments 118 to maintain, replenish, or move inventory items within the inventory system 110.
Communication interface module 198 facilitates communication between management module 115 and other components of inventory system 110, including reservation responses, reservation requests, route requests, route responses, and task assignments. These reservation responses, reservation requests, route requests, route responses, and task assignments may represent communication of any form appropriate based on the capabilities of management module 115 and may include any suitable information. Depending on the configuration of management module 115, communication interface module 198 may be responsible for facilitating either or both of wired and wireless communication between management module 115 and the various components of inventory system 110. In particular embodiments, management module 115 may communicate using communication protocols such as 802.11, Bluetooth, or Infrared Data Association (IrDA) standards. Furthermore, management module 115 may, in particular embodiments, represent a portion of mobile drive unit 120 or other components of inventory system 110. In such embodiments, communication interface module 198 may facilitate communication between management module 115 and other parts of the same system component.

In general, resource scheduling module 192, route planning module 194, segment reservation module 196, inventory module 197, and communication interface module 198 may each represent any appropriate hardware and/or software suitable to provide the described functionality. In addition, as noted above, management module 115 may, in particular embodiments, represent multiple different discrete components and any or all of resource scheduling module 192, route planning module 194, segment reservation module 196, inventory module 197, and communication interface module 198 may represent components physically separate from the remaining elements of management module 115. Moreover, any two or more of resource scheduling module 192, route planning module 194, segment reservation module 196, inventory module 197, and communication interface module 198 may share common components. For example, in particular embodiments, resource scheduling module 192, route planning module 194, segment reservation module 196, and inventory module 197 represent computer processes executing on processor 190 and communication interface module 198 comprises a wireless transmitter, a wireless receiver, and a related computer process executing on processor 190.

FIGS. 14 through 16 illustrate in greater detail the components of a particular embodiment of mobile drive unit 120. In particular, FIGS. 14 through 16 include a front and side view of an example mobile drive unit 120. Mobile drive unit 120 includes a docking head 210, a drive module 220, a docking actuator 230, and a control module 270. Additionally, mobile drive unit 120 may include one or more sensors configured to detect or determine the location of mobile drive unit 120, inventory holder 130, and/or other appropriate elements of inventory system 110. In the illustrated embodiment, mobile drive unit 120 includes a position sensor 240, a holder sensor 250, an obstacle sensor 260, and an identification signal transmitter 262.

Docking head 210, in particular embodiments of mobile drive unit 120, couples mobile drive unit 120 to inventory holder 130 and/or supports inventory holder 130 when mobile drive unit 120 is docked to inventory holder 130. Docking head 210 may additionally allow mobile drive unit 120 to maneuver inventory holder 130, such as by lifting inventory holder 130, propelling inventory holder 130, rotating inventory holder 130, and/or moving inventory holder 130 in any other appropriate manner. Docking head 210 may also include any appropriate combination of components, such as ribs, spikes, and/or corrugations, to facilitate such manipulation of inventory holder 130. For example, in particular embodiments, docking head 210 may include a high-friction portion that abuts a portion of inventory holder 130 while mobile drive unit 120 is docked to inventory holder 130. In such embodiments, frictional forces created between the high-friction portion of docking head 210 and a surface of inventory holder 130 may induce translational and rotational movement in inventory holder 130 when docking head 210 moves and rotates, respectively. As a result, mobile drive unit 120 may be able to manipulate inventory holder 130 by moving or rotating docking head 210, either independently or as a part of the movement of mobile drive unit 120 as a whole.

Drive module 220 propels mobile drive unit 120 and, when mobile drive unit 120 and inventory holder 130 are docked, inventory holder 130. Drive module 220 may represent any appropriate collection of components operable to propel mobile drive unit 120. For example, in the illustrated embodiment, drive module 220 includes a pair of motorized wheels 224, and a pair of stabilizing wheels 226. One motorized wheel 224 is located on each side of the mobile drive unit 20, and one stabilizing wheel 226 is positioned at each end of mobile drive unit 120. Each of the motorized wheels 224 is driven via an associated drive unit 225.

Docking actuator 230 moves docking head 210 towards inventory holder 130 to facilitate docking of mobile drive unit 120 and inventory holder 130. Docking actuator 230 may also be capable of adjusting the position or orientation of docking head 210 in other suitable manners to facilitate docking. Docking actuator 230 may include any appropriate components, based on the configuration of mobile drive unit 120 and inventory holder 130, for moving docking head 210 or otherwise adjusting the position or orientation of docking head 210. For example, in the illustrated embodiment, docking actuator 230 includes a motorized shaft (not shown) attached to the center of docking head 210. The motorized shaft is operable to lift docking head 210 as appropriate for docking with inventory holder 130.

Drive module 220 may be configured to propel mobile drive unit 120 in any appropriate manner. For example, in the illustrated embodiment, motorized wheels 224 are operable to rotate in a first direction to propel mobile drive unit 120 in a forward direction. Motorized wheels 224 are also operable to rotate in a second direction to propel mobile drive unit 120 in a backward direction. In the illustrated embodiment, drive module 220 is also configured to rotate mobile drive unit 120 by rotating motorized wheels 224 in different directions from one another or by rotating motorized wheels 224 at different speeds from one another.

Position sensor 240 represents one or more sensors, detectors, or other components suitable for determining the location of mobile drive unit 120 in any appropriate manner. For example, in particular embodiments, the workspace 170 associated with inventory system 110 includes a number of fiducial marks that mark points on a two-dimensional grid that covers all or a portion of workspace 170. In such embodiments, position sensor 240 may include a camera and suitable image- and/or video-processing components, such as an appropriately-programmed digital signal processor, to allow position sensor 240 to detect fiducial marks within the camera's field of view. Control module 270 may store location information that position sensor 240 updates as position sensor 240 detects fiducial marks. As a result, position sensor 240 may utilize fiducial marks to maintain an
accurate indication of the location mobile drive unit 120 and to aid in navigation when moving within workspace 170.

Holder sensor 250 represents one or more sensors, detectors, or other components suitable for detecting inventory holder 130 and/or determining, in any appropriate manner, the location of inventory holder 130, as an absolute location or as a position relative to mobile drive unit 120. Holder sensor 250 may be capable of detecting the location of a particular portion of inventory holder 130 or inventory holder 130 as a whole. Mobile drive unit 120 may then use the detected information for docking with or otherwise interacting with inventory holder 130.

Obstacle sensor 260 represents one or more sensors capable of detecting objects located in one or more different directions in which mobile drive unit 120 is capable of moving. Obstacle sensor 260 may utilize any appropriate components and techniques, including optical, radar, sonar, pressure-sensing and/or other types of detection devices appropriate to detect objects located in the direction of travel of mobile drive unit 120. In particular embodiments, obstacle sensor 260 may transmit information describing objects it detects to control module 270 to be used by control module 270 to identify obstacles and to take appropriate remedial actions to prevent mobile drive unit 120 from colliding with obstacles and/or other objects.

Obstacle sensor 260 may also detect signals transmitted by other mobile drive units 120 operating in the vicinity of the illustrated mobile drive unit 120. For example, in particular embodiments of inventory system 110, one or more mobile drive units 120 may include an identification signal transmitter 262 that transmits a drive identification signal. The drive identification signal indicates to other mobile drive units 120 that the object transmitting the drive identification signal is in fact a mobile drive unit. Identification signal transmitter 262 may be capable of transmitting infrared, ultraviolet, audio, visible light, radio, and/or other suitable signals that indicate to recipients that the transmitting device is a mobile drive unit 120.

Additionally, in particular embodiments, obstacle sensor 260 may also be capable of detecting state information transmitted by other mobile drive units 120. For example, in particular embodiments, identification signal transmitter 262 may be capable of including state information relating to mobile drive unit 120 in the transmitted identification signal. This state information may include, but is not limited to, the position, velocity, direction, and the braking capabilities of the transmitting mobile drive unit 120. In particular embodiments, mobile drive unit 120 may use the state information transmitted by other mobile drive units to avoid collisions when operating in close proximity with those other mobile drive units.

Control module 270 monitors and/or controls operation of drive module 220 and docking actuator 230. Control module 270 may also receive information from sensors such as position sensor 240 and holder sensor 250 and adjust the operation of drive module 220, docking actuator 230, and/or other components of mobile drive unit 120 based on this information. Additionally, in particular embodiments, mobile drive unit 120 may be configured to communicate with a management device of inventory system 110 and control module 270 may receive commands transmitted to mobile drive unit 120 and communicate information back to the management device utilizing appropriate communication components of mobile drive unit 120. Control module 270 may include any appropriate hardware and/or software suitable to provide the described functionality. In particular embodiments, control module 270 includes a general-purpose microprocessor programmed to provide the described functionality. Additionally, control module 270 may include all or portions of docking actuator 230, drive module 220, position sensor 240, and/or holder sensor 250, and/or share components with any of these elements of mobile drive unit 120.

Moreover, in particular embodiments, control module 270 may include hardware and software located in components that are physically distinct from the device that houses drive module 220, docking actuator 230, and/or the other components of mobile drive unit 120 described above. For example, in particular embodiments, each mobile drive unit 120 operating in inventory system 110 may be associated with a software process (referred to here as a “drive agent”) on behalf of the device that physically houses drive module 220, docking actuator 230, and the other appropriate components of mobile drive unit 120. This drive agent may be responsible for requesting and receiving tasks, requesting and receiving routes, transmitting state information associated with mobile drive unit 120, and/or otherwise interacting with management module 115 and other components of inventory system 110 on behalf of the device that physically houses drive module 220, docking actuator 230, and the other appropriate components of mobile drive unit 120. As a result, for the purposes of this description and the claims that follow, the term “mobile drive unit” includes software and/or hardware, such as agent processes, that provides the described functionality on behalf of mobile drive unit 120 but that may be located in physically distinct devices from the drive module 220, docking actuator 230, and/or the other components of mobile drive unit 120 described above.

While FIGS. 14 through 16 illustrate a particular embodiment of mobile drive unit 120 containing certain components and configured to operate in a particular manner, mobile drive unit 120 may represent any appropriate component and/or collection of components configured to transport and/or facilitate the transport of inventory holders 130. As another example, mobile drive unit 120 may represent part of an overhead crane system in which one or more crane assemblies are capable of moving within a network of wires or rails to a position suitable to dock with a particular inventory holder 130. After docking with inventory holder 130, the crane assembly may then lift inventory holder 130 and move inventory to another location for purposes of completing an assigned task.

FIG. 17 illustrates aspects of an example environment 1300 for implementing aspects in accordance with various embodiments. As will be appreciated, although a Web-based environment is used for purposes of explanation, different environments may be used, as appropriate, to implement various embodiments. The environment includes an electronic client device 1302, which can include any appropriate device operable to send and receive requests, messages, or information over an appropriate network 1304 and convey information back to a user of the device. Examples of such client devices include personal computers, cell phones, handheld messaging devices, laptop computers, set-top boxes, personal data assistants, electronic book readers, and the like. The network can include any appropriate network, including an intranet, the Internet, a cellular network, a local area network, or any other such network or combination thereof. Components used for such a system can depend at least in part upon the type of network and/or environment selected. Protocols and components for communicating via such a network are well known and will not be discussed herein in detail. Communication over the network can be
enabled by wired or wireless connections and combinations thereof. In this example, the network includes the Internet, as the environment includes a Web server 1306 for receiving requests and serving content in response thereto, although for other networks an alternative device serving a similar purpose could be used as would be apparent to one of ordinary skill in the art.

The illustrative environment includes at least one application server 1308 and a data store 1310. It should be understood that there can be several application servers, layers, or other elements, processes, or components, which may be chained or otherwise configured, which can interact to perform tasks such as obtaining data from an appropriate data store. As used herein the term “data store” refers to any device or combination of devices capable of storing, accessing, and retrieving data, which may include any combination and/or number of databases, data structures, data storage devices, and data storage media, in any standard, distributed, or clustered environment. The application server can include any appropriate hardware and software for integrating with the data store as needed to execute aspects of one or more applications for the client device, handling a majority of the data access and business logic for an application. The application server provides access control services in cooperation with the data store and is able to generate content such as text, graphics, audio, and/or video to be transferred to the user, which may be served to the user by the Web server in the form of HyperText Markup Language (“HTML”), Extensible Markup Language (“XML”), or another appropriate structured language in this example. The handling of all requests and responses, as well as the delivery of content between the client device 1302 and the application server 1308, can be handled by the Web server. It should be understood that the Web and application servers are not required and are merely example components, as structured code discussed herein can be executed on any appropriate device or host machine as discussed elsewhere herein.

The data store 1310 can include several separate data tables, databases or other data storage mechanisms and media for storing data relating to a particular aspect. For example, the data store illustrated includes mechanisms for storing production data 1312 and user information 1316, which can be used to serve content for the production side. The data store 1310 can include inventory information 1318, for example, including identification of items stored in the inventory system and identification of the storage location for each of the respective inventory items. The data store also is shown to include a mechanism for storing log data 1314, which can be used for reporting, analysis, or other such purposes. It should be understood that there can be many other aspects that may need to be stored in the data store, such as for page image information and to access right information, which can be stored in any of the above listed mechanisms as appropriate or in additional mechanisms in the data store 1310. The data store 1310 is operable, through logic associated therewith, to receive instructions from the application server 1308 and obtain, update or otherwise process data in response thereto. In one example, a user might submit a search request for a certain type of item. In this case, the data store might access the user information to verify the identity of the user and can access the catalog detail information to obtain information about items of that type. The information then can be returned to the user, such as in a results listing on a Web page that the user is able to view via a browser on the user device 1302. Information for a particular item of interest can be viewed in a dedicated page or window of the browser.

Each server typically will include an operating system that provides executable program instructions for the general administration and operation of that server and typically will include a computer-readable storage medium (e.g., a hard disk, random access memory, read only memory, etc.) storing instructions that, when executed by a processor of the server, allow the server to perform its intended functions. Suitable implementations for the operating system and general functionality of the servers are known or commercially available and are readily implemented by persons having ordinary skill in the art, particularly in light of the disclosure herein.

The environment in one embodiment is a distributed computing environment utilizing several computer systems and components that are interconnected via communication links, using one or more computer networks or direct connections. However, it will be appreciated by those of ordinary skill in the art that such a system could operate equally well in a system having fewer or a greater number of components than are illustrated in FIG. 17. Thus, the depiction of the system 1300 in FIG. 17 should be taken as being illustrative in nature and not limiting to the scope of the disclosure.

The various embodiments further can be implemented in a wide variety of operating environments, which in some cases can include one or more user computers, computing devices or processing devices which can be used to operate any of a number of applications. User or client devices can include any of a number of general purpose personal computers, such as desktop or laptop computers running a standard operating system, as well as cellular, wireless, and handheld devices running mobile software and capable of supporting a number of networking and messaging protocols. Such a system also can include a number of workstations running any of a variety of commercially-available operating systems and other known applications for purposes such as development and database management. These devices also can include other electronic devices, such as dummy terminals, thin-clients, gaming systems, and other devices capable of communicating via a network.

Most embodiments utilize at least one network that would be familiar to those skilled in the art for supporting communications using any of a variety of commercially-available protocols, such as Transmission Control Protocol/Internet Protocol (“TCP/IP”), Open System Interconnection (“OSI”), File Transfer Protocol (“FTP”), Universal Plug and Play (“UpnP®”), Network File System (“NFS”), Common Internet File System (“CIFS”), and AppleTalk. The network can be, for example, a local area network, a wide-area network, a virtual private network, the Internet, an intranet, an extranet, a public switched telephone network, an infrared network, a wireless network, and any combination thereof.

In embodiments utilizing a Web server, the Web server can run any of a variety of server or mid-tier applications, including Hypertext Transfer Protocol (“HTTP”) servers, FTP servers, Common Gateway Interface (“CGI”) servers, data servers, Java servers, and business application servers. The server(s) also may be capable of executing programs or scripts in response to requests from user devices, such as by executing one or more Web applications that may be implemented as one or more scripts or programs written in any programming language, such as Java®, C, C#, or C++, or any scripting language, such as Perl, Python, or TCL, as well as combinations thereof. The server(s) may also include
database servers, including without limitation those commercially available from Oracle®, Microsoft®, Sybase®, and IBM®.

The environment can include a variety of data stores and other memory and storage media as discussed above. These can reside in a variety of locations, such as on a storage medium local to (and/or resident in) one or more of the computers or remote from any or all of the computers across the network. In a particular set of embodiments, the information may reside in a storage-area network (“SAN”) familiar to those skilled in the art. Similarly, any necessary files for performing the functions attributed to the computers, servers, or other network devices may be stored locally and/or remotely, as appropriate. Where a system includes computerized devices, each such device can include hardware elements that may be electrically coupled via a bus, the elements including, for example, at least one central processing unit (“CPU”), at least one input device (e.g., a mouse, keyboard, controller, touch screen, or keypad), and at least one output device (e.g., a display device, printer, or speaker). Such a system may also include one or more storage devices, such as disk drives, optical storage devices, and solid-state storage devices such as random access memory (“RAM”) or read-only memory (“ROM”), as well as removable media devices, memory cards, flash cards, etc.

Such devices also can include a computer-readable storage medium reader, a communications device (e.g., a modem, a network card (wireless or wired)), an infrared communication device, etc.), and working memory as described above. The computer-readable storage media reader can be connected with, or configured to receive, a computer-readable storage medium, representing remote, local, fixed, and/or removable storage devices as well as storage media for temporarily and/or more permanently containing, storing, transmitting, and retrieving computer-readable information. The system and various devices also typically will include a number of software applications, modules, services, or other elements located within at least one working memory device, including an operating system and application programs, such as a client application or Web browser. It should be appreciated that alternate embodiments may have numerous variations from that described above. For example, customized hardware might also be used and/or particular elements might be implemented in hardware, software (including portable software, such as applets), or both. Further, connection to other computing devices such as network input/output devices may be employed.

Storage media computer readable media for containing code, or portions of code, can include any appropriate media known or used in the art, including storage media and communication media, such as but not limited to volatile and non-volatile, removable and non-removable media implemented in any method or technology for storage and/or transmission of information such as computer readable instructions, data structures, program modules, or other data, including RAM, ROM, Electrically Erasable Programmable Read-Only Memory ("EEPROM"), flash memory or other memory technology, Compact Disc Read-Only Memory ("CD-ROM"), digital versatile disk (DVD), or other optical storage, magnetic cassettes, magnetic tape, magnetic disk storage, or other magnetic storage devices, or any other medium which can be used to store the desired information and which can be accessed by a system device. Based on the disclosure and teachings provided herein, a person of ordinary skill in the art will appreciate other ways and/or methods to implement the various embodiments.

The specification and drawings are, accordingly, to be regarded in an illustrative rather than a restrictive sense. It will, however, be evident that various modifications and changes may be made thereunto without departing from the broader spirit and scope of the disclosure as set forth in the claims.

Other variations are within the spirit of the present disclosure. Thus, while the disclosed techniques are susceptible to various modifications and alternative constructions, certain illustrated embodiments thereof are shown in the drawings and have been described above in detail. It should be understood, however, that there is no intention to limit the disclosure to the specific form or forms disclosed, but on the contrary, the intention is to cover all modifications, alternative constructions, and equivalents falling within the spirit and scope of the disclosure, as defined in the appended claims.

The use of the terms “a” and “an” and “the” and similar referents in the context of describing the disclosed embodiments (especially in the context of the following claims) are to be construed to cover both the singular and the plural, unless otherwise indicated herein or clearly contradicted by context. The terms “comprising,” “having,” “including,” and “containing” are to be construed as open-ended terms (i.e., meaning “including, but not limited to,”) unless otherwise noted. The term “connected” is to be construed as partly or wholly contained within, attached to, or joined together, even if there is something intervening. Recitation of ranges of values herein are merely intended to serve as a shorthand method of referring individually to each separate value falling within the range, unless otherwise indicated herein and each separate value is incorporated into the specification as if it were individually recited herein. All methods described herein can be performed in any suitable order unless otherwise indicated herein or otherwise clearly contradicted by context. The use of any and all examples, or exemplary language (e.g., “such as”) provided herein, is intended merely to better illuminate embodiments of the disclosure and does not pose a limitation on the scope of the disclosure unless otherwise claimed. No language in the specification should be construed as indicating any non-claimed element as essential to the practice of the disclosure.

Disjunctive language such as the phrase “at least one of X, Y, or Z,” unless specifically stated otherwise, is intended to be understood within the context as used in general to present that an item, term, etc., may be either X, Y, or Z, or any combination thereof (e.g., X, Y, and/or Z). Thus, such disjunctive language is not generally intended to, and should not, imply that certain embodiments require at least one of X, at least one of Y, or at least one of Z to each be present. Preferred embodiments of this disclosure are described herein, including the best mode known to the inventors for carrying out the disclosure. Variations of those preferred embodiments may become apparent to those of ordinary skill in the art upon reading the foregoing description. The inventors expect skilled artisans to employ such variations as appropriate and the inventors intend for the disclosure to be practiced otherwise than as specifically described herein. Accordingly, this disclosure includes all modifications and equivalents of the subject matter recited in the claims appended hereto as permitted by applicable law. Moreover, any combination of the above-described elements in all possible variations thereof is encompassed by the disclosure unless otherwise indicated herein or otherwise clearly contradicted by context.
A system comprising:

fixed RF antennas transmitting RF interrogation signals and receiving RF response signals;

a user-wearable unit configured to be worn in proximity to a user's hand, the user-wearable unit including a portable RF transceiver configured to transmit at least one RF response signal in response to receiving the RF interrogation signals;

an RF transceiver operatively coupled with the fixed RF antennas; and

a management module operatively coupled with the RF transceiver and configured to process signals generated by the RF transceiver to continuously determine a location of the user-wearable unit in a three-dimensional space and identify one of a plurality of locations in the three-dimensional space based on proximity of the user-wearable unit to the identified location to monitor performance of a task.

7. The system of claim 6, wherein the user-wearable unit includes a haptic feedback mechanism configured to generate a haptic feedback to the user, the management module controlling operation of the haptic feedback mechanism via a control signal transmitted to the user-wearable unit, the haptic feedback indicating at least one of:

the identified location matches a designated location associated with the task;
the identified location does not match a designated location associated with the task;
an item held by the user has been identified by the management module;
an item held by the user has not been identified by the management module; and

guidance to the user to the designated location associated with the task.

8. The system of claim 6, wherein at least one of the RF response signals is indicative of an identification of the user.

9. The system of claim 6, wherein:

the user-wearable unit includes a motion detection unit that detects motion of the user-wearable unit; and

the user-wearable unit transmits a signal indicative of a command input by the user generated by moving the user-wearable unit in a predetermined manner, the command input relating to accomplishment of the task by the user.

10. The system of claim 9, wherein:

the user-wearable unit includes a processor that processes output of the motion detection unit to detect the command input by the user; and

the signal indicative of the command input is transmitted in response to detection of the command input by the processor.

11. The system of claim 6, wherein the management module is configured to process the location of the user-wearable unit via a processing mode selected from predetermined processing modes based on the location within the three-dimensional space, the predetermined processing modes relating to (a) retrieving an item from or placing an item into an inventory bin of an inventory holder, or (b) retrieving an item from or placing an item into an inventory tote.

12. The system of claim 6, further comprising a user-wearable grip sensor configured to generate a signal indicating that the user is holding an item or the user is not holding an item, the management module being configured to identify one of the plurality of locations into which an item is placed by the user or from which an item is retrieved by the user based on output from the grip sensor.
the mobile drive unit to controllably position the inventory holder relative to the plurality of fixed RF antennas the system being configured to control the mobile drive unit to controllably position the inventory holder including inventory bins comprising at least some of the plurality of locations.

controlling, by the management module, operation of a haptic feedback mechanism included in the user-wearable unit in a predetermined manner, the signal being indicative of a command input by the user generated by moving the user-wearable unit in a predetermined manner, the output from the motion detection unit being processed by a processor included in the user-wearable unit to detect the command input by the user; and

controlling, by the management module, operation of a haptic feedback mechanism included in the user-wearable unit to communicate a haptic feedback to the user indicating that an item held by the user has not been identified by the management module; and

controlling, by the management module, operation of a haptic feedback mechanism included in the user-wearable unit to communicate a haptic feedback to the user indicating that the identified storage location does not match a designated storage location associated with the task; and

controlling, by the management module, operation of a haptic feedback mechanism included in the user-wearable unit to communicate a haptic feedback to the user indicating that an item held by the user has been identified by the management module; and

controlling, by the management module, operation of a haptic feedback mechanism included in the user-wearable unit to communicate a haptic feedback to the user indicating that the identified storage location matches a designated storage location associated with the task.

controlling, by the management module, operation of a haptic feedback mechanism included in the user-wearable unit to communicate a haptic feedback to the user indicating that an item held by the user has been identified by the management module; and

controlling, by the management module, operation of a haptic feedback mechanism included in the user-wearable unit to communicate a haptic feedback to the user indicating that the identified storage location matches a designated storage location associated with the task.
A multi-level (ML) fulfillment center is designed to accommodate landing and takeoff of unmanned aerial vehicles (UAVs), possibly in an urban setting, such as in a densely populated area. Unlike traditional fulfillment centers, the ML fulfillment centers may include many levels (i.e., stories, floors, etc.) as permitted under zoning regulations for respective areas. The fulfillment center may have one or more landing locations and one or more deployment locations to accommodate UAVs, which may deliver at least some of the items from the fulfillment center to locations associated with customers.
DETAIL B

FIG. 8B
RECEIVE UAV 902

READY UAV FOR NEXT FLIGHT 904

COUPLE PACKAGE TO UAV 906

DEPLOY UAV 908

FIG. 9
FIG. 10

1000

RECEIVE UAV AT FIRST LOCATION 1002

READY UAV FOR NEXT FLIGHT 1004

COUPLE PACKAGE TO UAV 1006

MOVE UAV TO SECOND LOCATION 1008

DEPLOY UAV 1010
MULTI-LEVEL FULFILLMENT CENTER FOR UNMANNED AERIAL VEHICLES

BACKGROUND

[0001] Fulfillment centers are typically large-volume single-floor warehouse buildings used to temporarily store items prior to shipment to customers. Often, due to their large footprint, these buildings are located on the outskirts of cities where space is available to accommodate these large buildings. These locations are not convenience for deliveries into cities where an ever-increasing number of people live. Thus, there is a growing need and desire to locate fulfillment centers within cities, such as in downtown districts and densely populated parts of the cities. By locating the fulfillment centers within the cities, items may be more quickly delivered to the growing population of people that live in the cities, as well as the large population of people who work in the cities.

[0002] Conventionally, items have been delivered from fulfillment centers by common carriers, which travel from the fulfillment centers located outside of the city into the cities to the customer’s residence or designated delivery location. Smaller businesses, such as restaurants, sometimes use bicycle delivery and walking delivery of items to customers that are located near the business. More recently, additional types of deliveries have grown in popularity and feasibility, such as delivery by unmanned aerial vehicles (UAVs) and delivery by short-term hired ground vehicle drivers.

BRIEF DESCRIPTION OF THE DRAWINGS

[0003] The detailed description is described with reference to the accompanying figures. In the figures, the leftmost digit(s) of a reference number identifies the figure in which the reference number first appears. The same reference numbers in different figures indicate similar or identical items.

[0004] FIG. 1A is an isometric view of an illustrative multi-level fulfillment center designed to accommodate landing and takeoff of unmanned aerial vehicles (UAVs).

[0005] FIG. 1B is a side elevation view of a cross-section of the multi-level fulfillment center shown in FIG. 1A.

[0006] FIG. 1C is a side elevation view of a detailed view of an illustrative level of the multi-level fulfillment center 100 shown in FIG. 1B.

[0007] FIG. 2 is an isometric view of an illustrative multi-level fulfillment center having a hub and spoke profile as viewed from a top view. The hub and spoke profile increases external surface area usable to land and deploy UAVs from sides of the fulfillment center.

[0008] FIG. 3 is an isometric view of an illustrative multi-level fulfillment center having an exterior that converges toward the top of the fulfillment center. The converging exterior enables placement of landing and deployment surfaces about the exterior that have relatively clear airspace above each surface.

[0009] FIG. 4 is an isometric view of an illustrative multi-level fulfillment center having a top section that extends outward beyond a base section of the fulfillment center. The top section provides additional surface area for landing and deploying UAVs from a high elevation of the fulfillment center.

[0010] FIG. 5 is an isometric view of an illustrative multi-level fulfillment center having a vertical corridor to accommodate entrance and exit of unmanned aerial vehicles (UAVs).

[0011] FIG. 6A is an isometric view of an illustrative multi-level fulfillment center having multiple vertical corridors to accommodate entrance and exit of UAVs.

[0012] FIG. 6B is a side elevation view of a cross-section of the multi-level fulfillment center shown in FIG. 6A.

[0013] FIG. 7 is a top plan view of an illustrative multi-level fulfillment center having multiple corridors, where some corridors are configured for deployment of UAVs while other corridors are configured to receive incoming UAVs.

[0014] FIG. 8A is an isometric view of an illustrative multi-level fulfillment center designed to accommodate movement of UAVs pods about an exterior of the fulfillment center. The UAV pods are configured for landing and takeoff of UAVs and movement about the exterior of the fulfillment center.

[0015] FIG. 8B is a detail view of an exterior of the fulfillment center shown in FIG. 8A showing illustrative movement options for various moveable UAV platforms.

[0016] FIG. 8C is a side elevation view of a cross-section from FIG. 8B of a moveable UAV platform coupled to the exterior of the fulfillment center.

[0017] FIGS. 8D and 8E show deployment of a UAV using a tilt action of the moveable UAV platform.

[0018] FIG. 9 is a flow diagram of illustrative operation of a fulfillment center that uses UAVs to perform at least some deliveries of items from the fulfillment center.

[0019] FIG. 10 is a flow diagram of additional illustrative operation of a fulfillment center that uses UAVs to perform at least some deliveries of items from the fulfillment center.

DETAILED DESCRIPTION

[0020] This disclosure is directed to multi-level (ML) fulfillment centers designed to accommodate landing and takeoff of unmanned aerial vehicles (UAVs). The fulfillment centers may be located in downtown districts and/or other densely populated urban areas. Unlike traditional fulfillment centers, the ML fulfillment centers may include many levels (i.e., stories, floors, etc.) as permitted under zoning regulations for respective areas. The fulfillment center may have one or more landing locations and one or more deployment locations to accommodate UAVs, which may delivery at least some of the items from the fulfillment center to locations associated with customers.

[0021] Freight (e.g., bulk merchandise, supplies, etc.) may be delivered to the fulfillment center using conventional ground transit, such as by semi-trailer and tractor. Freight may also be delivered using other modes of transit, such as by rail, air drop, maritime vessel, and/or other techniques that enable safe and reliable delivery of freight to the fulfillment center in accordance with local ordinances and customs.

[0022] The ML fulfillment centers may support traditional deliveries by common carriers that use ground vehicles to deliver items to customers. The fulfillment centers may also include a self-service space where customers can pick up items. The items may be temporarily stored in lockers or otherwise made available to customers for self-pick-up.

[0023] Like traditional fulfillment centers, the ML fulfillment centers may include shelves and other storage areas to...
temporarily stow items that are eventually picked for shipment to customers. The processes of stowing items and picking items may be performed at least partly by use of robotic devices that assist human operators and/or operate autonomously to perform at least some tasks. In some embodiments, the robotic devices may transport UAVs within the ML fulfillment center, such as from a landing location to a deployment location, as well as to other locations such as a service location, a battery replacement location, a payload securedment location, and so forth. In some embodiments, the UAVs may fly at least partially within the fulfillment center, such as from an entrance location to a landing location within the fulfillment center or from a deployment location to an exit location from the fulfillment center.

The ML fulfillment center may be used to fulfill hundreds or thousands of orders each day using UAVs for at least some of the orders. Therefore, the ML fulfillment center is configured to support a large volume of UAVs that continually pick up deliveries from the ML fulfillment center and then deploy toward a destination for the particular delivery. The ML fulfillment center may include services to charge batteries of the UAVs, inspect and/or service the UAVs, and/or perform other operations for the UAVs between flights. The ML fulfillment center may also be equipped with a central command to control at least some operations of the UAVs, which may be analogous to a flight controller at an airport, which manages incoming and outgoing flights, as well as air traffic in nearby airspace.

In some embodiments, the ML fulfillment center may prioritize UAV interaction near a top level of the fulfillment center, which may have several benefits such as reduced noise near at a street level, closer proximity to a cruising altitude used by the UAVs during delivery, and centralized entry/exit points in the fulfillment center, which are secured. In some embodiments, UAV pods or other mechanisms may transport UAVs toward a top of the fulfillment center prior to deployment of the UAV to reduce power consumption of the UAV that climbs this altitude under self-powered flight. For example, the UAV pods may use internal elevators or may scale coupling features on an exterior of the fulfillment center to move a UAV upward before deployment of the UAV.

The fulfillment centers, devices, techniques, and systems described herein may be implemented in a number of ways. Example implementations are provided below with reference to the following figures.

FIG. 1A is an isometric view of an illustrative multi-level (ML) fulfillment center 100 designed to accommodate landing and takeoff of unmanned aerial vehicles (UAVs) that deliver items from the fulfillment center to customers. The ML fulfillment center 100 may be shaped similar to a high-rise office building, but may include many custom features to accommodate receipt of freight, access by UAVs, and access by people. The profile of the ML fulfillment center 100, as viewed from above, may be circular, rectangular, or have other shapes, as described below.

The ML fulfillment center 100 may include freight dock locations 102 near a bottom of the ML fulfillment center 100. The freight dock locations 102 may accommodate receipt of freight, such as bulk merchandise, supplies, and other items via trucks, rail deliveries, and/or other types of deliveries, possibly even by maritime vessels when the ML fulfillment center 100 is located proximate to a navigable body of water. The freight may be processed within the ML fulfillment center 100, such as stowed in designated locations, picked, and then boxed and/or otherwise packaged for delivery. In some embodiments, the freight dock locations 102 may support traditional deliveries by common carriers that use ground vehicles to deliver items to customers.

In some embodiments, the ML fulfillment center 100 may include a self-service location 104 for customers to pick-up items in person rather than have the items delivered to the customers. For example, the self-service location 104 may enable customers to obtain items with minimal delay. Items may be temporarily stored in the self-service location 104, such as in lockers or in a room accessible by one or more staff that provides the items to customers.

The ML fulfillment center 100 may include UAV platforms 106 configured to receive and deploy UAVs 108, which may carry packages 110 from the ML fulfillment center to destinations associated with customers. The UAV platforms 106 may be located on an exterior of the fulfillment center and/or in an interior of the fulfillment center, such as proximate to an exterior shell 112 and/or proximate to an internal airway. The UAV platforms 106 may include a UAV service site, which is used to service the UAV as discussed below, including loading the UAV with a package to be delivered to a customer. The internal airway may have direct access to a navigable airway (i.e., open air) that has a cruising zone (or cruising altitude) used by many of the UAVs during delivery of the packages 110 and during return flights back to the ML fulfillment center 100.

The exterior shell 112 may include apertures 114, which may enable the UAVs to gain entrance to and/or exit from the ML fulfillment center 100 and/or may enable loading UAVs that are external to the ML fulfillment center 100 with packages and/or other equipment (e.g., charged batteries and/or other supplies). The apertures 114 may be circular, rectangular, oval, polygon-shaped, or shaped in other ways to accommodate entry and exit of UAVs. The apertures 114 may be spaced apart from one another to enable takeoff and landing of UAV from a location proximate to the aperture without conflict with other UAVs. The apertures may be arranged about the exterior in a grid that provides at least a predetermined vertical spacing between vertically adjacent apertures and a horizontal spacing between horizontally adjacent apertures. The conflicts may include physical conflict or downwash resulting from UAVs flying nearby. In some embodiments, the UAVs may be subjected to external forces that assist the UAV in a launch, referred to herein as launch assist mechanisms and/or lift assist mechanisms, such as devices and techniques discussed in U.S. patent application Ser. No. 14/501,702 titled "Automated Aerial Vehicle Launch Assist" and filed on Sep. 30, 2014, which is incorporated herein by reference in its entirety. In some embodiments, a central command may manage arrival and departure of UAVs with respect to the specific locations of the apertures 114 such that UAVs are not flying at or near adjacent apertures at a same time, for example. In various embodiments, some apertures may be designated for entry of UAVs into the ML fulfillment center 100 while other apertures may be designated for exit of UAVs from the ML fulfillment center 100. Some apertures may only enable entry or exit of a single UAV at a time while other apertures may be configured to allow multiple UAVs to enter or exit, at a same time or one-after-another.
example, larger apertures may be used to accommodate multiple UAVs at once or one-after-another for entrance to the ML fulfillment center 100, exit from the ML fulfillment center 100, or both. Some apertures may be used to access the UAVs, but may not be configured to allow passage of UAVs through the apertures.

**[0032]** The apertures 114 may be secured by doors and/or other physical mechanisms to prevent unauthorized access, such as physical access, line of sight access (visual access), or both. Techniques and devices described in U.S. patent application Ser. No. 14/735,070 titled “Unmanned Aerial Vehicle Secure Egress and Ingress” and filed on Jun. 9, 2015, which is incorporated herein by reference in its entirety, may be used with the apertures to provide security for the ML fulfillment center 100. In some embodiments, apertures 114 may be located adjacent to a corresponding UAV platform of the UAV platforms 106. However, some UAV platforms may not be located proximate to an aperture, such as overflow UAV platforms used when no aperture is currently available for a UAV.

**[0033]** During operation, a UAV may land on the UAV platform 106 and power down. A controller may authenticate a UAV to determine if the UAV is authorized to access the ML fulfillment center 100. Authentication may include a one-way or bi-directional communication of information wirelessly between the controller and the UAV to positively identify the UAV and access permissions of the UAV. The aperture 114 may be opened when the UAV is authenticated and while the UAV is located at or near the platform. The UAV may be serviced, which may include inspecting the UAV, charging one or more batteries of the UAV and/or providing the UAV with a charged power source, and/or performing other services of the UAV, which may be performed while the aperture is open or closed. The UAV may then be coupled to a package to be delivered to a destination associated with a recipient. The package may be provided through the aperture when the aperture is open. Finally, the UAV may be deployed from the UAV platform to initiate the delivery by the UAV. In some embodiments, the UAV may enter through the aperture to gain access to an internal location within the ML fulfillment center 110.

**[0034]** In various embodiments, a roof 116 (e.g., a top level) of the ML fulfillment center 100 may accommodate some functions and interaction with the UAVs. The roof 116 may include passages 118 to enable UAV access to/from the ML fulfillment center 100 and/or access to/from the roof 116 by other devices, such as workers, robots, conveyers, and/or other objects, which may perform any number of operations such as servicing UAVs, loading UAVs with packages to be delivered, and so forth. The passages 118 may be secured from unauthorized access (e.g., physical access, line of sight access (visual access), etc.) using the same or similar techniques described above with respect to the apertures 114 and using the techniques and devices described in U.S. patent application Ser. No. 14/735,070 titled “Unmanned Aerial Vehicle Secure Egress and Ingress” and filed on Jun. 9, 2015, which is incorporated herein by reference in its entirety.

**[0035]** In some embodiment, the roof 116 may be used for expedited landings, such as by UAVs that have limited remaining power reserves or otherwise are in need of service. The roof 116 may also accommodate larger UAVs that may not be supportable by the UAV platforms 106 or are unable to fit through the apertures 114 (if when the apertures are used for entry/exit of UAVs). The roof 116 may also support other equipment, such as heating, ventilating, and air conditioning (HVAC) equipment, communication equipment (e.g., antennas, controllers, etc.), and/or other devices or equipment.

**[0036]** FIG. 1B is a side elevation view of a cross-section of the multi-level fulfillment center 100 shown in FIG. 1A, showing a simplified depiction of some of the inner workings of the ML fulfillment center 100. As shown in FIG. 1B, the ML fulfillment center 100 may include a plurality of levels 120 (e.g., floors, layers, etc.), which may span between a first level 120(1) and a top level 120(N) that is located below the roof 116. The first level 120(1) and possible other levels, may be located underground in some implementations. In various embodiments, a substantial amount of the operations and/or volume of the ML fulfillment center 100 may be located below ground level, possibly including freight receiving facilities. The first level 120(1) may include special facilities for receiving freight. However, other levels may include similar facilities depending on an entry point of the freight.

**[0037]** In some embodiments, some of the levels 120 may have a different height and/or volume of space than an adjacent level. For example, some levels may be used to transport UAVs about the ML fulfillment center 100, and thus may be relatively shorter in height than other levels (e.g., less than a conventional floor having a ceiling height of approximately 8 feet). Other levels may include a higher ceiling height, which may accommodate flight of UAVs within such levels, such as flight above locations where items are stowed.

**[0038]** The levels 120 may include storage locations 122, such as bins, racks, or other fixed or mobile devices for placing, at least temporarily, items to be delivered and/or other items for the ML fulfillment center 100. Robots 124(1), 124(2), . . . 124(M), human workers 126, or both, may occupy locations within the levels to stow items, pick items, and/or perform other item-related operations. The robots, the human workers, or both may also perform other operations, such as transport UAVs, inspect and/or service UAVs, and/or perform other non-item-based operations. The robots may include item transport robots 124(1), UAV transport robots 124(2), and elevator robots 124(M). The elevator robots 124(M) may be configured to move items, UAVs, and/or other objects between different floors. In some embodiments, multifunctional robots may perform some or all of these operations of the robots 124(1), 124(2), . . . 124(M). In some embodiments, the robots may perform some service of UAVs, such as charging batteries, swapping batteries, inspecting, cleaning, and/or other service operations. More advanced services operations may be performed by human workers. In some embodiments, the UAVs may fly or otherwise move within the ML fulfillment center 100 under their own power. For example, the UAVs may include wheels that allow them to roll from a first location proximate to a landing site to a second location proximate to a takeoff site, which may or may not be on a same level as the first location.

**[0039]** As discussed above, the ML fulfillment center 100 may include the self-service location 104 for customers to pick-up packages or items in person rather than having the items delivered to the customers. The items may be temporarily stored in lockers 128 in the self-service location 104, possibly by the robots used in the ML fulfillment center 100.
The lockers may use revolving access codes that enable users to access items within the lockers 128.

[0040] FIG. 1C is a side elevation view of Detail “A” from FIG. 1B, showing detail of an illustrative level 130 the multi-level fulfillment center 100. As shown, items, robots, and/or the storage locations 122 may be located on the level 130, and may work in cooperation to create packages for delivery by the UAV to a destination associated with a customer. In some embodiments, a UAV may enter the ML fulfillment center 100 at the level 130 at a first location 132, such on the UAV platform 106, which may be located on the exterior of the ML fulfillment center 100 or inside the ML fulfillment center 100. The UAV may be transported, via a passage 136, to a second location 134, which may be another UAV platform 106. During the transit, between the first location 132 and the second location 134, the UAV may be charged or equipped with a charged battery (or other power source), be serviced and/or inspected, and be coupled to a package for delivery. In some embodiments, the UAV may obtain the package and/or items for the package while the UAV is within the ML fulfillment center 100, such as when the UAV is configured to pick items from the storage locations 122. One of the human workers 126 may perform an inspection of the UAV prior to deployment of the UAV, possibly by reviewing data collected from the UAV as well as visually inspecting the UAV.

[0041] FIG. 2 is an isometric view of an illustrative multi-level fulfillment center 200 having a hub and spoke profile as viewed from a top view. The hub and spoke profile increases external surface area usable to land and deploy UAVs from sides of the fulfillment center. The ML fulfillment center 200 may include some or all of the features shown and described with reference to the ML fulfillment center 100, while having a different exterior profile.

[0042] In some embodiments, a spoke 202 (i.e., an arm extending outward from the hub) may include a UAV service site located between two apertures, such as a first aperture 204 on a first side 206 of the spoke 202 and a second aperture 208 on a second side 210 of the spoke 202. A UAV may enter the first aperture 204, proceed to be serviced and coupled to a package for delivery from the UAV operation site, and then deploy from the first aperture 206. In these embodiments, the same UAV operation site may be used to service multiple different UAVs (two in this example, but possibly more). In some embodiments, the UAV may land at the UAV operation site, and may deploy from a different aperture than the aperture used to enter the ML fulfillment center 200. The ML fulfillment center 200 may consolidate some or all of the item and package processing within a central core 212 of the ML fulfillment center 200. The packages may then be moved to the spokes, such as the spoke 202, for distribution by the UAVs to destinations associated with customers. Although the hub and spoke design shown in FIG. 2 resembles a star shape, other hub and spoke profiles may be used that include radiuses or rectangular shaped spokes that extend outward from the hub.

[0043] FIG. 3 is an isometric view of an illustrative multi-level fulfillment center 300 having a converging exterior 302 that converges toward the top of the fulfillment center. The converging exterior 302 enables placement of landing and deployment surfaces about the converging exterior 302 that have relatively open and clear airspace above each surface. The clear airspace may limit or minimize possible interference between UAVs, including interference from downwash or other movement of air caused by nearby UAVs. The ML fulfillment center 300 may include some or all of the features shown and described with reference to the ML fulfillment center 100, while having a different exterior profile.

[0044] The ML fulfillment center 300 includes a first UAV platform 304 located adjacent to a second UAV platform 306, which is located on a higher level than the first UAV platform 304. However, because of the converging profile of the ML fulfillment center 300, the second UAV platform 306 is not located directly above of the first UAV platform 304, but is instead offset and closer to a center longitudinal axis 308 of the ML fulfillment center 300 than the first UAV platform 304.

[0045] As shown in FIG. 3, the ML fulfillment center 300 may include the converging exterior 302 that resembles a profile of a beehive. However, the converging exterior 302 may be shaped like a cone, a pyramid, or otherwise shaped to have a converging or at least partially converging exterior that converges over at least a portion of the exterior surface (e.g., converges near a top portion of the ML fulfillment center 300). As another example, some sides may have a converging profile while other sides may not have a converging profile, which may accommodate additional interior volume of the ML fulfillment center 300.

[0046] FIG. 4 is an isometric view of an illustrative multi-level fulfillment center 400 having a top section 402 that extends outward beyond a base section 404 of the ML fulfillment center 400. The ML fulfillment center 400 may include some or all of the features shown and described with reference to the ML fulfillment center 100, while having a different exterior profile.

[0047] The top section 402 may provide a large surface area 406 for landing and deploying UAVs from a high elevation of the fulfillment center, among other possible uses. As discussed above, it may be advantageous to deploy UAVs as close to a cruising altitude as possible to reduce drain of power sources used by UAVs to climb to the cruising altitude. Similarly, it may be advantageous to land some UAVs at a higher elevation, such as larger UAVs and/or noisier UAVs. The top section 402 may include a service location 408, which may be easily accessible by UAVs that may approach the ML fulfillment center 400 with limited remaining power, limited flight controls, and/or other limitations. The top section 402 may include apertures 410 to enable UAVs to gain access to an interior of the ML fulfillment center 400 as described above. The apertures 410 may be circular, rectangular, oval, polygon-shaped, or shaped in other ways to accommodate entry and exit of UAVs.

[0048] The top section 402 may include any number of levels, which may include internal UAV service sites (or external landing UAV platforms that include UAV service sites, as discussed above). The top surface may consume available airspace above adjacent buildings, which may be available for acquisition under some local zoning ordinances. In an exemplary operation, a UAV may fly into and through an open aperture to a UAV service site located within the ML fulfillment center 400. The aperture may open just prior to entry by the UAV and may close just after the entry of the UAV. The apertures 410 may remain in a closed position as a default to provide security and to protect an interior of the ML fulfillment center 400 from environmental conditions such as precipitation and wind. The UAV may be
assigned to an aperture and arrival of a specific assigned
AUV may trigger the opening and closing of the aperture,
such as using an exchange or one-way wireless commu­
nication and/or other secure communications exchanged
between the UAV and a controller of the aperture.

[0049] In some embodiments, the ML fulfillment center
may include one or more intermediate extended surfaces
that span outward from the ML fulfillment center
between different ones of the apertures. The interme­
diate extended surfaces may provide landing and
and exterior apertures may be serviced, inspected, and/or coupled to packages to be
inside the ML fulfillment center. The UAV may be serviced, inspected, and/or coupled to packages to be
inside the ML fulfillment center. The UAV may be serviced, inspected, and/or coupled to packages to be
delivered to a destination. The UAVs may be deployed, in stages, to exit the ML fulfillment center
using the main aperture. In these embodiments, the flight plans of the UAVs may cause some or all of the
UAVs to enter the ML fulfillment center laterally from the various exterior apertures and then exit the ML
fulfillment center from above via the main aperture, which may minimize potential flight path conflicts of the
UAVs, even when large volumes of UAVs are entering and exiting the ML fulfillment center during a
relatively short period of time. In these embodiments, a lift assist mechanism or launch assist mechanism may be
located at or near the bottom of the internal corridor, which may provide additional lift for exiting UAVs to lessen
drain of power sources of the UAVs while climbing to the cruising altitude.

[0050] In some embodiments, the main aperture may include a door that opens or closes. In various embodi­
ments, the main aperture may be open for extended periods of
time to allow UAVs to move through the main aperture. The
ML fulfillment center may include internal securing doors within the internal corridor, which may select­
vively secure the ML fulfillment center from access by unauthorized UAVs that enter via the main aperture. In
some embodiments, the internal corridor may include multiple entry points to internal locations of the ML fulfillment
center at various different levels within the ML fulfillment center, possibly to every level of the ML fulfillment
center or to all levels designated for access by UAVs. Some levels may be restricted from access by
UAVs such levels used for customer pick-ups and levels used for receipt of freight.

[0051] FIG. 5 is an isometric view of an illustrative multi-level fulfillment center having a vertical
corridor to accommodate entrance and exit of unmanned aerial
vehicles (UAVs). The ML fulfillment center may include some or all of the features shown and described with reference
to the ML fulfillment center while having a different exterior profile.

[0052] In some embodiments, using a second process, the UAVs may be routed into the exterior apertures
to gain entry into the ML fulfillment center. The UAVs, once inside the ML fulfillment center, may land at
internal landing sites inside the ML fulfillment center. While inside the ML fulfillment center, the UAVs may
be serviced, inspected, and/or coupled to packages to be
inside the ML fulfillment center. The UAVs may be deployed, in stages, to exit the ML fulfillment center
by UAVs to move through the main aperture. The UAV may fly to
an assigned level within the ML fulfillment center. The
UAVs, once inside the ML fulfillment center, may land at
internal UAV service sites inside the ML fulfillment center.
While inside the ML fulfillment center, the UAVs may be serviced, inspected, and/or coupled to packages to be
delivered to a destination. The UAVs may be moved to
deployment site proximate to the main aperture and ready for flight. The UAV may then exit the ML fulfillment center
using the main aperture. In these embodiments, the flight plans of the UAVs may cause some or all of the
UAVs to enter the ML fulfillment center laterally from the various exterior apertures and then exit the ML
fulfillment center from above via the main aperture, which may minimize potential flight path conflicts of the
UAVs, even when large volumes of UAVs are entering and exiting the ML fulfillment center during a
relatively short period of time. In these embodiments, a lift assist mechanism or launch assist mechanism may be
located at or near the bottom of the internal corridor, which may provide additional lift for exiting UAVs to lessen
drain of power sources of the UAVs while climbing to the cruising altitude.

[0053] FIG. 6A is an isometric view of an illustrative multi-level fulfillment center having multiple vertical
 corridors to accommodate entrance and exit of unmanned aerial
vehicles (UAVs). The ML fulfillment center may include some or all of the features shown and described with reference
to the ML fulfillment center while having a different exterior profile.

[0054] FIG. 6A is an isometric view of an illustrative multi-level fulfillment center having multiple vertical
corridors to accommodate entrance and exit of unmanned aerial
vehicles (UAVs). The ML fulfillment center may include some or all of the features shown and described with reference
to the ML fulfillment center while having a different exterior profile.

[0055] The ML fulfillment center may include a first aperture
and a second aperture. In some embodiments, the UAVs may be routed into the first aperture to gain entry into the ML fulfillment center. The UAVs may fly through the first aperture and into a first internal
corridor that may extend deep within the ML fulfillment center. The UAV may fly to an assigned level within the ML fulfillment center. The UAVs, once inside the ML fulfillment center, may land at
internal UAV service sites inside the ML fulfillment center.
While inside the ML fulfillment center, the UAVs may be serviced, inspected, and/or coupled to packages to be
delivered to a destination. The UAVs may be moved to
deployment site proximate to the main aperture and ready for flight. The UAV may then exit the ML fulfillment center
using the main aperture. In these embodiments, the flight plans of the UAVs may cause some or all of the
UAVs to enter the ML fulfillment center laterally from the various exterior apertures and then exit the ML
fulfillment center from above via the main aperture, which may minimize potential flight path conflicts of the
UAVs, even when large volumes of UAVs are entering and exiting the ML fulfillment center during a
relatively short period of time. In these embodiments, a lift assist mechanism or launch assist mechanism may be
located at or near the bottom of the internal corridor, which may provide additional lift for exiting UAVs to lessen
drain of power sources of the UAVs while climbing to the cruising altitude.

[0056] The ML fulfillment center may include a first aperture
and a second aperture. In some embodiments, the UAVs may be routed into the first aperture to gain entry into the ML fulfillment center. The UAVs may fly through the first aperture and into a first internal
corridor that may extend deep within the ML fulfillment center. The UAV may fly to an assigned level within the ML fulfillment center. The UAVs, once inside the ML fulfillment center, may land at
internal UAV service sites inside the ML fulfillment center.
While inside the ML fulfillment center, the UAVs may be serviced, inspected, and/or coupled to packages to be
delivered to a destination. The UAVs may be moved to
deployment site proximate to the main aperture and ready for flight. The UAV may then exit the ML fulfillment center
using the main aperture. In these embodiments, the flight plans of the UAVs may cause some or all of the
UAVs to enter the ML fulfillment center laterally from the various exterior apertures and then exit the ML
fulfillment center from above via the main aperture, which may minimize potential flight path conflicts of the
UAVs, even when large volumes of UAVs are entering and exiting the ML fulfillment center during a
relatively short period of time. In these embodiments, a lift assist mechanism or launch assist mechanism may be
located at or near the bottom of the internal corridor, which may provide additional lift for exiting UAVs to lessen
drain of power sources of the UAVs while climbing to the cruising altitude.
In various embodiments, an impact dampener 610, such as a net, foam, and/or other impact dampeners may be located at or near the bottom of the first internal corridor 606, which may absorb impact forces of a UAV, such as when a UAV falls toward the impact dampener due to lack of power or mechanical failure. A lift assist mechanism 612 (or launch assist mechanism) may be located at or near the bottom of the second internal corridor 608, which may provide additional lift for exiting UAVs to lessen drain of power sources of the UAVs while climbing to the cruising altitude. The lift assist mechanism 612 may create an upward airflow 614 to enable UAVs to exit the second internal corridor 608 using less power than would otherwise be used without operation of the lift assist mechanism 612. The lift assist mechanism 612, in some embodiments, may propel or launch UAVs toward the second aperture 604.

In some embodiments, the first aperture 602 may be selectively secured by a first door 616 that opens and closes and the second aperture 602 may be selectively secured by a second door 618 that opens and closes. In various embodiments, the first door 616 and/or the second door 618 may be open for extended periods of time to allow UAVs to move through the respective apertures. The ML fulfillment center 600 may include internal securing doors 620 within the first internal corridor 606 and/or the first internal corridor 608, which may selectively secure the ML fulfillment center 600 from access by unauthorized UAVs that enter the ML fulfillment center 600. In some embodiments, the internal securing doors 620 may be used in lieu of the first door 616 and/or the second door 618. In some embodiments, the first internal corridor 606 may include multiple entry points to internal locations of the ML fulfillment center 600 at various different levels within the ML fulfillment center 600, possibly to every level of the ML fulfillment center 600 or to all levels designated for access by UAVs. Some levels may be restricted from access by UAVs such levels used for customer pick-ups and levels used for receipt of freight. After landing from entry from the first internal corridor 606, UAVs may be transported, via passages 626, to a location proximate to the second internal corridor 608, which may or may not be on a same level as the landing site for a particular UAV. In some embodiments, UAVs may be moved internally by mechanisms, such as robots, elevators, conveyers, and/or other lifting mechanisms to gain a higher location prior to deployment for at least the purpose of reducing power consumption by the UAV to climb to the cruising altitude.

UAVs entering the first aperture 606 may generally adhere to an approach flight path 622 while UAVs exiting the second aperture 608 may generally adhere to a departure flight path 624 for at least a portion of a flight. The UAVs, once exited from the second aperture 608 and a predetermined distance from the ML fulfillment center 600 and/or from other UAVs, may then deviate from the departure flight path 624 and initiate a specific flight plan for the UAV to direct the UAV to a destination for that UAV.

The ML fulfillment center 700 may include multiple apertures, including a first aperture 702 and a second aperture 704. In some embodiments, the UAVs 108 may be routed into the first aperture 702 to gain entry into the ML fulfillment center 700. The UAVs may fly through the first aperture 702, and into a first internal corridor 706(1) that may extend deep within the ML fulfillment center 700. The UAV may fly to an assigned level within the ML fulfillment center 700. The UAVs, once inside the ML fulfillment center 700, may land at internal landing sites inside the ML fulfillment center 700. While inside the ML fulfillment center 700, the UAVs may be serviced, inspected, and/or coupled to packages to be delivered to a destination. The UAVs may be moved to deployment site proximate to a second internal corridor 708(1) and readied for flight. The UAVs may be deployed, in stages, to exit the second aperture 704 of the ML fulfillment center 700 via the second internal corridor 708(2). The first internal corridor 706(1) and the second internal corridor 708(1) may be used together with UAVs that access a particular portion of the ML fulfillment center 700 via passages. However, in some embodiments, UAVs entering the first internal corridor 706(1) may exit another second internal corridor, such as any of second internal corridors 708(2) . . . 708(N). Similarly, UAVs may enter any of first internal corridors 706(2) . . . 706(N). The arrangement shown in FIG. 7 may be applied to a fulfillment center having an internal shape similar to that shown in FIG. 2, which resembles a hub and spoke profile and possibly to other fulfillment center designs having different exterior shapes. The corridors may not all have a same depth and/or access to same levels within the ML fulfillment center 700. By having different depths, the ML fulfillment center 700 may have more internal volume to store items and/or more volume useable for other operations.

As discussed above, the impact dampener 610, such as a net, foam, and/or other impact dampeners may be located at or near the bottom of the first internal corridors 706(1)-(N), which may absorb impact forces of a UAV, such as when a UAV falls toward the impact dampener due to lack of power or mechanical failure. The lift assist mechanism 612 (or launch assist mechanism) may be located at or near the bottom of the second internal corridors 708(1)-(N), which may provide additional lift for exiting UAVs to lessen drain of power sources of the UAVs while climbing to the cruising altitude. The lift assist mechanism 612, in some embodiments, may propel or launch UAVs toward the second apertures. Each aperture may have an associated door to secure the aperture and/or doors may be used within each corridor as discussed above to secure entry and/or exit points for levels within the ML fulfillment center 700.

FIG. 8A is an isometric view of an illustrative multi-level fulfillment center 800 designed to accommodate movement of UAVs pods about an exterior of the fulfillment center. The UAV pods are configured for landing and takeoff of UAVs and movement about the exterior of the fulfillment center. The ML fulfillment center 800 may include some or all of the features shown and described with reference to the ML fulfillment center 100, while having a different exterior profile.

The ML fulfillment center 800 may include movable UAV platforms 802 configured to receive and deploy UAVs 108, which may carry packages 110 from the ML fulfillment center to destinations associated with customers. The moveable UAV platforms 802 may be located on an
may be charged or otherwise replenished with a power takeoff of the UAV, which may save power resources of the particular UAV. The aperture may move in more than two directions, such as by moving up, down, or laterally right/left along the grid. However, unlike trains, the moveable UAV platforms 802 may be capable of moving in more than two directions, such as by moving up, down, or laterally right/left along the grid 804, as further explained below.

The exterior shell 112 may include the apertures 114, which may enable the UAVs to gain entrance to and/or exit from the ML fulfillment center 800 and/or may enable loading UAVs that are external to the ML fulfillment center 800 with packages and/or other equipment (e.g., charged batteries and/or other supplies). The apertures 114 may be spaced apart from one another to enable takeoff and landing of UAV from a location proximate to the aperture without conflict with other UAVs. The apertures 114 may be secured by doors and/or other physical mechanisms to prevent unauthorized access, such as physical access, line of sight access (visual access), or both.

FIG. 8A is a detail view of portion 810 of the exterior of the ML fulfillment center 800 shown in FIG. 8A showing illustrative movement options for various moveable UAV platforms. During operation, a UAV 108 may land on a moveable UAV platform 802, which may or may not be proximate to one of the apertures 114. The moveable UAV platform 804 may move the UAV 108 to align with an aperture of the various apertures 114, such as an aperture assigned to the particular UAV. The aperture 114 may be opened via opening a door 812 to enable servicing, coupling a package, and/or other tasks. The UAV 108 may then be prepared for deployment. In some embodiments, a moveable UAV platform 802 may move a UAV to a higher location on the exterior shell 112 of the ML fulfillment center 800 before takeoff of the UAV, which may save power resources of the UAV from being used to climb this distance during flight. In some embodiments, a moveable UAV platform 802 may traverse over closed apertures, which may include the doors 810 having the grid 804 or doors that are configured to enable the moveable UAV platform to travel across the doors without hindering movement of the moveable UAV platform, which may span across the door and/or couple to the door.

In some embodiments, the grid 804 may include horizontal rows 814 and vertical columns 816 of the coupling features, which may enable the moveable UAV platforms 802 to move about as discussed below. However, other configurations of the grid may be used, which may use any type of symmetric or non-symmetric arrangement of features on the exterior of the ML fulfillment center 800.

In some embodiments, there may be more moveable UAV platforms 802 than apertures 114 to access the UAVs. The additional moveable UAV platforms 802 may accommodate UAVs that are waiting for access to an aperture, on standby, or otherwise unused. For example, UAVs may be charged or otherwise replenished with a power supply while located on a moveable UAV platform 802.

FIG. 8C is a side elevation view of a cross section from FIG. 83 of a moveable UAV platform 820 coupled to the exterior of the ML fulfillment center 800. The moveable UAV platform 820 may include a pod 822 to receive the UAV 108. The pod 822 may be coupled to a traversal base 824 that includes a movement mechanism 826 configured to couple to and traverse the grid 804. In some embodiments, the movement mechanism 826 may include arms that selectively couple to the coupling features of the grid 804. The arms may include rollers or pivoting features that enable movement of the pod 822 relative to the grid 804.

The pod 822 may include features to secure to a UAV that lands on the pod, such as to keep the UAV secure and stationary during winds or other possible unintended movement of the UAV. The pod 822 may be powered and may provide power to the UAVs, such as to charge a power source of the UAV (e.g., a battery) and/or to perform other services and/or functions as described herein. In some embodiments, the pod 822 may detach, at least temporarily, from the traversal base 824, which may enable the pod 822 to move inside of the ML fulfillment center 800. The pod 822 may include wheels or other movement mechanisms to enable the pod 824 to move about the ML fulfillment center 800, such as described above with regard to the robots 124.

In various embodiments, the pod 822 may be coupled to the traversal base 824, but may extend through the aperture 114 to enable the UAV to be serviced and/or loaded with a package while inside or partially inside the ML fulfillment center 800. The door 812 may open to allow access to the ML fulfillment center 800 and may later close to prevent the access.

The traversal base 824 may include the movement mechanism 826, such as arms, that may engage coupling features of the grid 804. The grid 804 may include at least first components 828 and second components 830, some of which the movement mechanism 826 may couple to, thus enabling the traversal base to secure to the ML fulfillment center 800. In some embodiments, the grid 804 may provide power to the moveable UAV platform 820 via the first components 828 and/or the second components 830. For example, the first components 828 may be “live” or “hot” while the second components 830 may be neutral, or vice versa. The movement mechanism 826 may receive power through connection with at least some of the first components 828 and/or the second components 830. The power may then be used to support movement of the moveable UAV platform 820 about the exterior shell 112 of the ML fulfillment center 800. In various embodiments, the moveable UAV platform 820 may include a battery 832. The battery may be charged via charging locations via the grid, which may be limited locations about the exterior of the ML fulfillment center 800, such as locations adjacent to the apertures 114 where the platforms may spend a majority of their time.

The moveable UAV platform 820 may include a controller to control operation and movement of the moveable UAV platform 820. The controller may navigate the moveable UAV platform 820 using a set of instructions from a central control and/or using at least some autonomous operation to avoid conflict with other moveable UAV platforms. The controller 834 may use similar logic as an autonomous household vacuum cleaner to navigate the exterior of the ML fulfillment center 800, for example.
US 2017/0175413 A1

[0072] FIGS. 8D and 8F show deployment of a UAV using a tilt mechanism 836 of the moveable UAV platform 820. As shown in FIG. 8D, the pod 822 may include a pod portion 836 that may tilt or otherwise move in response to activation of a tilt mechanism 838 to cause the UAV 108 to be directed to a particular launch direction. The tilt mechanism 838 may be a mechanical mechanism, pneumatic mechanism, and/or other type of mechanism that causes movement of the pod portion 836 relative to the traversal base 824 to cause the UAV 108 to launch in a direction away from the exterior shell 112 of the ML fulfillment center 800.

[0073] FIG. 8F shows the UAV 108 launching away from the pod portion 836. In some embodiments, a launch assist mechanism 840 may assist the launch of the UAV 108, such as by providing a force to move the UAV in an outward direction from the pod portion 836. The launch assist mechanism 840 may be a mechanical mechanism, pneumatic mechanism, and/or other type of mechanism that causes movement of the UAV 108 relative to the pod portion 836 to cause the UAV 108 to launch in a direction away from the exterior shell 112 of the ML fulfillment center 800.

[0074] FIGS. 9 and 10 are flow diagrams illustrated as a collection of blocks in a logical flow graph, which represent a sequence of operations that can be implemented in hardware, software, or a combination thereof. The order in which the operations are described is not intended to be construed as a limitation, and any number of the described blocks can be combined in any order and/or in parallel to implement the process.

[0075] FIG. 9 is a flow diagram of illustrative operation 900 of a fulfillment center that uses UAVs to perform at least some deliveries of items from the fulfillment center. The process 900 is described with reference to the preceding FIGS. 1A-8E. Of course, the process 900 may be performed in other similar and/or different environments.

[0076] At 902, the UAV may be received at a ML fulfillment center. For example, the UAV may fly to a designated landing site of the ML fulfillment center, which may be located on one of multiple levels of the ML fulfillment center. The landing site may be external to the ML fulfillment center or may be within the ML fulfillment center.

[0077] At 904, the UAV may be readied for a next flight. For example, the UAV may be serviced, inspected, powered, undergo a battery replacement, coupled to a package for delivery, and/or otherwise interacted with prior to the next flight. In some embodiments, the UAV may be coupled to the ML fulfillment center at a first location. For example, the UAV may be received at a ML fulfillment center, which may be located on one of multiple levels of the ML fulfillment center. The landing site may be external to the ML fulfillment center or may be within the ML fulfillment center.

[0078] At 906, the package 110 may be coupled to the UAV 108. The coupling may be performed by a robot, by the UAV 108, and/or by a human worker. The package may be coupled to the UAV while the UAV is inside of the ML fulfillment center or while the UAV is outside of the ML fulfillment center and on a launch platform, for example.

[0079] At 908, the UAV may be deployed with the package for the destination associated with the package. In some embodiments, the UAV may be deployed with a launch mechanism and/or with assistance by a launch assist mechanism, which may at least partially reduce an amount of energy used by the UAV to reach a cruising altitude. In some embodiments, the coupling of the package may be used to impart a launch force on the UAV. The UAV may launched at any angle outward from the ML fulfillment center, including in a direction perpendicular to the exterior shell 112 of the ML fulfillment center.

[0080] FIG. 10 is a flow diagram of additional illustrative operation 1000 of a fulfillment center that uses UAVs to perform at least some deliveries of items from the fulfillment center. The process 1000 is described with reference to the preceding FIGS. 1A-8E. Of course, the process 1000 may be performed in other similar and/or different environments.

[0081] At 1002, the UAV may be received at a ML fulfillment center at a first location. For example, the UAV may fly to a landing site of the ML fulfillment center, which may be located on one of multiple levels of the ML fulfillment center. The landing site may be external to the ML fulfillment center or may be within the ML fulfillment center.

[0082] At 1004, the UAV may be readied for a next flight. For example, the UAV may be serviced, inspected, powered, undergo a battery replacement, coupled to a package for delivery, and/or otherwise interacted with prior to the next flight. In some embodiments, the UAV may be moved to a second location. For example, the UAV may be moved to a landing site of the ML fulfillment center, which may be located on one of multiple levels of the ML fulfillment center. The landing site may be external to the ML fulfillment center or may be within the ML fulfillment center. In some embodiments, the launch site may be on a different level of the ML fulfillment center than the landing site. In various embodiments, the UAV may be moved to a launch site that is higher than the landing site, thereby at least partially reducing an amount of energy used by the UAV to reach a cruising altitude. The UAV may be moved to the launch site by flight of the UAV, by one of the robots 124, by a human worker, and/or by other mechanisms (e.g., a conveyer, an elevator, a launch mechanism, a pneumatic tube, etc.).

[0083] At 1006, the package 110 may be coupled to the UAV 108. The coupling may be performed by a robot, by the UAV 108, and/or by a human worker. The package may be coupled to the UAV while the UAV is inside of the ML fulfillment center or while the UAV is outside of the ML fulfillment center and on a launch platform, for example.

[0084] At 1008, the UAV may be coupled to the package for the destination associated with the package. In some embodiments, the UAV may be launched with a launch mechanism and/or with assistance by a launch assist mechanism, which may at least partially reduce an amount of energy used by the UAV to reach a cruising altitude.

[0085] At 1010, the UAV may be deployed with the package for the destination associated with the package. In some embodiments, the UAV may be launched with a launch mechanism and/or with assistance by a launch assist mechanism, which may at least partially reduce an amount of energy used by the UAV to reach a cruising altitude.

Although the subject matter has been described in language specific to structural features and/or methodological acts, it is to be understood that the subject matter defined in the appended claims is not necessarily limited to the specific features or acts described. Rather, the specific features and acts are disclosed as illustrative forms of implementing the claims.

1. A multi-level fulfillment center configured to support distribution of items by unmanned aerial vehicles (UAVs), the multi-level fulfillment center comprising:
an exterior shell to secure internal operations of the multi-level fulfillment center;
6. A multi-level structure comprising:
UAV platforms to support landings and takeoffs of the UAVs, the UAV platforms coupled to the exterior shell; apertures located in the exterior shell at different altitudes to provide at least access to the UAVs located on the UAV platforms, wherein a first aperture provides access to an authenticated UAV on a first UAV platform located proximate to the first aperture, the authenticated UAV to be readied for a next flight while on the first UAV platform to deliver an item from the multi-level fulfillment center to a destination associated with a customer;
aperture doors to selectively close the apertures, wherein a first door is configured to secure the first aperture in a closed position at least when the first UAV platform is not occupied by the authenticated UAV;
a controller to authenticate the UAVs and control the aperture doors, wherein the controller causes a second door to open based at least in part on a determination that an incoming UAV being received at a second UAV platform is authorized to access the multi-level fulfillment center;
a receiving area within the exterior shell to receive freight that includes the item and other items available for consumption by customers; and
a storage area within the exterior shell to organize and store the items and the other items prior to distribution to customers by the UAVs.
2. The multi-level fulfillment center as recited in claim 1, wherein the apertures are arranged about the exterior shell to provide at least a predetermined vertical spacing between vertically adjacent apertures and a horizontal spacing between horizontally adjacent apertures, the predetermined vertical spacing and the horizontal spacing enabling concurrent use of adjacent apertures by different ones of the UAVs.
3. The multi-level fulfillment center as recited in claim 1, further comprising:
an internal corridor accessible by at least one of the apertures, the internal corridor providing access by the UAVs to the different altitudes within the multi-level fulfillment center; and
at least one of a lift assist mechanism or an impact dampener located proximate to a bottom of the internal corridor, the lift assist mechanism to provide upward air movement through the internal corridor, the impact dampener to reduce potential damage to a UAV that falls into the impact dampener.
4. The multi-level fulfillment center as recited in claim 1, wherein the first UAV platform includes arms that selectively engage coupling features coupled to the exterior shell and move the first UAV platform relative to the coupling features; and further comprising a grid of the coupling features extending outward from the exterior shell, the coupling features to provide power to the first UAV platform as the first UAV platform moves about the coupling features.
5. The multi-level fulfillment center as recited in claim 1, further comprising an internal transport robot to move a UAV from the first UAV platform to a second UAV platform used for takeoff of the UAV and to charge a power source of the UAV.
6. A multi-level structure comprising:
an exterior shell to secure an interior of the multi-level structure;
a receiving area within the exterior shell to receive freight that includes items available for consumption by customers;
a storage area within the exterior shell to organize and store the items prior to distribution to customers by unmanned aerial vehicles (UAVs);
a plurality of apertures in the exterior shell to enable access by the UAVs to different levels within the interior of the multi-level structure;
a controller to authenticate UAVs based at least in part on a determination that the UAVs are authorized to access the multi-level structure; and
UAV service sites located proximate to the plurality of apertures, the UAV service sites configured for at least landing and takeoff of the UAVs.
7. The multi-level structure as recited in claim 6, further comprising aperture doors to selectively close the plurality of apertures at least during time periods that have an absence of authenticated UAVs.
8. The multi-level structure as recited in claim 7, further comprising the controller to further control operation of the aperture doors.
9. The multi-level structure as recited in claim 6, wherein the exterior shell includes a converging profile that converges toward a point at a top of the exterior shell, the converging profile to provide unobstructed air space above at least some of the UAV service sites to enable the UAVs to land and deploy vertically.
10. The multi-level structure as recited in claim 6, wherein the exterior shell includes levels having a hub and spoke design including multiple spokes that span out from the hub, each of the spokes and the hub having interior space configured to support fulfillment operations, and wherein the spokes internally include the UAV service sites, wherein a first UAV service site is adjacent to a first aperture and a second aperture enabling at least servicing a first UAV and a second UAV from a single location, the servicing including at least loading the first UAV with a package that includes one or more of the items.
11. (canceled)
12. The multi-level structure as recited in claim 6, further comprising an internal corridor accessible by at least one of the plurality of apertures, the internal corridor providing access by the UAVs to at least some of the different levels within the multi-level structure.
13. The multi-level structure as recited in claim 12, further comprising at least one of:
a lift assist mechanism located proximate to a bottom of the internal corridor, the lift assist mechanism to provide upward air movement through the internal corridor; or
an impact dampener located proximate to the bottom of the internal corridor, the impact dampener to reduce potential damage to a UAV that falls into the impact dampener.
14. The multi-level structure as recited in claim 6, wherein the apertures include an entry aperture and an exit aperture, the entry aperture providing access to a first internal corridor that provides access by the UAVs to different levels within the multi-level structure, the exit aperture providing an exit from a second internal corridor, and further comprising UAV
passages connecting the first internal corridor to the second internal corridor, wherein the UAV service sites are located within the UAV passages.

15. The multi-level structure as recited in claim 6, wherein the UAV service sites are further configured to:
   - charge or replace a battery of a UAV, and
   - couple a package to the UAV.

16. The multi-level structure as recited in claim 6, further comprising a launch assist mechanism configured with the UAV service site, the launch assist mechanism to provide a trajectory force to a UAV during a launch of the UAV from the UAV service site.

17. A multi-level unmanned aerial vehicle (UAV) landing structure comprising:
   - an exterior shell that includes coupling features extending outward from the exterior shell; and
   - UAV platforms to support landings and takeoffs of the UAVs, the UAV platforms coupled to the exterior shell, and the UAV platforms including a plurality of arms that selectively engage the coupling features and move the UAV platforms relative to the coupling features and about the exterior shell.

18. The multi-level UAV landing structure as recited in claim 17, wherein the coupling features include power coupling components to provide power to the UAV platform as the UAV platform moves about the coupling features.

19. The multi-level UAV landing structure as recited in claim 17, further comprising apertures located in the exterior shell, the apertures to selectively open in response to positioning of a UAV platform proximate to an aperture.

20. The multi-level UAV landing structure as recited in claim 17, wherein the UAV platform includes a controller to move the UAV platform about the exterior shell while avoiding conflicts with other UAV platforms.

21. The multi-level UAV landing structure as recited in claim 17, wherein the UAV platform is configured to raise a UAV readied for deployment to a higher location on the exterior shell than a location of a coupling of a package to the UAV.

22. The multi-level structure as recited in claim 6, further comprising an internal transport robot to move a UAV within the interior of the multi-level structure and to charge a power source of the UAV.

* * * * *
Intermodal vehicles may be loaded with items and an aerial vehicle, and directed to travel to areas where demand for the items is known or anticipated. The intermodal vehicles may be coupled to locomotives, container ships, road tractors or other vehicles, and equipped with systems for loading one or more items onto the aerial vehicle, and for launching or retrieving the aerial vehicle while the intermodal vehicles are in motion. The areas where the demand is known or anticipated may be identified on any basis, including but not limited to past histories of purchases or deliveries to such areas, or events that are scheduled to occur in such areas. Additionally, intermodal vehicles may be loaded with replacement parts and/or inspection equipment, and configured to conduct repairs, servicing operations or inspections on aerial vehicles within the intermodal vehicles, while the intermodal vehicles are in motion.

20 Claims, 23 Drawing Sheets
References Cited

U.S. PATENT DOCUMENTS

9,139,210 B1 * 9/2015 Wang ....................... B64F 1/36
9,545,852 B2 * 1/2017 Streett .................. B64C 39/024
2012/0219397 A1 8/2012 Baker
2013/0073477 A1 3/2013 Grinberg
2014/0136282 A1 5/2014 Fedele

* cited by examiner
ORDER
MAMA BEAR
LITTLE GUYS
DIAPER PANTS
SIZE 6 100 CT
02/04/2014 03:28 PM

ORDER
ITEM NO. GET3811
DELIVER TO:
96 LARCH RD, GROTON, CT

FIG. 1D
FIG. 2B
START

MOBILE DELIVERY SYSTEM WITH INTERMODAL MAINTENANCE VEHICLE AND INTERMODAL CARRIER HAVING UAV AND ITEMS ABOARD IS IN TRANSIT IN REGION

ORDER FOR DELIVERY OF ITEM ABOARD INTERMODAL CARRIER TO LOCATION IN REGION RECEIVED

ITEM LOADED ONTO UAV WITHIN INTERMODAL CARRIER

LAUNCH CONDITIONS ESTABLISHED WITHIN INTERMODAL CARRIER

INTERMODAL CARRIER OPENS TO PERMIT LAUNCH OF UAV

UAV LAUNCHES FROM INTERMODAL CARRIER AND DEPARTS FOR LOCATION

INTERMODAL CARRIER CLOSES

MOBILE DELIVERY SYSTEM REMAINS IN TRANSIT

DELIVERY OPERATION COMPLETE?

STOP

FIG. 3
DEMAND FOR ITEMS ANTICIPATED IN REGIONS AT PREDETERMINED TIMES

PLACEMENT OF ITEMS IN INTERMODAL CARRIER SELECTED BASED ON DEMAND IN RESPECTIVE REGIONS AND TIMES

ITEMS AND UAVS LOADED INTO INTERMODAL CARRIER

SPEEDS OF INTERMODAL CARRIER SELECTED BASED ON DEMAND IN RESPECTIVE REGIONS AND DISTANCES OF RESPECTIVE REGIONS FROM INTERMODAL ROUTE

POWERED VEHICLE CAUSES INTERMODAL CARRIER TO TRAVEL ALONG INTERMODAL ROUTE AT SELECTED SPEEDS

ORDER FOR DELIVERY OF ITEM TO LOCATION WITHIN ONE OF THE REGIONS RECEIVED WITH INTERMODAL CARRIER IN MOTION ALONG INTERMODAL ROUTE

ORDER ASSIGNED TO UAV WITHIN INTERMODAL CARRIER

ORDERED ITEM LOADED ONTO UAV WITHIN INTERMODAL CARRIER

UAV LAUNCHED FROM INTERMODAL CARRIER ON COURSE FOR LOCATION AT DEPARTURE POINT ALONG INTERMODAL ROUTE

UAV DEPLOYS ITEM AT LOCATION

UAV DEPLOYS FROM LOCATION ON COURSE TO MEET INTERMODAL CARRIER AT ARRIVAL POINT ALONG INTERMODAL ROUTE

UAV LANDS WITHIN INTERMODAL CARRIER AT ARRIVAL POINT

FIG. 7
START

1110

ANTICIPATED UAV ROUTES ACROSS AREAS DETERMINED

1115

POWERED VEHICLE COUPLED TO INTERMODAL MAINTENANCE VEHICLE AT SERVICE STATION

1120

INTERMODAL ROUTE THROUGH OR WITHIN OPERATING RANGES OF AREAS OF ANTICIPATED UAV ROUTES DETERMINED

1125

POWERED VEHICLE DEPARTS FROM SERVICE STATION ON INTERMODAL ROUTE WITH INTERMODAL MAINTENANCE VEHICLE

1130

POWERED VEHICLE TRANSITS ALONG INTERMODAL ROUTE WITH INTERMODAL MAINTENANCE VEHICLE

1140

UAV Requires servicing within areas? NO

1150

POSITION OF RENDEZ-VOUS POINT DETERMINED

1160

COURSE FROM UAV AND DISTANCE FROM INTERMODAL MAINTENANCE VEHICLE TO RENDEZ-VOUS POINT DETERMINED

1165

UAV AND INTERMODAL MAINTENANCE VEHICLE PROCEED TO RENDEZ-VOUS POINT

1170

INTERMODAL MAINTENANCE VEHICLE OPENS TO RECEIVE UAV FOR SERVICING

1180

SERVICING OPERATIONS PERFORMED

1190

UAV DEPARTS FROM INTERMODAL MAINTENANCE VEHICLE

STOP

FIG. 11
GROUND-BASED MOBILE MAINTENANCE FACILITIES FOR UNMANNED AERIAL VEHICLES

BACKGROUND

Online marketplaces enable customers to visit one or more network sites from any corner of the globe, to view and evaluate items, and to place orders for the purchase of such items over the Internet. Initially, orders for items that were placed at online marketplaces over the Internet were fulfilled at the original locations of vendors (or manufacturers, merchants or other sources of the items), from which the items would be shipped to customers via first-class mail or another common carrier. Today, however, many online marketplaces operate in association with one or more fulfillment centers. A fulfillment center is a facility, a warehouse or another like structure that is constructed in a distributed, centralized location and adapted to receive items from sources of the items (e.g., vendors or other fulfillment centers). Fulfillment centers may include stations for receiving shipments of items, for storing such items, and/or for preparing such items for delivery to customers. When an order for the purchase of one or more items stored in a fulfillment center is received from a customer, the ordered items may be retrieved from spaces or areas in which such items are stored, and prepared for delivery to the customer, e.g., by packing the ordered items into one or more appropriate containers with a sufficient type and amount of dunnage, and delivering the containers to a destination designated by the customer.

Aerial vehicles such as airplanes or helicopters are commonly used to transport people or cargo from an origin to one or more destinations by air. Additionally, loading passengers or cargo onto an aerial vehicle at an origin, and unloading passengers or cargo from the aerial vehicle at a destination, typically requires the use and support of one or more machines, buildings, facilities and/or structures, as well as the assistance of numerous personnel. For this reason, aerial vehicles typically depart from and return to immovable facilities or structures such as airports, helipads, heliports, jetports or the like, which may, like fulfillment centers, occupy substantially large areas or include one or more large buildings and connections to various transportation systems. For example, Denver International Airport occupies a land area that is more than twice the size of New York’s Manhattan Island.

Moreover, performing planned or unplanned maintenance on an aerial vehicle requires the aerial vehicle to be taken out of service for extended durations. For example, depending on its size, or a length of time since its most recent inspection, a typical inspection of an aerial vehicle may require tens or hundreds of man-hours in order to be completed. Even where maintenance results in a determination that the integrity of an aerial vehicle is sound, and that the aerial vehicle is operating in a safe and satisfactory manner, or that the aerial vehicle requires a simple repair, the aerial vehicle must still be taken out of service in order to arrive at that determination, or to complete the repair. Every hour in which an aerial vehicle is out-of-service is an hour in which the aerial vehicle is not providing value.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. 1A through 1I are views of aspects of operation of one mobile intermodal delivery system in accordance with embodiments of the present disclosure.

FIGS. 2A and 2B are block diagrams of components of one system including a mobile intermodal delivery system in accordance with embodiments of the present disclosure.

FIG. 3 is a flow chart of one process for operation of a mobile intermodal delivery system in accordance with embodiments of the present disclosure.

FIGS. 4A through 4D are views of aspects of one mobile intermodal delivery system in accordance with embodiments of the present disclosure.

FIGS. 5A through 5C are views of components for use in mobile intermodal delivery systems in accordance with embodiments of the present disclosure.

FIG. 6 is a view of aspects of one mobile intermodal delivery system in accordance with embodiments of the present disclosure.

FIG. 7 is a flow chart of one process for operation of a mobile intermodal delivery system in accordance with embodiments of the present disclosure.

FIG. 8 is a view of aspects of operation of one mobile intermodal delivery system in accordance with embodiments of the present disclosure.

FIGS. 9A and 9B are views of aspects of operation of mobile intermodal delivery systems in accordance with embodiments of the present disclosure.

FIG. 10 is a view of aspects of operation of one mobile intermodal delivery system in accordance with embodiments of the present disclosure.

FIG. 11 is a flow chart of one process for operation of a mobile intermodal delivery system in accordance with embodiments of the present disclosure.

DETAILED DESCRIPTION

As is set forth in greater detail below, the present disclosure is directed to the use of mobile intermodal delivery systems in combination with one or more aerial vehicles such as unmanned aerial vehicles (e.g., “UAV’s”), or drones. In particular, some embodiments of the present disclosure are directed to the fulfillment of orders for items using aerial vehicles that are launched from mobile intermodal carriers, including but not limited to intermodal carriers that are loaded onto well cars or like cars that are pushed or pulled on rails by locomotives, as well as intermodal carriers that are loaded onto container ships traveling on waterways and/or tractor-trailers traveling on suitable roads (e.g., highways having sufficient vertical and lateral clearance). The intermodal carriers may be constructed in any manner, and from any materials. For example, in some embodiments, an intermodal carrier may be formed from two or more prefabricated or preconstructed intermodal containers of standard dimensions or shapes that may be stacked atop or otherwise associated with one another.

Some other embodiments of the present disclosure are directed to the forward deployment of inventory to regions of predicted demand using mobile intermodal carriers (e.g., carriers placed in motion by locomotives, seagoing vessels and/or road vehicles) for delivery by UAVs. Some other embodiments of the present disclosure are also directed to mobile maintenance facilities within mobile intermodal carriers that are configured to receive one or more UAVs that require maintenance, repairs or other servicing operations, and to automatically perform such operations within the intermodal carriers before launching the UAV’s therefrom, thereby promptly restoring the UAV’s to an operational state without requiring the UAV to return to a fixed structure or other facility for the performance of such operations.
Referring to FIGS. 1A through 1L, a mobile intermodal delivery system 140 is shown. The mobile intermodal delivery system 140 includes a powered vehicle 145 (e.g., a locomotive) as well as an intermodal carrier vehicle 150 and an intermodal maintenance vehicle 160 traveling on a set of rails 125. The intermodal carrier vehicle 150 is formed from a pair of intermodal containers 161A, 161B that are stacked atop one another and placed on a well car 143A that is coupled to the powered vehicle 145. The intermodal container 151A, which is stacked atop the intermodal container 161B on the well car 143A, includes a pair of top doors 154A, 154B that may be hingedly opened or closed to provide access to the intermodal container vehicle 150 from above. The intermodal maintenance vehicle 160 is also formed from a pair of intermodal containers 161A, 161B that are stacked atop one another and placed on the well car 143B that is coupled to the powered vehicle 145 via the intermodal carrier vehicle 150. The intermodal container 161A, which is stacked atop the intermodal container 161B on the well car 143B, includes a pair of top doors 164A, 164B that may be hingedly opened or closed to provide access to the intermodal maintenance vehicle 160 from above.

FIG. 1B is a cutaway view of the intermodal carrier vehicle 150. As is shown in FIG. 1B, the intermodal carrier vehicle 150 includes a plurality of items 10-n (e.g., consumer goods), an aerial vehicle launch and retrieval system 152, the doors 154A, 154B and an item engagement system 158. The launch and retrieval system 152 of FIG. 1B includes a conveyor having an aerial vehicle 170 thereon, and may be configured to launch the aerial vehicle 170 from the intermodal carrier vehicle 150 when the doors 154A, 154B are opened, or to retrieve one or more aerial vehicles (not shown) therein. For example, the embodiment of the launch and retrieval system 152 shown in FIG. 1B may be configured to rotate about a lateral axis to any desired degree, e.g., in order to place the conveyor at an incline or a decline angle, as well as about a vertical axis, e.g., to place the conveyor at a predetermined orientation, for loading items onto the aerial vehicle 170 and/or for launching the aerial vehicle 170 therefrom. The item engagement system 158 comprises one or more components (e.g., robotic arms or other like elements) for engaging items or materials, such as one or more of the items 10-n, and loading such items or materials onto the aerial vehicle 170.

FIG. 1C is a cutaway view of the intermodal maintenance vehicle 160, which features a construction similar to that of the intermodal carrier vehicle 150. As is shown in FIG. 1C, the intermodal maintenance vehicle 160 includes a plurality of spare parts 181-n, 184-n, 187-n, including motors (or other propulsion modules), batteries (or other power sources), and propellers of various sizes, shapes or other characteristics. The intermodal maintenance vehicle 160 further includes a launch and retrieval system 162 that may operate in a manner that is similar to that of the launch and retrieval system 152 discussed above with regard to FIG. 1B, and a pair of doors 164A, 164B that may operate in a manner that is similar to that of the doors 154A, 154B discussed above with regard to FIG. 1B. The intermodal maintenance vehicle 160 also includes an item engagement system 168 that comprises one or more components (e.g., robotic arms or other like elements) for engaging one or more of the spare parts 181-n, 184-n, 187-n, such as one or more of the motors, batteries and/or propellers, and installing such spare parts 181-n, 184-n, 187-n as replacements onto one or more aerial vehicles within the intermodal maintenance vehicle 160 (not shown).

As is shown in FIG. 1D, the mobile intermodal delivery system 140 may be configured to receive orders for deliveries of one or more of the items 10-n within the intermodal carrier vehicle 150, as the mobile intermodal delivery system 140 travels along the rails 125 in a predetermined direction and at a selected speed, within the aerial vehicle 170 within the intermodal carrier vehicle 150, and to provide instructions to one or more of the components therein for causing such items to be delivered by the intermodal carrier vehicle 150. For example, as is shown in FIG. 1D, a customer 120 may place an order for a specific item (viz., a box of diapers) with an online marketplace or other electronic system over a network 190, and the order may be assigned to the mobile intermodal delivery system 140 for fulfillment by one or more instructions received over the network 190.

After an order for an item has been received and assigned to the intermodal delivery system 140 for fulfillment, the ordered item may be loaded into the aerial vehicle 170 within the intermodal carrier vehicle 150. As is shown in FIG. 1E and FIG. 1F, the item engagement system 158 may retrieve the item 10-1 from storage within the intermodal carrier vehicle 150, e.g., by automatically determining a position of the item 10-1 among the items 10-n and gripping the item 10-1, e.g., by one or more end effectors or mechanical grips. The item 10-1 may then be transported to a point where the item 10-1 may be loaded onto the aerial vehicle 170, which may itself be transported to the point by the launch and retrieval system 152.

Subsequently, as is shown in FIG. 1G, after the item engagement system 158 has loaded the item 10-1 onto the aerial vehicle 170, the launch and retrieval system 152 may place the aerial vehicle 170 in an appropriate position for launch. Alternatively, one or more preferred launching conditions may be established within the intermodal carrier vehicle 150, such as by establishing a desired air velocity, a desired air pressure and/or a desired air temperature within the intermodal carrier vehicle 150. As is shown in FIG. 1H, the launch and retrieval system 152 may be aligned in a desired orientation for launching the aerial vehicle 170 therefrom. As is shown in FIG. 1I, after the top doors 154A, 154B have opened, the aerial vehicle 170 may be launched from the launch and retrieval system 152 at a departure point P. The aerial vehicle 170 may be launched under its own power or, alternatively, under power provided by the launch and retrieval system 152, or by a combination of the aerial vehicle 170 and the launch and retrieval system 152.

Upon clearing the intermodal carrier vehicle 150, the aerial vehicle 170 may then travel on a desired course and speed to reach a location designated by the customer 120 and to deposit the item 10-1 there. As is shown in FIG. 1J, the aerial vehicle 170 may travel on a course from the departure point P on the rails 125 to the location of the customer 120, and deposit the item 10-1 there before meeting the mobile intermodal delivery system 140 at a rendezvous point P on the rails 125 at a later time. The departure point P, and the rendezvous point P may be selected based on the location of the customer 120, as well as any operational or logistical factors, considerations or constraints (e.g., prevailing weather conditions, available power levels aboard the mobile intermodal delivery system 140 or the aerial vehicle 170, as well as a required delivery date or time for the item 10-1, or for one or more of the items 10-n that may have been ordered by other customers, or other traffic on the rails 125). Additionally, the speed of the mobile intermodal delivery system 140 prior to, while, or after launching the aerial vehicle 170 may also be selected based on the posi-
tems carried thereon. The intermodal carrier vehicles may be
that utilizes one or more aerial vehicles for fulfilling orders 50
transit. Such modes may include, but are not limited to, 40
tems that may transport aerial vehicles, and items to be
modal carrier vehicle
may be installed in the aerial vehicle
the intermodal maintenance vehicle
the aerial vehicle
motors, propellers and/or batteries, or any other mainte­
tions of the departure point P₁ and the rendezvous point P₂,
 or on any other operational or logistical factors, consider­
ations or constraints.
After the item 10-1 has been delivered to the customer 120, and after the aerial vehicle 170 has met the mobile intermodal delivery system 140 at the rendezvous point P₂, the aerial vehicle 170 may be retrieved by the intermodal carrier vehicle 150 or, as is shown in FIG. 1K, by the intermodal maintenance vehicle 160. For example, if the aerial vehicle 170 requires replacement of one or more motors, propellers and/or batteries, or any other mainte­
nance, repairs or servicing operations, the doors 164A, 164B of the aerial vehicle 170 may be opened as the mobile intermodal delivery system 140 travels along the tracks, and the aerial vehicle 170 may land within the intermodal maintenance vehicle 160.

As is shown in FIG. 1L, with the aerial vehicle 170 within the intermodal maintenance vehicle 160, one of the batteries 184-n may be installed into the aerial vehicle 170 as a replacement. For example, the item engagement system 168 may automatically determine a position of a battery 184-n having an appropriate voltage level, power rating or other like attribute for use in the aerial vehicle 170, and transport the battery 184-1 to a point where the battery 184-1 may be installed in the aerial vehicle 170. After the battery 184-1 has been installed, and any testing or verifications have been performed, the aerial vehicle 170 may then remain within the intermodal maintenance vehicle 160 until the mobile intermodal delivery system 140 reaches its destination, or may depart from the intermodal maintenance vehicle 160, e.g., via the launch and retrieval system 162, and travel to one or more other locations, or to the intermodal carrier vehicle 150. For example, one or more of the remaining items 10-n may be loaded onto the aerial vehicle 170 and delivered thereby to another customer (not shown).

Accordingly, the systems and methods of the present disclosure are directed to mobile intermodal delivery systems that may transport aerial vehicles, and items to be delivered by such vehicles, along one or more modes of transit. Such modes may include, but are not limited to, rail-based systems (e.g., railways) as well as sea-based systems (shipping routes or channels) or other ground-based systems (e.g., interstate highways or other suitable roadways). The mobile intermodal delivery systems may be formed from intermodal containers (e.g., a standardized structure originally intended for shipping or holding items), or from similarly sized structures and systems. In this regard, a mobile intermodal delivery system of the present disclosure may effectively act as a mobile fulfillment center that utilizes one or more aerial vehicles for fulfilling orders for items, or a mobile repair facility for conducting repairs on aerial vehicles, while remaining in location within one or more selected regions.

Additionally, one or more of the mobile intermodal delivery systems disclosed herein may include intermodal carrier vehicles, such as the intermodal carrier vehicle 150 of FIGS. 1A through 1L, that may be loaded with inventory items and one or more aerial vehicles, as well as automated systems or components for loading items onto or unloading items from such aerial vehicles, e.g., loading and/or engagement systems carried thereon. The intermodal carrier vehicles may be placed in motion via one or more modes or transportation networks. Such intermodal carrier vehicles may be configured to automatically launch and retrieve aerial vehicles therefrom, and automatically load items onto (or unloading items from) such aerial vehicles, by way of one or more loading and/or engagement systems carried thereon.

Likewise, one or more of the mobile intermodal delivery systems disclosed herein may include intermodal maintenance vehicles, such as the intermodal maintenance vehicle 160 of FIGS. 1A through 1L, which may be loaded with replacement parts or other supplies or resources required in order to maintain an aerial vehicle in an operable and/or optimal condition, as well as automated systems or components for installing such parts, supplies or resources onto an aerial vehicle. The intermodal maintenance vehicles may be placed in motion via one or more modes or transportation networks. Such intermodal maintenance vehicles may be configured to automatically launch and retrieve aerial vehicles therefrom, and automatically load items onto (or unloading items from) such aerial vehicles, by way of one or more loading and/or engagement systems carried thereon.

Although the intermodal carrier vehicle 150 and the intermodal maintenance vehicle 160 of FIGS. 1A through 1L are shown as including well cars 143A, 143B that are coupled to the powered vehicle 145, those of ordinary skill in the pertinent arts will recognize that intermodal carrier vehicles and/or intermodal maintenance vehicles, such as the intermodal carrier vehicle 150 and/or the intermodal maintenance vehicle 160, may be coupled to any type or form of powered vehicle, e.g., a container ship and/or a tractor-trailer, and operated in a similar manner on waterways or roads. Moreover, one or more of the intermodal carrier vehicles and/or intermodal maintenance vehicles, such as the intermodal carrier vehicle 150 and/or the intermodal maintenance vehicle 160, may be utilized in multiple transit modes. For example, referring again to FIG. 1A, the intermodal carrier vehicle 150 may be transported to a sea port, lifted from the well car 143A, and loaded onto a container ship for transit on one or more bodies of water. Alternatively, the intermodal carrier vehicle 150 may be transported to a rail station, lifted from the well car 143A, and loaded onto a train, and hitched to a road tractor for further road-based transit.

Additionally, some embodiments of the mobile intermodal delivery systems disclosed herein may include both an intermodal carrier vehicle and an intermodal maintenance vehicle, such as the mobile intermodal delivery system 140 of FIGS. 1A through 1L. Some other embodiments of the mobile intermodal delivery systems disclosed herein may include an intermodal carrier vehicle, or an intermodal maintenance vehicle, but not both an intermodal carrier vehicle and an intermodal maintenance vehicle. Still other embodiments of the mobile intermodal delivery systems disclosed herein may include two or more intermodal carrier vehicles, such as two or more of the intermodal carrier vehicles 150 of FIGS. 1A through 1L, and/or two or more intermodal maintenance vehicles, such as two or more of the intermodal maintenance vehicles 160 of FIGS. 1A through 1L. Additionally, a mobile intermodal delivery system may include any number of powered vehicles for placing one or more intermodal carrier vehicles and/or intermodal maintenance vehicles in motion, e.g., two or more locomotives, containers ships and/or road tractors. Moreover, a mobile intermodal delivery system may include a single combined vehicle that includes carrier and maintenance systems, and is configured to perform the functions of both an intermodal carrier vehicle and an intermodal maintenance vehicle, or two or more of such combined vehicles.

In accordance with some embodiments of the present disclosure, inventory items may be loaded onto mobile intermodal delivery systems (e.g., onto one or more intermodal carrier vehicles) along with one or more aerial vehicles and placed in motion along a route associated with
In the twentieth century, Henry Ford’s assembly lines began operating in 1913, thereby enabling the low-cost, mass production of cars and trucks for personal use. Automobiles continued to grow in popularity and efficiency with the advent of the Eisenhower Interstate Highway System in 1956, which permitted Americans to independently traverse the nation at elevated speeds on wide, structurally sound roadways and bridges. Finally, with the development of wide-body airliners such as the Boeing 747 in 1969, and the deregulation of airlines in the United States beginning in 1976, the delivery of passengers and cargo by air became increasingly efficient and cost-effective in the latter half of the twentieth century.

Intermodal containers (sometimes called intermodal freight containers, dry vans, box containers, International Standards Organization containers, or “ISO containers”) are some of the most common vessels for transporting goods across the nation’s transportation networks today. Intermodal containers may be easily transferred between rail-based, marine or roadway transportation systems, and may be fixed in place on a transport vehicle (e.g., a well car configured for travel on rail, a container ship, or a trailer). In some applications, intermodal containers may be stacked while in transit or in storage. By some estimates, more than twenty million intermodal containers are in use today.

One advantage of the use of intermodal containers is the relative ease with which such containers may be transferred between transit modes or carriers (e.g., rail-based, marine or roadway transportation systems). For this reason, intermodal containers typically have standard dimensions including widths of approximately eight to eight-and-one-half feet (8 to 8.5 ft) and lengths of twenty, forty, forty-five, forty-eight or fifty-three feet (20, 40, 45, 48 or 53 feet) and heights of approximately eight to ten feet (8 to 10 ft), typically eight-and-one-half or nine-and-one-half feet (8.5 or 9.5 ft). The carrying capacity of an intermodal carrier is often measured in a nominal term known as Twenty-foot Equivalent Units, or “TEU,” which refer to a number of eight foot by eight foot by twenty foot (8 ft x 8 ft x 20 ft) volumes that may be accommodated within a given intermodal carrier. Intermodal containers are frequently constructed from steel and include steel frames and/or castings that are sufficiently durable and strong enough to accommodate cargo within while still withstanding impacts due to stacking, shocks or other contact during normal operation, and to protect the cargo therein against the elements. Because intermodal containers are constructed with durability and strength in mind, intermodal carriers have recently been repurposed into secondary uses, including for use as temporary or permanent buildings, shelters, offices or the like.

As is discussed above, and in greater detail below, the systems and methods of the present disclosure are directed to mobile intermodal delivery systems having powered vehicles along with one or more intermodal carriers and/or one or more intermodal maintenance vehicles. The powered vehicles may include locomotives coupled to one or more well cars or like vehicles that are configured to travel on one or more rails of any head sizes or shapes. Where a set of rails includes two or more of such rails, the rails may be separated by any gauge distance. Additionally, the locomotives may include one or more diesel engines, electric engines, or engines or motors that are powered by any other source of energy (e.g., gasoline, fuel cells, nuclear reactors, solar power). The well cars or like vehicles may include one or more structures, beams, trusses or other wheeled systems for accommodating intermodal containers or vehicles in accordance with the present disclosure thereon. The mobile intermodal delivery systems may include intermodal containers and/or intermodal vehicles for transporting items, launching and retrieving aerial vehicles, loading items onto or unloading items from aerial vehicles, or conducting maintenance, repairs or servicing operations on such aerial vehicles.

In some embodiments, a mobile intermodal delivery system may be used to forward-deploy inventory items, along with one or more aerial vehicles, to areas where demand for such inventory items may be reasonably anticipated, thereby enabling orders for such items to be fulfilled using such aerial vehicles from shorter distances and in shorter times than if the orders were received and assigned...
to fulfillment centers, warehouses or other fixed locations. Similarly, a mobile intermodal delivery system may also be routed to areas having large numbers of items that are intended to be retrieved therefrom, and such items may be retrieved using one or more aerial vehicles. In this regard, the mobile intermodal delivery systems of the present disclosure may be used to pick up items from one or more manufacturers, merchants, sellers and/or vendors or other sources for subsequent resale, or to retrieve unwanted items from customers, as well as to perform any number of other functions unrelated to electronic commerce, including but not limited to the retrieval of garbage and/or recyclable waste.

The intermodal containers of the present disclosure may have any size, shape and/or dimension that may be utilized and/or supported by powered vehicles and/or associated carriers (e.g., locomotives and/or well cars, container ships, tractors and/or trailers or the like), as well as any associated structures or systems (e.g., cranes, elevators, conveyors at fulfillment centers or other sources, or canals, channels, roadways, tunnels, bridges or other transportation infrastructure) that may be required in order to accommodate their travel or use.

Areas where demand for items, or supplies of items, are anticipated may be identified on any basis. In some embodiments, such areas may be identified by resort to information or data regarding prior purchases of items by residents living in the respective areas, or prior deliveries of items to residents of the respective areas, which may indicate that such items, or substitutes for or complements to such items, are in demand in such areas. Likewise, such areas may also be identified based on their similarities to other areas, and the demand for items or supplies of items that were previously observed in such other areas. For example, when a particular area is experiencing a lengthy spell of good weather, a national championship by a local sports team, a natural disaster, or other unique event, demand for items within the area may be identified based on demand for items observed in other areas that recently experienced lengthy spells of good weather, national championships, natural disasters, or other such unique events. Furthermore, the areas of the anticipated demand and/or supplies may be identified by determining information or data regarding demographics of residents in such areas, and identifying items that are in demand to members of such demographics, including not only members of such demographics who are residents of such areas but also other areas. Any means, methods or techniques for determining a level of demand or a level of supply for a given item, on a local or regional basis, may be utilized in accordance with embodiments of the present disclosure.

The mobile intermodal delivery systems of the present disclosure may be used to distribute items on a local basis in any manner. For example, items may be loaded into and secured within intermodal carriers on a homogenous basis, e.g., where an intermodal carrier includes a common type of item, and no others. Alternatively, items may be loaded into and secured within intermodal carriers on a heterogeneous basis, e.g., where an intermodal carrier includes a variety of types of items. Items may also be loaded into and secured within mobile intermodal delivery systems in storage compartments that are specifically tailored for such items, e.g., refrigerated or heated storage compartments within intermodal carriers for maintaining cold or hot items therein, as well as storage compartments that are generally provided for multiple types of items. Alternatively, an intermodal carrier may include any number of compartments that are configured to maintain items therein at any desired temperature (e.g., hot or cold).

Moreover, once items and aerial vehicles have been loaded into and secured within one or more intermodal carriers, the intermodal carriers may be delivered to selected regions by one or more powered vehicles based on the demand for the items maintained therein on any basis. For example, in some embodiments, intermodal carriers may be configured to travel from a fulfillment center or one or more locations on trains, on container ships or on road vehicles, with such locations being selected based on known, observed or predicted demand for such items. In some other embodiments, intermodal carriers may be delivered singly or in bulk to such regions by one or more powered vehicles, which may be manned or unmanned. For example, intermodal carriers that are loaded with items and aerial vehicles may be delivered to regions where such items are known, observed or predicted to be in demand in or by one or more powered vehicles that may be configured to travel in the air, on land or sea, or within the physical universe beyond the Earth’s atmosphere (e.g., outer space), such as cars, trucks, trailers, freight cars, container ships, cargo aircraft or spacecraft, or other like vehicles. Likewise, intermodal carriers may be retrieved from such regions by one or more powered vehicles, and returned to a fulfillment center or other facility, e.g., for loading, reloading or maintenance, as desired.

Referring to FIGS. 2A and 2B, a block diagram of components of one system 200 including a mobile intermodal delivery system 240 in accordance with embodiments of the present disclosure is shown. The system 200 includes a marketplace 210, a customer 220, a fulfillment center 230, a mobile intermodal delivery system 240 and an aerial vehicle 270 that are connected to one another across a network 290, which may include the Internet in whole or in part. Except where otherwise noted, reference numerals preceded by the number “2” in FIG. 2A or FIG. 2B refer to elements that are similar to elements having reference numerals preceded by the number “1” shown in FIGS. 1A through 1I.

The marketplace 210 may be any entity or individual that wishes to make items from a variety of sources (e.g., manufacturers, merchants, sellers or vendors) available for download, purchase, rent, lease or borrowing by customers using a networked computer infrastructure, including one or more physical computer servers 212 and data stores 214 (e.g., databases) for hosting a network site 216. The marketplace 210 may be physically or virtually associated with one or more storage or distribution facilities, such as the fulfillment center 230. The network site 216 may be implemented using the one or more servers 212, which connect or otherwise communicate with the one or more data stores 214 as well as the network 290, as indicated by line 218, through the sending and receiving of digital data. Moreover, the data store 214 may include any type of information regarding items that have been made available for sale through the marketplace 210, or ordered by customers, such as the customer 220, from the marketplace 210, or any information or data regarding the delivery of such items to the customers by any means, including but not limited to the mobile intermodal delivery system 240 and/or the aerial vehicle 270. For example, the servers 212 may be configured to make one or more determinations regarding regions or areas where one or more specific items are in demand based on information or data stored in the data stores 214 or on one or more external computer devices, e.g., over the network 290.
The servers 212, or one or more other computer devices, may determine actual or predicted demand for one or more items in any number of regions or areas on any basis. Once demand in any given region or area has been determined, the demand may be compared to one or more thresholds or limits to determine whether the demand is sufficiently great, on an actual or relative basis, in order to justify distributing or forward-deploying items to the given region by one or more mobile intermodal delivery systems. For example, in some embodiments, a total-market prediction of demand may be determined by defining a market, identifying drivers of demand in each of the markets, predicting how such drivers may be anticipated to change, and localizing the effects of such changes to a given region or location. In some other embodiments, a prediction of local demand in a region or location may be determined based on prior sales of items in the region or location, and determining whether such sales are expected to increase, decrease or remain constant. For example, where a neighborhood includes a fixed number of homes, demand for specific items (e.g., bicycles, smartphones, outdoor grills, basketballs) may be determined based on an analysis of demographics (e.g., residents who are of varying ages, genders, ethnicities or religions), within the neighborhood, as compared to demographics in the neighborhood in previous years, or demographics in other similarly situated neighborhoods. In some embodiments, the servers 212, or the one or more other computer devices, may identify any upcoming local, regional, national or global events, and project demand for items pertaining to such events in a general manner, or in specific locations or regions. The level of specificity or granularity associated with a projection may be selected on any basis. In other embodiments, demand for items in a given region may be determined based on local laws, regulations or customs in effect within the region.

The fulfillment center 230 may be any facility that is adapted to receive, store, process and/or distribute items. As is shown in FIG. 2A, the fulfillment center 230 includes a server 232, a data store 234, and one or more computer processors 236. The fulfillment center 230 also includes stations for receiving, storing and distributing items to customers, including but not limited to a receiving station 231, a storage area 233 and a distribution station 235.

The server 232 and/or the processors 236 may operate one or more order processing and/or communication systems and/or software applications having one or more user interfaces, or communicate with one or more other computing devices or machines that may be connected to the network 290, as indicated by line 238, for transmitting or receiving information in the form of digital or analog data, or for any other purpose. For example, the server 232 and/or the processors 236 may also operate or provide access to one or more reporting systems for receiving or displaying information or data regarding orders for items received by the marketplace 210, or deliveries made by any means, e.g., the mobile intermodal delivery system 240 and/or the aerial vehicle 270, and may provide one or more interfaces for receiving interactions (e.g., text, numeric entries or selections) from one or more operators, users, workers or other persons in response to such information or data. The server 232, the data store 234 and/or the processor 236 may be a general-purpose device or machine, or a dedicated device or machine that features any form of input and/or output peripherals such as scanners, readers, keyboards, keypads, touchscreens or like devices, and may further operate or provide access to one or more engines for analyzing the information or data regarding the workflow operations, or the interactions received from the one or more operators, users, workers or persons.

For example, the server 232 and/or the processors 236 may be configured to determine an optimal path or route between two locations for the execution of a given mission or task to be executed by the mobile intermodal delivery system 240 and/or the aerial vehicle 270 on any basis, such as according to one or more traditional shortest path or shortest route algorithms such as Dijkstra's Algorithm, Bellman-Ford Algorithm, Floyd-Warshall Algorithm, Johnson's Algorithm or a hub labeling technique. Additionally, the server 232 and/or the processors 236 may be configured to control or direct, or to recommend or suggest, collaboration between or among one or more of the mobile intermodal delivery systems 240 and/or the aerial vehicle 270 and any number of other vehicles in the performance of one or more tasks or in the execution of one or more functions. For example, the server 232 and/or the processors 236 may be configured to identify levels of inventory distributed among one or more of the mobile intermodal delivery systems 240 or aboard other vehicles or in other locations, and to identify an optimal path to be traveled by the mobile intermodal delivery systems 240 and/or one or more aerial vehicles 270 in delivering such items to a customer or other destination. Moreover, the server 232 may be configured to provide one or more aerial vehicles 270 with one or more sets of instructions for traveling from an origin to a destination, or from the destination to the origin, or for performing any task in accordance with the present disclosure.

Additionally, the server 232 and/or the processor 236 may determine which of the mobile intermodal delivery systems 240 and/or aerial vehicles 270 is appropriately equipped to deliver one or more items to a location or to retrieve one or more items therefrom on any basis, including but not limited to their respective proximity to the location and/or a departure point on one or more modes or networks or a rendezvous point on one or more such modes or networks, e.g., the points P₁ and P₂ shown in FIG. 1G, as compared to those of other mobile intermodal delivery systems 240 and/or aerial vehicles 270, or on any other relevant factor or basis. The server 232 and/or the processor 236 may select the appropriate departure points and/or rendezvous points where one or more mobile intermodal delivery systems 240 and/or aerial vehicles 270 may meet in order to transfer inventory or materials therebetween, or for any other purpose. The departure points and/or the rendezvous points may be selected on any basis, including but not limited to a net cost, a net distance or a net time required for a given mobile intermodal delivery system 240 and/or a given aerial vehicle 270 to execute a given task, or on any other basis.

The receiving station 231 may include any apparatuses that may be required in order to receive shipments of items at the fulfillment center 230 from one or more sources and/or through one or more channels, including but not limited to docks, lifts, cranes, jacks, belts or other conveying apparatuses for obtaining items and/or shipments of items from carriers such as cars, trucks, trains, freight cars, container ships or cargo aircraft (e.g., manned aircraft or unmanned aircraft, such as drones), as well as one or more of the mobile intermodal delivery systems 240 and/or aerial vehicles 270, and preparing such items for storage or distribution to customers. The storage area 233 may include one or more predefined two-dimensional or three-dimensional spaces for accommodating items and/or containers of such items, such as aisles, rows, bays, shelves, slots, bins, racks, tiers, bars,
hooks, cubbies or other like storage means, or any other appropriate regions or stations. The distribution station 235 may include one or more regions or stations where items that have been retrieved from a designated storage area may be evaluated, prepared and packed for delivery from the fulfillment center 230 to locations or destinations specified by customers, e.g., by way of one or more of the mobile intermodal delivery systems 240 and/or aerial vehicles 270, or any other vehicle of any type, e.g., cars, trucks, trailers, freight cars, container ships or cargo aircraft (e.g., manned aircraft or unmanned aircraft, such as drones). Such locations or destinations may include, but are not limited to, facilities having specific addresses or other geocoded identifiers (e.g., dwellings or businesses), as well as storage lockers or other temporary storage or receiving facilities. Those of ordinary skill in the pertinent art will recognize that shipments of items arriving at the receiving station 231 may be processed, and the items placed into storage within the storage areas 233 or, alternatively, transferred directly to the distribution station 235, or "cross-ducted," for prompt delivery to one or more customers.

The fulfillment center 230 may further include one or more control systems that may generate instructions for conducting operations at one or more of the receiving station 231, the storage area 233 or the distribution station 235. Such control systems may be associated with the server 232, the data store 234 and/or the processor 236, or with one or more other computing devices or machines, and may communicate with the receiving station 231, the storage area 233 or the distribution station 235 within the fulfillment center 230 by any known wired or wireless means, or with the marketplace 210, the customer 220 or one or more of the mobile intermodal delivery systems 240 and/or aerial vehicles 270 over the network 290, as indicated by line 238, through the sending and receiving of digital data.

Additionally, the fulfillment center 230 may include one or more systems or devices (not shown in FIG. 2A or FIG. 2B) for determining locations of one or more elements therein, such as cameras or other image recording devices. Furthermore, the fulfillment center 230 may also include one or more workers or staff members (not shown in FIG. 2A or FIG. 2B), who may handle or transport items within the fulfillment center 230. Such workers may operate one or more computing devices or machines for registering the receipt, retrieval, transportation or storage of items within the fulfillment center, or a general-purpose device such as a personal digital assistant, a digital media player, a smart phone, a tablet computer, a desktop computer or a laptop computer, and may include any form of input and/or output peripherals such as scanners, readers, keyboards, keypads, touchscreens or like devices.

The customer 220 may be any entity or individual that wishes to download, purchase, rent, lease, borrow or otherwise obtain items (which may include goods, products, services or information of any type or form) from the marketplace 210, e.g., for delivery by one or more of the mobile intermodal delivery systems 240 and/or aerial vehicles 270. The customer 220 may utilize one or more computing devices 222 (e.g., a smartphone, a tablet computer, a laptop computer, a desktop computer, or computing devices provided in wristwatches, televisions, set-top boxes, automobiles or any other appliances or machines), or any other like machine, that may operate or access one or more software applications 224, such as a web browser or a shopping application, and may be connected to or otherwise communicate with the marketplace 210, the fulfillment center 230, or one or more of the mobile intermodal delivery systems 240 and/or aerial vehicles 270 through the network 290, as indicated by line 228, by the transmission and receipt of digital data.

The mobile intermodal delivery system 240 may be any self-powered system for transporting and/or receiving items via aerial vehicles, for performing maintenance, repairs or servicing operations on such aerial vehicles, or for forwarding deploying items for delivery by such aerial vehicles in accordance with one or more embodiments of the present disclosure. As is shown in FIG. 2A, the mobile intermodal delivery system 240 includes a networked computer infrastructure, including one or more physical computer processors 242, transceivers 244 and/or data stores (e.g., data bases and/or other memory components) 246 that may connect or otherwise communicate with one or more external computer devices over the network 290, as indicated by line 248, by the transmission and/or receipt of information or data in the form of digital or analog data, or for any other purpose. For example, the mobile intermodal delivery system 240 may receive instructions or other information or data via the transceiver 244 regarding an item that is to be delivered from the intermodal carrier vehicle 250 to the customer 220 from the marketplace server 212, the customer computing device 222 and/or the fulfillment center server 232, or from any other computing device over the network 290. The transceiver 244 may be configured to enable the mobile intermodal delivery system 240 to communicate through one or more wired or wireless means, e.g., wired technologies such as Universal Serial Bus (or "USB") or fiber optic cable, or standard wireless protocols such as Bluetooth® or any Wireless Fidelity (or "Wi-Fi") protocol, such as over the network 290 or directly.

The transceiver 244 may further include or be in communication with one or more input/output (or "I/O") interfaces, network interfaces and/or input/output devices, and may be configured to allow information or data to be exchanged between one or more of the components of the mobile intermodal delivery system 240 or to one or more other computer devices or systems (e.g., other aerial vehicles, not shown) via the network 290. For example, in some embodiments, the transceiver 244 may be configured to coordinate I/O traffic between the processor 242 and one or more onboard or external computer devices or components. The transceiver 244 may perform any necessary protocol, timing or other data transformations in order to convert data signals from a first format suitable for use by one component into a second format suitable for use by another component. In some embodiments, the transceiver 244 may include support for devices attached through various types of peripheral buses, e.g., variants of the Peripheral Component Interconnect (PCI) bus standard or the Universal Serial Bus (USB) standard. In some other embodiments, functions of the transceiver 244 may be split into two or more separate components, or incorporated directly into the processor 242 and/or the data stores 246.

Additionally, the mobile intermodal delivery system 240 may further include one or more powered vehicles 245 as well as one or more intermodal carrier vehicles 250 and/or one or more intermodal maintenance vehicles 260, which may be coupled directly or indirectly to the one or more powered vehicles 245. In some embodiments, the powered vehicles 245 may be any type of train and/or locomotive (e.g., light rail trains, heavy rail trains, high-speed trains, maglev trains), any type of seagoing vessel (e.g., container ships and/or cargo ships), any type of road vehicle (e.g., cars, trucks, tractors and/or trailers, or the like), as well as vehicles configured for travel via other forms or modes of
transit (e.g., hyperloop systems having low-pressure or vacuum tubes and capsules transported therein) powered by any type or form of power source and/or prime mover. For example, the powered vehicle 245 may receive power by any manner and in any form, including but not limited to alternating current (AC) electric power, direct current (DC) electric power, solar power, geothermal power, wind power, nuclear power, fuel cells or any form of petroleum-based power, e.g., gasoline, diesel fuel, natural gas and/or propane.

The intermodal carrier vehicle 250 may be any vehicle or vessel configured to carry one or more items and/or aerial vehicles that may be releasably coupled to the powered vehicle 245 and/or to one or more of the intermodal maintenance vehicles 260, and configured to launch and/or retrieve aerial vehicles while in transit. As is shown in FIG. 2A, the intermodal carrier vehicle 250 includes one or more launch and retrieval mechanisms 252, one or more doors 254 or other access points, one or more sensors 255, one or more environmental controls 256 and one or more item engagement systems 258.

The launch and retrieval mechanisms 252 may include one or more elevators, pulleys, lifts, catapaults or other components for raising, lowering and/or rotating the aerial vehicles 270 or for otherwise placing the aerial vehicles 270 in a desired position and/or orientation within a compartment defined by the intermodal carrier vehicle 250. Additionally, the launch and retrieval mechanisms 252 may include one or more conveyors for causing the aerial vehicles 270 to travel in one or more directions thereon, or for guiding one or more items into a payload compartment or other aspect of the aerial vehicles 270.

The doors 254 are any motorized systems that may be automatically opened and/or closed to provide or restrict access to a compartment defined by the intermodal carrier vehicle 250. The doors 254 may include any number of manual or automatic features for causing the opening or closing thereof, and may have any suitable dimensions with respect to the dimensions of the compartment. The doors 254 are preferably disposed on an upper surface (e.g., a roof and/or ceiling of the compartment) of the intermodal carrier vehicle 250. In some embodiments, the doors 254 may be rotatably connected to one or more aspects of the intermodal carrier vehicle 250 by a pair of hinges. In other embodiments, the doors 254 may take the form of one or more slidable or rollable (e.g., roll-top, roll-up or roll-back) doors having one or more shafts, bearings, adapter rings, guide rails and/or slats for guiding the doors 254 during opening and/or closing operations. For example, in some embodiments, the intermodal carrier vehicle 250 may include a single door 254 that is configured to open in a single direction, e.g., by sliding, swinging or translating from left to right, from right to left, from forward aft or from aft forward. In other embodiments, the intermodal carrier vehicle 250 may include two or more doors 254 that may open in a split fashion, i.e., with a first door 254 sliding, swinging or translating in one direction from an intersection point and a second door 254 sliding, swinging or translating in an opposite direction from the intersection point.

The sensors 255 may include one or more position sensors (e.g., Global Positioning Satellite system receivers, accelerometers, compasses, gyroscopes, altimeters), imaging devices (e.g., digital cameras, depth sensors, range cameras, infrared cameras, radiographic cameras or other optical sensors), speedometers (e.g., anemometers), thermometers, barometers, hygrometers, air monitoring sensors (e.g., oxygen, ozone, carbon monoxide or carbon dioxide sensors), infrared sensors, ozone monitors, pH sensors, magnetic anomaly detectors, metal detectors, radiation sensors (e.g., Geiger counters, neutron detectors, alpha detectors), attitude indicators, depth gauges or sound sensors (e.g., microphones, piezoelectric sensors, vibration sensors or other transducers for detecting and recording acoustic energy from one or more directions). The sensors 255 may include any number of memory or storage components and processors, photosensitive surfaces, filters, chips, electrodes, clocks, boards, timers or other relevant features (not shown) for aiding in their operation.

For example, one or more of the sensors 255 may be an imaging device including any form of optical recording sensor or device (e.g., digital cameras, depth sensors or range cameras, infrared cameras, radiographic cameras or other optical sensors) that may be configured to photograph or otherwise capture visual information or data (e.g., still or moving images in color or black and white that may be captured at any frame rates, or depth imaging data such as ranges), or associated audio information or data, or metadata, regarding objects or activities occurring within a vicinity of the intermodal carrier vehicle 250, or for any other purpose. For example, a sensor 255 may be configured to capture or detect reflected light if the reflected light is within a field of view of the sensor 255, which is defined as a function of a distance between an imaging sensor and a lens within the sensor 255, viz., a focal length, as well as a location of the sensor 255 and an angular orientation of the lens. Accordingly, where an object appears within a depth of field, or a distance within the field of view where the clarity and focus is sufficiently sharp, the sensor 255 may capture light that is reflected off objects of any kind to a sufficiently high degree of resolution using one or more sensors thereof, and store information regarding the reflected light in one or more data files.

The sensors 255 may also include manual or automatic features for modifying a field of view or orientation. For example, one or more of the sensors 255 may be a digital camera configured in a fixed position, or with a fixed focal length (e.g., fixed-focus lenses) or angular orientation. Alternatively, one or more of the sensors 255 may include one or more actuated or motorized features for adjusting a position of a sensor 255, or for adjusting either the focal length (e.g., zooming the imaging device) or the angular orientation (e.g., the roll angle, the pitch angle or the yaw angle), by causing a change in the distance between the imaging sensor and the lens (e.g., optical zoom lenses or digital zoom lenses), a change in the location of the sensor 255, or a change in one or more of the angles defining the angular orientation of the sensor 255.

For example, one or more of the sensors 255 may be an imaging device that is hard-mounted to a support or mounting that maintains the imaging device in a fixed configuration or angle with respect to one, two or three axes. Alternatively, however, a sensor 255 may be provided with one or more motors and/or controllers for manually or automatically operating one or more of the components, or for reorienting the axis or direction of the sensor 255, i.e., by panning or tilting the sensor 255. Panning the sensor 255 may cause a rotation within a horizontal plane or about a vertical axis (e.g., a yaw), while tilting the sensor 255 may cause a rotation within a vertical plane or about a horizontal axis (e.g., a pitch). Additionally, the sensor 255 may be rolled, or rotated about an axis of rotation, and within a plane that is perpendicular to the axis of rotation and substantially parallel to a field of view of the sensor 255.
In some embodiments, imaging data (e.g., still or moving images, as well as associated audio data or metadata) captured using the sensor 255 may be processed according to any number of recognition techniques. In some embodiments, edges, contours, outlines, colors, textures, silhouettes, shapes or other characteristics of objects, or portions of objects, expressed in still or moving digital images may be identified using one or more algorithms or machine-learning tools. The objects or portions of objects may be stationary or in motion, and may be identified at single, finite periods of time, or over one or more periods or durations. Such algorithms or tools may be directed to recognizing and marking transitions (e.g., the edges, contours, outlines, colors, textures, silhouettes, shapes or other characteristics of objects or portions thereof) within the digital images as closely as possible, and in a manner that minimizes noise and disruptions, and does not create false transitions. Some detection algorithms or techniques that may be utilized in order to recognize characteristics of objects or portions thereof in digital images in accordance with the present disclosure include, but are not limited to, Canny edge detectors or algorithms; Sobel operators, algorithms or filters; Kassyali operators; Roberts edge detection algorithms; Prewitt operators; Frei-Chen methods; or any other algorithms or techniques that may be known to those of ordinary skill in the pertinent arts.

The sensors 255 may further include one or more compasses, speedometers, altimeters, thermometers, barometers, hygrometers, gyroscopes, air monitoring sensors (e.g., oxygen, ozone, hydrogen, carbon monoxide or carbon dioxide sensors), ozone monitors, pH sensors, magnetic anomaly detectors, metal detectors, radiation sensors (e.g., Geiger counters, neutron detectors, alpha detectors), accelerometers, ranging sensors (e.g., radar or LIDAR ranging sensors) or sound sensors (e.g., microphones, piezoelectric sensors, vibration sensors or other transducers for detecting and recording acoustic energy from one or more directions). One or more of the sensors 255 may also be an item identification sensor and may include a bar code scanner, a radiofrequency identification (or RFID) reader, or other technology that is utilized to determine an identification of an item that is being retrieved or deposited, or has been retrieved or deposited, by the aerial vehicle 270. In some embodiments, the sensor 255 may be a presence detection sensor and/or a motion sensor for detecting the presence or absence of one or more objects within the intermodal carrier vehicle 250, or movement of objects therein.

One or more of the sensors 255 may be further configured to capture, record and/or analyze information or data regarding its positions, velocities, accelerations or orientations of the intermodal carrier vehicle 250, and to analyze such data or information by one or more means, e.g., by aggregating or summing such data or information to form one or more qualitative or quantitative metrics of the movement of the sensor 255 and/or the intermodal carrier vehicle 250. For example, a net vector indicative of any and all relevant movements of the intermodal carrier vehicle 250, including but not limited to physical positions, velocities, accelerations or orientations of the intermodal carrier vehicle 250, may be derived based on information or data captured by the sensor 255. Additionally, coefficients or scalars indicative of the relative movements of the intermodal carrier vehicle 250 may also be derived based on such information or data.

The environmental controls 256 may include one or more ducts, vents, intakes or outlets that enable air flow to enter the compartment defined by the intermodal carrier vehicle 250, to travel therethrough at desired velocities and/or pressures, and/or to exit from the compartment defined by the intermodal carrier vehicle 250. For example, the environmental controls 256 may include one or more intake ducts and/or valves or other systems of any size or shape and having any dimensions, as required. Such intake ducts may be formed as one or more fairings in an external surface of the intermodal carrier vehicle 250, e.g., the same width as the intermodal carrier vehicle 250 or a larger or smaller width. Likewise, the environmental controls 256 may include one or more outlets or outlet ducts and/or valves or other systems of any size or shape and having any dimensions, as required. The environmental controls 256 may include one or more air openings or channels extending to an exterior of the intermodal carrier vehicle 250, and may include one or more sub-openings or sub-channels in parallel. Additionally, the environmental controls 256 may be aligned coaxially with the intermodal carrier vehicle 250, or parallel to an axis of the intermodal carrier vehicle 250. Alternatively, the environmental controls 256 may be aligned at another angle with respect to the intermodal carrier vehicle 250. Moreover, the environmental controls 256 may be any type of manually or automatically operable opening, e.g., a louver, a flap or any other type of valve that may be controlled (e.g., opened, closed or throttled) in order to cause or alter a flow of air passing therethrough. The environmental controls 256 may include one or more expansion sections for diffusing air, as well as one or more sets of screens, filters or traps which cause any debris or unwanted materials to fall out of the airflow and into a tank or other holding system. The environmental controls 256 may further include any number of heaters, chillers, humidifiers, dehumidifiers or any other systems for achieving a desired environmental condition (e.g., temperature, humidity) within the compartment defined by the intermodal carrier vehicle 250.

The engagement systems 258 may be any mechanical components, e.g., robotic arms, cable robots or other systems, for engaging an item within the intermodal carrier vehicle 250, for disengaging the item, or for loading the item into the aerial vehicles 270. As desired. For example, when the aerial vehicles 270 are tasked with delivering items or materials from a departure point of the mobile intermodal delivery system 240 to a destination, the engagement system 258 may be used to engage the items or materials within the compartment of the intermodal carrier vehicle 250 and to deposit the items or materials in a cargo bay or other storage compartment of the aerial vehicles 270 prior to departing. After an aerial vehicle 270 has arrived at the destination and returned to the intermodal carrier vehicle 250, the engagement system 258 may load another item into the cargo bay or other storage compartment of the aerial vehicles 270. Conversely, the engagement system 258 may also be used to retrieve items or materials from a cargo bay or storage compartment of an aerial vehicle 270, and deposit the items or materials in a desired location at of the compartment defined by the intermodal carrier vehicle 250. The engagement systems 258 may include any number of controllers, arms, end effectors, drive systems and/or sensors for identifying locations of one or more items within the intermodal carrier vehicle 250, engaging one or more of the items at such locations, delivering such items to the aerial vehicles 270 or another location within the intermodal carrier vehicle 250, and depositing or installing such items within the aerial vehicles 270 either directly or by way of one or more conveyors or other systems.

In some embodiments, the intermodal carrier vehicle 250 may be formed from one or more intermodal containers,
e.g., steel structural vessels having standard sizes and/or shapes, by way of repurposing or reconstructing such intermodal containers in order to install the launch and retrieval mechanisms 252, the doors 254, the sensors 255, the environmental controls 256 and/or the item engagement systems 258 therein. The intermodal carrier vehicle 250 may also include any number of computer processors, data stores, memory components or communications equipment for controlling the operation of the launch and retrieval mechanism 252, the doors 254, the sensors 255, the environmental controls 256 and/or the engagement system 258, or for receiving instructions for the operation thereof.

The intermodal maintenance vehicle 260 may be any vehicle or vessel that may be releasably coupled to the powered vehicle 245 and/or to one or more of the intermodal carrier vehicles 250, and configured to launch and/or retrieve aerial vehicles while in transit. In particular, the intermodal maintenance vehicle 260 may receive an aerial vehicle 270 within a compartment and execute one or more maintenance, repairs or servicing evolutions on the aerial vehicle 270 within the compartment before launching the aerial vehicle 270 therefrom. As is shown in FIG. 2A, the intermodal maintenance vehicle 260 includes one or more launch and retrieval mechanisms 262, one or more doors 264 or other access points, one or more sensors 265, one or more environmental controls 266 and one or more item engagement systems 268. The launch and retrieval mechanisms 262, the doors 264, the sensors 265 and/or the environmental controls 266 may operate in the manner described above with regard to the launch and retrieval mechanisms 252, the doors 254, the sensors 255 and/or the environmental controls 256 of the intermodal carrier vehicle 250, or in a similar manner, and may include any of the attributes or features of the launch and retrieval mechanisms 252, the doors 254, the sensors 255 and/or the environmental controls 256 described above.

Additionally, the engagement system 268 may be any mechanical components, e.g., robotic arms, cable robots or other automated systems for performing one or more maintenance, repairs or servicing evolutions on an aerial vehicle 270 within the intermodal maintenance vehicle 260, as desired. For example, when an aerial vehicle 270 has a broken propeller, a faulted motor, a battery with a low charge level, or any other issue or discrepancy, or otherwise requires any other maintenance, repairs or servicing evolutions (e.g., inspections or evaluations), the aerial vehicle 270 may be received within the compartment defined by the intermodal maintenance vehicle 260, e.g., by the launch and retrieval mechanism 262, and a replacement propeller, a replacement motor or a replacement battery may be installed therein. Alternatively, any type or form of inspections or evaluations may be performed on an aerial vehicle 270 within the intermodal maintenance vehicle 260. Like the engagement systems 258, the engagement systems 268 may include any number of controllers, arms, end effectors, drive systems and/or sensors for identifying locations of one or more items within the intermodal maintenance vehicle 260, engaging one or more of the items at such locations, delivering such items to the aerial vehicle 270 at another location within the intermodal maintenance vehicle 260, and depositing or installing such items within the aerial vehicle 270 either directly or by way of one or more conveyors or other systems.

In some embodiments, the intermodal maintenance vehicle 260 may, like the intermodal carrier vehicle 250, be formed from one or more intermodal containers, e.g., steel structural vessels having standard sizes and/or shapes, by way of repurposing or reconstructing such intermodal containers in order to install the launch and retrieval mechanisms 262, the doors 264, the environmental controls 266 and/or the item engagement systems 258 therein. The intermodal carrier vehicle 260 may also include any number of computer processors, data stores, memory components or communications equipment for controlling the operation of the launch and retrieval mechanism 262, the doors 264, the environmental controls 266 and/or the engagement system 268, or for receiving instructions for the operation thereof.

As is shown in FIG. 2B, the aerial vehicle 270 includes a processor 272, a memory 274 and a transceiver 276, as well as a control system 280, one or more propulsion motors 281, one or more control surfaces 283, one or more item engagement systems 285, one or more sensors 282, one or more power modules 284 and one or more navigation modules 286.

The processor 272 may be configured to perform any type or form of computing function, including but not limited to the execution of one or more machine learning algorithms or techniques. For example, the processor 272 may control any aspects of the operation of the aerial vehicle 270 and the one or more computer-based components thereon, including but not limited to the propulsion motors 281, the control surfaces 283, the item engagement systems 285, the sensors 282, the power modules 284 and/or the navigation modules 286.

The processor 272 may be a uniprocessor system including one processor, or a multiprocessor system including several processors (e.g., two, four, eight, or another suitable number), and may be capable of executing instructions. For example, in some embodiments, the processor 272 may be a general-purpose or embedded processor implementing any of a number of instruction set architectures (ISAs), such as the x86, PowerPC, SPARC, or MIPS ISAs, or any other suitable ISA. Where the processor 272 is a multiprocessor system, each of the processors within the multiprocessor system may operate the same ISA, or different ISAs.

The aerial vehicle 270 further includes one or more memory or storage components 274 (such as databases or data stores) for storing any type of information or data, e.g., instructions for operating the aerial vehicle 270, or information or data captured during operations of the aerial vehicle 270. Additionally, the memory 274 may be configured to store executable instructions, flight paths, flight control parameters and/or other data items accessible by or to the processor 272. The memory 274 may be implemented using any suitable memory technology, such as static random access memory (SRAM), synchronous dynamic RAM (SDRAM), nonvolatile/Flash-type memory, or any other type of memory. In some embodiments, program instructions, flight paths, flight control parameters and/or other data items may be received or sent via the transceiver 276, e.g., by transmission media or signals, such as electrical, electromagnetic, or digital signals, which may be conveyed via a communication medium such as a wired and/or a wireless link.

The transceiver 276 may be configured to enable the aerial vehicle 270 to communicate through one or more wired or wireless means, e.g., wired technologies such as Universal Serial Bus (or “USB”) or fiber optic cable, or standard wireless protocols such as Bluetooth® or any Wireless Fidelity (or “Wi-Fi”) protocol, such as over the network 290 or directly. The transceiver 276 may further include or be in communication with one or more input/output (or “I/O”) interfaces, network interfaces and/or input/output devices, and may be configured to allow information
or data to be exchanged between one or more of the components of the aerial vehicle 270, or to one or more other computer devices or systems (e.g., other aerial vehicles, not shown) via the network 290. For example, in some embodiments, the transceiver 276 may be configured to coordinate I/O traffic between the processor 272 and one or more onboard or external computer devices or components. The transceiver 276 may perform any necessary protocol, timing or other data transformations in order to convert data signals from a first format suitable for use by one component into a second format suitable for use by another component. In some embodiments, the transceiver 276 may include support for devices attached through various types of peripheral buses, e.g., variants of the Peripheral Component Interconnect (PCI) bus standard or the Universal Serial Bus (USB) standard. In some other embodiments, functions of the transceiver 276 may be split into two or more separate components, or incorporated directly into the processor 272.

In some embodiments, the transceiver 276 may transmit and/or receive signals according to the Bluetooth® Low Energy, e.g., within a frequency spectrum of approximately 2,4000 to 2,4835 gigahertz (GHz), and in two-megahertz (2 MHz) channels, or according to the Ultra Wideband standard, e.g., within a frequency spectrum of approximately 3.1 to 10.6 gigahertz (GHz), with bandwidth of at least five hundred megahertz (500 MHz), or at least twenty percent of a center frequency. The transceiver 276 may include any number of processors, chips (e.g., chipsets) or other components that are commonly associated with or required for communication according to a selected communications protocol or standard, or programmed as necessary (e.g., with one or more applications and/or sets of instructions) in order to communicate according to the selected protocol or standard. The signals transmitted and/or received by the transceiver 276 may be of any kind or type, and may be sent over the network 290, e.g., as is indicated by line 278, or directly to one or more of the computing device 222 of the customer 220, to the processor 242 of the powered vehicle 245, the intermodal carrier vehicle 250 and/or the intermodal maintenance vehicle 260, or to other aerial vehicles (not shown).

The control system 280 may include one or more software applications or hardware components configured for controlling or monitoring operations of one or more components such as the propulsion motors 281, the control surfaces 283, the item engagement systems 285, the sensors 282, the power modules 284 and/or the navigation modules 286, e.g., by receiving, generating, storing and/or transmitting one or more computer instructions to such components. The control system 280 may communicate with the marketplace 210, the customer 220, the fulfillment center 230 and/or the mobile intermodal delivery system 240, over the network 290, as indicated by line 278, through the sending and receiving of digital data. In some embodiments, the control system 280 may be integrated with or include the processor 272.

The propulsion motors 281 may be any type or form of motor (e.g., electric, gasoline-powered or any other type of motor) capable of generating sufficient rotational speeds of one or more propellers or other components to provide lift and/or thrust forces to the aerial vehicle 270 and any engaged payload, and to aerially transport the engaged payload thereby. For example, one or more of the propulsion motors 281 may be configured to provide forces of lift to the aerial vehicle 270 exclusively, while one or more of the propulsion motors 281 may be configured to provide forces of lift and/or thrust to the aerial vehicle 270, as needed. For example, when the aerial vehicle 270 is tasked with delivering items from the mobile intermodal delivery system 240, the item engagement system 285 may receive an item from the engagement system 258 of the intermodal carrier vehicle 250, and deposit the intermodal carrier vehicle 250 for a location to which the items are to be delivered. The item engagement systems 285 may then be used to deposit the items at the location, and to engage with one or more other items upon a return of the aerial vehicle 270 to the intermodal carrier vehicle 250. The item engagement systems 285 may include any number of controllers, arms, end effectors, drive systems and/or sensors for receiving one or more items, for repositioning the one or more items with respect to a frame or other structure of the aerial vehicle 270, and for depositing the one or more items at a desired location.

The sensors 282 may be any components or other features for capturing information or data during the operation of the aerial vehicle 270, including but not limited to one or more position sensors (e.g., GPS system receivers, accelerometers, compasses, gyroscopes, altimeters), imaging devices (e.g., digital cameras, depth sensors, range cameras, infrared cameras, radiographic cameras or other optical sensors), speedometers (e.g., anemometers), thermometers, barometers, hygrometers, air monitoring sensors (e.g., oxygen, ozone, hydrogen, carbon monoxide or carbon dioxide sensors), infrared sensors, ozone monitors, pH sensors, magnetic anomaly detectors, metal detectors, radiation sensors (e.g., Geiger counters, neutron detectors, alpha detectors), attitude indicators, depth gauges or sound sensors (e.g., microphones, piezoelectric sensors, vibration sensors or other transducers for detecting and recording acoustic energy from one or more directions). The sensors 282 may include any number of memory or storage components and processors, photosensitive surfaces, filters, chips, electrodes, clocks, boards, timers or any other relevant features (not shown) for aiding in their operation.

The power modules 284 may be any type of power source for providing electrical power, mechanical power or other forms of power in support of one or more electrical or mechanical loads aboard the aerial vehicle 270. In some embodiments, the power modules 284 may include one or more batteries or other power cells, e.g., dry cell or wet cell batteries such as lead-acid batteries, lithium ion batteries, nickel cadmium batteries or nickel metal hydride batteries, or any other type, size or form of batteries. The power modules 284 may each have any cell voltages, peak load...
The aerial vehicles via the network, the power modules may be another form of prime mover (e.g., electric, gasoline-powered or any other type of motor) capable of generating sufficient mechanical forces for the aerial vehicle. For example, the navigation modules may include one or more software applications or hardware components including or having access to information or data regarding aspects of transportation systems within a given region, including the locations, dimensions, capacities, conditions, statuses or other attributes of various paths or routes in the region (e.g., one or more sets of rails, roads or shipping channels). For example, the navigation modules may receive inputs from the sensors, e.g., from a GPS receiver, an imaging device or another sensor, and determine an optimal direction and/or an optimal speed of the aerial vehicle for travelling on a given path or route based on such inputs. The navigation modules may select a path or route to be traveled by the aerial vehicle, and may provide information or data regarding the selected path or route to the control system.

Although the block diagram includes single boxes corresponding to the marketplace, the fulfillment center or mobile intermodal delivery system, the powered vehicle, the intermodal carrier vehicle, the intermodal maintenance vehicle and the aerial vehicle, those of ordinary skill in the pertinent arts will recognize that the system may include any number of marketplaces, fulfillment centers, customers, mobile intermodal delivery systems, powered vehicles, intermodal carrier vehicles, intermodal maintenance vehicles and/or aerial vehicles for performing one or more of the operations disclosed herein, each of which may include features that are identical to one another, or may be customized in any manner.

Any combination of networks or communications protocols may be utilized in accordance with the systems and methods of the present disclosure. For example, each of the mobile intermodal delivery systems and/or the respective powered vehicles, the intermodal carrier vehicles and/or the intermodal maintenance vehicles and each of the aerial vehicles may be configured to communicate with one another or with the marketplace server via the network, such as is shown in FIGS. 2A and 2B, e.g., via an open or standard protocol such as Wi-Fi, alternative, each of the mobile intermodal delivery systems and/or the respective powered vehicles, the intermodal carrier vehicles and/or the intermodal maintenance vehicles and each of the aerial vehicles may be configured to communicate with one another directly outside of a centralized network, such as the network, e.g., by a wireless protocol such as Bluetooth, in which two or more of the mobile intermodal delivery systems may communicate with one another or with the marketplace server or the respective powered vehicles, the intermodal carrier vehicles and/or the intermodal maintenance vehicles and each of the aerial vehicles may be configured to communicate with one another.

The aerial vehicles and may be controlled by the marketplace server or the respective powered vehicles, the intermodal carrier vehicles and/or the intermodal maintenance vehicles and each of the aerial vehicles may be controlled by the marketplace server or the respective powered vehicles, the intermodal carrier vehicles and/or the intermodal maintenance vehicles and each of the aerial vehicles may be configured to be powered via a connection to a power source or be powered via a connection to a power source. The aerial vehicles, the marketplace server or the respective powered vehicles, the intermodal carrier vehicles and/or the intermodal maintenance vehicles and each of the aerial vehicles may be configured to be powered via a connection to a power source or be powered via a connection to a power source. The aerial vehicles, the marketplace server or the respective powered vehicles, the intermodal carrier vehicles and/or the intermodal maintenance vehicles and each of the aerial vehicles may be configured to be powered via a connection to a power source or be powered via a connection to a power source. The aerial vehicles, the marketplace server or the respective powered vehicles, the intermodal carrier vehicles and/or the intermodal maintenance vehicles and each of the aerial vehicles may be configured to be powered via a connection to a power source or be powered via a connection to a power source.

The computers, servers, devices and the like described herein have the necessary electronics, software, memory, storage, databases, firmware, logic/state machines, microprocessors, communication links, displays or other visual or audio user interfaces, printing devices, and any other input/output interfaces to provide any of the functions or services described herein and/or achieve the results described herein. Also, those of ordinary skill in the pertinent art will recognize that users of such computers, servers, devices and the like may operate a keyboard, keypad, mouse, stylus, touch screen, or other device (not shown) or method to interact with the computer, servers, devices and the like, or to “select” an item, link, node, hub or any other aspect of the present disclosure.

Those of ordinary skill in the pertinent arts will understand that process steps described herein as being performed by a “marketplace,” a “customer,” a “fulfillment center,” a “mobile intermodal delivery system” or a “powered vehicle,” an “intermodal carrier vehicle” or an “intermodal maintenance system”), or like terms, may be automated steps performed by their respective computer systems, or implemented within software modules (or computer programs) executed by one or more general purpose computers. Moreover, process steps described as being performed by a “marketplace,” a “customer,” a “fulfillment center,” a “mobile intermodal delivery system” or a “powered vehicle,” an “intermodal carrier vehicle” or an “intermodal maintenance system”), or like terms, may be typically
The marketplace 210, the customer 220, the fulfillment center 230, the mobile intermodal delivery system 240 and/or the aerial vehicle 270 may use any web-enabled Internet applications or features, or any other client-server applications or features including electronic mail (or E-mail), or other messaging techniques, to connect to the network 290 or to communicate with one another, such as through short or multimedia messaging service (SMS or MMS) text messages, social network messages, online marketplace messages, telephone calls or the like. For example, in some embodiments, the fulfillment center 230 and/or the server 232 may be adapted to transmit information or data in the form of synchronous or asynchronous messages to the marketplace 210 and/or the server 212, the customer 220 and/or the computing device 222, the mobile intermodal delivery system 240 or the aerial vehicle 270, or any other computer device in real time or in near-real time, or in one or more offline processes, via the network 290. Those of ordinary skill in the pertinent art would recognize that the marketplace 210, the customer 220, the fulfillment center 230, the mobile intermodal delivery system 240 and/or the aerial vehicle 270 may operate any of a number of computing devices that are capable of communicating over the network, including but not limited to set-top boxes, personal digital assistants, digital media players, web pads, smartphones, tablet computers, laptop computers, desktop computers, electronic book readers, and the like. The protocols and components for providing communication between such devices are well known to those skilled in the art of computer communications and need not be described in more detail herein.

The data and/or computer executable instructions, programs, firmware, software and the like (also referred to herein as “computer executable” components) described herein may be stored on a computer-readable medium that is within or accessible by computers or computer components and having sequences of instructions which, when executed by a processor (e.g., a central processing unit, or “CPU”), cause the processor to perform all or a portion of the functions, services and/or methods described herein. Such computer executable instructions, programs, software and the like may be loaded into the memory of one or more computers using a drive mechanism associated with the computer readable medium, such as a floppy drive, CD-ROM drive, DVD-ROM drive, network interface, or the like, or via external connections.

Some embodiments of the systems and methods of the present disclosure may also be provided as a computer executable program product including a non-transitory machine-readable storage medium having stored therein instructions (in compressed or uncompressed form) that may be used to program a computer (or other electronic device) to perform processes or methods described herein. The machine-readable storage medium may include, but is not limited to, hard drives, floppy diskettes, optical disks, CD-ROMs, DVDs, ROMs, RAMs, electrically erasable programmable ROMs (“EPROM”), flash memory, magnetic or optical cards, solid-state memory devices, or other types of media/machine-readable medium that may be suitable for storing electronic instructions. Further, embodiments may also be provided as a computer executable program product that includes a transitory machine-readable signal (in compressed or uncompressed form). Examples of machine-readable signals, whether modulated using a carrier or not, may include, but are not limited to, signals that a computer system or machine hosting or running a computer program can be configured to access, or including signals that may be downloaded through the internet or other networks.

As is discussed above, the mobile intermodal delivery systems of the present disclosure may be utilized to fulfill orders for deliveries of one or more items to customers. In particular, mobile intermodal delivery systems may be loaded with one or more items and one or more aerial vehicles, and dispatched throughout a transportation network (e.g., rails, shipping channels and/or waterways, or highways). When an order for the delivery of an item to a location is received, a mobile intermodal delivery system having the item may be identified, and the order may be assigned to the mobile intermodal delivery system for fulfillment. The item may then be automatically loaded onto an aerial vehicle, which may then depart the mobile intermodal delivery system and travel to the location to deposit the item there. The aerial vehicle may then return to the mobile intermodal delivery system, e.g., at a rendezvous point, where the aerial vehicle may remain available to fulfill another order, or may receive one or more maintenance, repairs or servicing operations.

At box 310, a mobile carrier system having an intermodal maintenance vehicle and an intermodal carrier having an unmanned aerial vehicle and one or more items aboard is in transit within a region. For example, in some embodiments, such as is shown in FIGS. 1A through 11, one or more of the intermodal carrier vehicles 150 may be pulled, pushed or otherwise caused to travel along the tracks 125 by the powered vehicle 145, and may be coupled to one or more intermodal maintenance vehicles 160. At box 320, an order for delivery of an item aboard the intermodal carrier to a location in the region is received, e.g., by an online marketplace or other electronic platform, from a customer over a network. In some embodiments, the intermodal carrier may be the only available source of the item. In other embodiments, the intermodal carrier may be selected on any relevant basis, including but not limited to the proximity of the intermodal carrier to the location in the region, the operational capacity of one or more unmanned aerial vehicles thereon to fulfill the order (e.g., the types, classes, sizes or capacities of the aerial vehicles on the intermodal carrier, or any other operational commitments to which the intermodal carrier may be dedicated), prevailing environmental conditions, or on any other factor. For example, the intermodal carrier and/or one or more of the aerial vehicles therein may be selected based at least in part on a minimum net cost, distance and/or time required to fulfill the order thereby.

At box 330, the item is loaded onto the unmanned aerial vehicle. In some embodiments, the intermodal carrier may include a single unmanned aerial vehicle that may be available for deliveries of items from the intermodal carrier to one or more destinations. In other embodiments, however, the intermodal carrier may include a plurality of unmanned aerial vehicles that may be available for deliveries of items. In such embodiments, the unmanned aerial vehicle onto which the item is loaded may be selected on any basis, including an available power level, a speed rating, a noise rating, or any other factor, e.g., a minimum net cost, distance and/or time required to fulfill the order thereby, as well as an operating range, a power rating or a carrying capacity. Alternatively, the unmanned aerial vehicle may be selected at random, or may be the next available unmanned aerial vehicle for performing a delivery.
At box 340, launch conditions may be established within the intermodal carrier. For example, in some embodiments, the course and/or a speed of a powered vehicle may be changed, as necessary, in order to generate optimal wind conditions for launch outside of the intermodal carrier. In some other embodiments, the intermodal carrier may be outfitted with one or more ducts, vents, intakes or outlets that enable air flow to enter the intermodal carrier vehicle, to travel therethrough at desired velocities and/or pressures, and/or to exit from the intermodal carrier vehicle. In some other embodiments, the intermodal carrier may include one or more heaters, chillers, humidifiers and/or dehumidifiers to establish one or more desired temperatures and/or humidity levels within the intermodal carrier prior to launch.

At box 345, the intermodal carrier opens to permit the unmanned aerial vehicle to launch therefrom, and, after the unmanned aerial vehicle has cleared the intermodal carrier, at box 355, the intermodal carrier closes. For example, the intermodal carrier may include one or more doors, e.g., split doors that may open side-to-side, or from front and back, or, alternatively, slideable or rollable doors that may open forward-to- aft or aft-to-forward. The intermodal carrier may further include one or more launching or retrieval systems for lifting or expelling the unmanned aerial vehicle out of the intermodal carrier, such as elevators, pulleys, lifts, catapults or other systems.

At box 360, after having cleared the intermodal carrier, the unmanned aerial vehicle departs for the location specified in the order while the mobile delivery system remains in transit, e.g., on a set of rails, in a shipping channel and/or on a roadway. The unmanned aerial vehicle may be programmed with general or specific instructions for causing the unmanned aerial vehicle to travel on a desired course, or at a desired speed or altitude, or in accordance with any other operating characteristic. Alternatively, or additionally, the unmanned aerial vehicle may be programmed with general or specific instructions for responding to one or more contingencies or other factors that may be encountered while the unmanned aerial vehicle is in transit. At box 365, whether the delivery operation is complete is determined. If the delivery operation is not complete, then the process returns to box 360, where the intermodal carrier remains in transit while the unmanned aerial vehicle is en route to the location. If the delivery operation is complete, however, then the process advances to box 370, where the unmanned aerial vehicle returns to the intermodal carrier, e.g., at a designated or predetermined rendezvous point that may be selected based on a variety of factors including but not limited to a course and speed of the intermodal carrier, the location where the item was delivered, operational capacities and/or constraints of the intermodal carrier and/or the unmanned aerial vehicle, or any other relevant factor.

At box 375, whether the unmanned aerial vehicle requires servicing is determined. For example, the unmanned aerial vehicle may have a low battery level, or may require scheduled and/or preventive maintenance or inspections. Alternatively, one or more propulsion motors, propellers or other components may be radiating abnormal or high levels of noise, or may be observed to be performing at substandard or unacceptable levels. If the unmanned aerial vehicle requires servicing, then the process advances to box 385, where an intermodal maintenance vehicle opens to receive the unmanned aerial vehicle therein. As is discussed above, the intermodal maintenance vehicle may include the same numbers and/or types of doors as the intermodal carrier vehicle, or different numbers or types of doors, which may be operated in the same manner as the doors of the intermodal carrier vehicle at box 350 or in a different manner. At box 390, one or more servicing operations (e.g., maintenance, repairs, inspections or any other relevant evolutions relating to the air-worthiness of the aerial vehicle) are performed, and the process ends. Alternatively, in some embodiments, when the unmanned aerial vehicle requires servicing, the unmanned aerial vehicle may be routed not to a mobile intermodal delivery system from which it was launched but to an alternate destination that may be specifically configured to perform the servicing operations that may be required, e.g., another mobile intermodal delivery system and/or a fixed facility, before returning to the intermodal carrier from which the unmanned aerial vehicle was launched.

If the aerial vehicle does not require servicing, however, then the process advances to box 380, where the intermodal carrier reopens to receive the unmanned aerial vehicle therein, and the process ends.

As is discussed above, the intermodal carrier vehicles and/or the intermodal maintenance vehicles of the present disclosure may be formed from one or more intermodal containers and may utilize any type of form of doors or other systems.

As is shown in FIG. 4A, an intermodal carrier 450 includes a pair of intermodal containers 451A, 451B that are stacked atop one another and configured for placement aboard a well car, a container ship, a trailer or another carrier and pushed, pulled or carried by any type of powered vehicle. Each of the intermodal containers 451A, 451B features corrugated sides and has a height h_{450}, a width w_{450} and a length l_{450}. Additionally, the upper intermodal container 451A includes a slidable door (e.g., a roller shutter door) 454, a forward intake duct 456A and an aft outlet duct 456B. Alternatively, the intermodal carrier 450 may include any number of other doors including one or more doors that may open side-to-side, forward-to-aft or aft-to-forward. Thus, the intermodal carrier 450 of FIG. 4A has a height of 2h_{450} when the intermodal containers 451A, 451B are stacked atop one another. The intermodal containers 451A, 451B may be selected on any basis, including whether the height 2h_{450}, the width w_{450} and the length l_{450} of the intermodal carrier 450 may be accommodated by the infrastructure associated with one or more transit modes, e.g., heights of bridges, tunnels or other features, or on any other factor. For example, in some embodiments, the intermodal containers 451A, 451B may have been previously utilized in connection with one or more items to a predetermined destination, and may be repurposed for use as an intermodal carrier or, alternatively, as an intermodal maintenance vehicle.

As is shown in FIG. 4B and FIG. 4C, a view of an interior compartment of the intermodal carrier 450 shows a plurality of items 40, a launch and retrieval system 452, a motorized roller (e.g., a tubular roller) 455 for retracting or extending the slidable door 454, an item engagement system 458 and a plurality of aerial vehicles 470-1, 470-2, 470-3, 470-4, 470-5. The aerial vehicles 470-1, 470-2, 470-3, 470-4, 470-5 are shown in a stack in an aft portion of the intermodal carrier 450. The aerial vehicle 470-4 is shown on the launch and
retrieval system 452, which includes a conveyor that extends to the stack of the aerial vehicles 470-1, 470-2, 470-3, 470-5, and may be raised and/or lowered, as necessary, in order to retract one or more of the aerial vehicles 470-1, 470-2, 470-3, 470-5 from the stack. Additionally, the conveyor may be rotated about a vertical axis, e.g., in order to place an aerial vehicle on the conveyor (e.g., the aerial vehicle 470-4) within a range of the item engagement system 458. Alternatively, the interior compartment of the intermodal carrier 450 may further include any number of sensors or other systems or components (not shown), including but not limited to position sensors, imaging devices or other systems that may be used to monitor operations of the intermodal carrier 450 or one or more of the aerial vehicles 470-1, 470-2, 470-3, 470-4, 470-5 therein, or for aiding in their operation.

As is shown in FIG. 4D, the intermodal carrier 450 is configured to launch the aerial vehicle 470-4 therefrom, in order to enable the aerial vehicle 470-4 to deliver an item to a predetermined destination. First, an item may be loaded onto the aerial vehicle 470-4 by rotating the conveyor of the launch and retrieval system 452 about a vertical axis, e.g., by approximately one hundred eighty degrees (180°), and raising the conveyor to within a range of the item engagement system 458. Next, preferred launching conditions, such as conditions consistent with an exterior of the intermodal carrier 450, may be established by operating the forward intake duct 456A and the aft outlet duct 456B until a desired air velocity and/or pressure is established within the intermodal carrier 450. Finally, the slidable door 454 may be retracted by the motorized roller 455. Once the slidable door 454 has been retracted to a sufficient extent, the aerial vehicle 470-4 may be raised or lowered, as necessary, to align the aerial vehicle 470-4 in a desired orientation prior to takeoff. As is discussed above, the intermodal carrier 450 may be further configured to conduct landing or retrieving operations, such as by operating one or more of the systems disclosed herein in a reverse or reciprocal fashion, and, alternatively, by establishing preferred landing or retrieving conditions within the intermodal carrier 450, as necessary, prior to commencing any landing or retrieving operations.

As is discussed above, aerial vehicles may be launched and/or retrieved from a mobile intermodal delivery system using any type of launching and/or retrieval system. Referring to FIGS. 5A through 5C, views of components for use in mobile intermodal delivery systems in accordance with embodiments of the present disclosure are shown. Except where otherwise noted, reference numerals preceded by the number “5” in FIGS. 5A through 5C refer to elements that are similar to elements having reference numerals preceded by the number “4” in FIGS. 4A through 4D, by the number “2” in FIG. 2A or FIG. 2B or by the number “1” shown in FIGS. 1A through 1L.

As is shown in FIG. 5A, a launch and retrieval system 552A includes a substantially rectangular platform that may be raised or lowered, as necessary. For example, the launch and retrieval system 552A of FIG. 5A may be configured to receive an aerial vehicle and/or an item thereon, to raise the aerial vehicle in a desired height within or beyond an intermodal carrier vehicle or intermodal maintenance vehicle for vertical takeoff operations, and to enable the aerial vehicle to be launched therefrom. Reciprocally, the launch and retrieval system 552A may also be used to retrieve an aerial vehicle thereon following operations, to lower the aerial vehicle to a height within the intermodal carrier, and to enable the aerial vehicle to be removed therefrom. As is shown in FIG. 5B, a launch and retrieval system 552B includes a sliding platform on a pair of rails, each of which is supported by a corresponding pair of hydraulic jacks, pistons or other systems. By independently or collectively operating the hydraulic jacks, pistons or other systems, the pair of rails may be raised in a vertical direction (or along a z-axis, as is shown in FIG. 5B), rotated about a forward axis (or an x-axis, as is shown in FIG. 5B), or rotated about a lateral axis (or a y-axis, as is shown in FIG. 5B), thereby enabling an aerial vehicle placed thereon to be aligned in a variety of orientations prior to takeoff, or during or after landing. Additionally, the sliding platform may be translated in a direction of the forward axis (or the x-axis) in any manner, e.g., by one or more motors, rockets, catapults or other like systems, to impart an additional force in this direction to an aerial vehicle prior to takeoff.

As is shown in FIG. 5C, a launch and retrieval system 552C includes a circular disc that may be rotated about a vertical axis (or a z-axis, as is shown in FIG. 5C), raised or lowered in the direction of the vertical axis, or gimbaled in any direction, thereby enabling an aerial vehicle placed thereon to be aligned in a variety of orientations prior to takeoff, or during or after landing.

The engagement systems of the present disclosure may include any number of components or features for interacting with one or more items and/or aerial vehicles within an intermodal carrier vehicle and/or within an intermodal maintenance vehicle in accordance with the present disclosure, including but not limited to one or more controllers, arms, end effectors, drive systems and/or sensors or like components or features. Referring to FIG. 6, a view of aspects of one mobile intermodal delivery system in accordance with embodiments of the present disclosure is shown. Except where otherwise noted, reference numerals preceded by the number “6” in FIG. 6 refer to elements that are similar to elements having reference numerals preceded by the number “5” in FIGS. 5A through 5C, by the number “4” in FIGS. 4A through 4D, by the number “2” in FIG. 2A or FIG. 2B or by the number “1” shown in FIGS. 1A through 1L.

FIG. 6 shows an outline of components within a compartment of an intermodal carrier vehicle 650, including but not limited to components that may be installed or mounted within one or more repurposed intermodal containers. As is shown in FIG. 6, the intermodal carrier vehicle 650 includes a plurality of items 60, a launch and retrieval system 652 and an engagement system 658 within a compartment defined by the intermodal carrier vehicle 650. The launch and retrieval system 652 is shown as including a conveyor with an aerial vehicle 670 resting thereon. The engagement system 658 includes a cable robot suspended within the compartment of the intermodal carrier vehicle 650 by a plurality of tensioning actuators 657A, 657B, 657C, 657D, 657E, 657F, 657G, 657H, each of which is mounted to an interior of the intermodal carrier vehicle 650 and connected in tension to the engagement system 658 by way of a cable in tension. In some embodiments, the engagement system 658 may further include a pair of opposed induction conveyors that are substantially vertically aligned and configured to automatically receive an item 60 therebetween on the engagement system 658, and to expel the item 60 therefrom when the engagement system 658 is in a desired position with respect to the launch and retrieval system 652 and/or the aerial vehicle 670. The induction conveyors may be operated by one or more controllers (not shown), and may be provided
in any other relevant alignment that permits items to be fixed therewith or onto the engagement system 658 in another manner, and to be expelled from the engagement system 658 thereby, including but not limited to substantially horizontal alignments, or alignments at one or more non-horizontal and non-vertical angles.

Although the components such as the intermodal containers 451A, 451B, the launch and retrieval platform 452, the slidable door 454, the ducts 456A, 456B and the item engagement system 458 shown in FIGS. 4A through 4D or the engagement system 658 of FIG. 6 are utilized in connection with an intermodal carrier, those of ordinary skill in the pertinent arts will recognize that one or more of such components may be utilized in connection with an intermodal maintenance vehicle, or in connection with a combined intermodal vehicle that includes both item carrying and maintenance capacities or features. Additionally, those of ordinary skill in the pertinent arts will recognize that an intermodal carrier vehicle and/or an intermodal maintenance vehicle may include one or more launch and retrieval systems, including one or more of the systems 152, 162, 452, 552A, 552B, 552C, 652 shown in FIGS. 1B, 1C, 1E-1G, 11, 41B-4D, 5A-5C and 6, or other such systems. Alternatively, in some embodiments, an intermodal carrier vehicle and/or an intermodal maintenance vehicle may include separate systems for launching and/or retrieving aerial vehicles.

As is discussed above, in some embodiments, the systems and methods of the present disclosure may be used to distribute, or forward-deploy, inventory from one location to another location where demand for such items is known, observed or predicted, using intermodal carriers that include such items and one or more aerial vehicles. The intermodal carriers of the present disclosure may ultimately act as a mobile fulfillment center, and place one or more items within a shorter distance and a shorter time of delivery of customers along transit modes such as railroads, shipping channels and/or highways. Referring to FIG. 7, a flow chart 700 of one process for operation of a mobile intermodal delivery system in accordance with embodiments of the present disclosure is shown. At box 710, demand for one or more items is anticipated in regions within an operating range of an unmanned aerial vehicle of an intermodal route (e.g., a railway, a shipping channel, a highway) at one or more predetermined times. For example, in some embodiments, the regional demand for the items may be determined based on prior purchasing or delivering histories of customers in such regions, or demographics to which such customers belong. In other embodiments, the regional demand may also be predicted based on attributes of the respective items, on any upcoming events occurring at the local, regional, national or global events levels, or on any traditional, prevailing or emerging attitudes or mores within the respective regions that may be determined on any basis and using information or data obtained from any source, including but not limited to one or more postings or comments made to social networks, or to details pages for items maintained at an online marketplace or any other locations. In some embodiments, once a level of demand is determined or predicted for a region, the level of demand may be compared to one or more thresholds or limits in order to determine whether the distribution or forward-deployment of items to the region is justifiable or necessary.

At box 720, the placement of the items in an intermodal carrier is selected based on levels of demand in such regions. For example, a number of items and their locations within an intermodal carrier may be selected based on the locations where their demand is anticipated with respect to an intermodal route. Where a train pulling an intermodal carrier is expected to travel within an unmanned aerial vehicle operating range of three regions in series, items that are anticipated to be in demand in the most distant region may be selected for loading into a most distant corner or section of the intermodal carrier, and items that are anticipated to be in demand in the nearest region may be selected for loading into a nearest corner or section of the intermodal carrier, thereby facilitating access to such items at appropriate times, and the loading of such items onto aerial vehicles accordingly.

At box 730, the items and one or more unmanned aerial vehicles are loaded onto the intermodal carrier, and at box 735, speeds for the intermodal carrier are selected based on levels of demand in the respective regions, and distances of the respective regions from the intermodal route. Such speeds may be selected in consideration of travel times for not only the intermodal carrier to arrive at a departure point on an intermodal route but also the aerial vehicle to arrive at one or more locations within the region in anticipation of the demand. For example, where the intermodal carrier is to be placed on a well car and pulled on a set of rails by a locomotive, in anticipation of demand for an item in two hours, a departure point for the aerial vehicle along the set of rails may be selected in order to ensure that the locomotive may reach the departure point, and the aerial vehicle may travel from the departure point to locations where the demand is anticipated, in two hours or less.

At box 740, a powered vehicle causes the intermodal carrier to travel along the intermodal route at the speeds that were selected at box 735. At box 750, an order for a delivery of an item to a location is received while the intermodal carrier is in motion along the intermodal route, e.g., by way of a network site associated with an online marketplace, or a dedicated shopping application operating on a smartphone or other computer device, or by any other means, and at box 755, the order is assigned to an unmanned aerial vehicle within the intermodal carrier. For example, upon receipt of an order for one or more items from a customer, computer devices or resources operated by an online marketplace, a fulfillment center or any other commercial entity may determine that the ordered items are available onboard the intermodal carrier within a given region, and provide one or more instructions to the intermodal carrier, e.g., over a network, to cause the item to be loaded onto an unmanned aerial vehicle within the aerial vehicle prior to reaching a departure point, and to cause the unmanned aerial vehicle to take off from the intermodal carrier when the departure point is reached. The intermodal carrier and/or the aerial vehicle to which the fulfillment of the order is assigned may be selected on any basis, including but not limited to a minimum net cost, a minimum net time or a minimum net distance required in order to fulfill the order, or on any other factor.

At box 765, the unmanned aerial vehicle is launched from the intermodal carrier and heads on a course for the location at a departure point along the intermodal route, which may be selected on any basis. In some embodiments, the departure point may be a closest (e.g., tangential) point between the location and the intermodal route. In other embodiments, the departure point may be selected based on operational considerations and/or constraints of the intermodal carrier and/or the aerial vehicle, or on any other factor. At box 770, the unmanned aerial vehicle deposits the item at the location, and at box 780, the unmanned aerial vehicle departs from the location on a course to meet the intermodal carrier at an arrival point (or a rendezvous point) along the intermodal
route. The arrival point may also be selected on any basis, including but not limited to distances between the intermodal route and the location, as well as operational considerations and/or constraints of the intermodal carrier and/or the aerial vehicle, or any other factor. At box 790, the unmanned aerial vehicle lands within the intermodal carrier at the arrival point, and the process ends. Theretofore, the unmanned aerial vehicle may be subjected to one or more maintenance, repairs or servicing evolutions before being loaded with one or more additional items and utilized in connection with another delivery.

Items may be deployed in intermodal carriers along any route associated with a transportation system, e.g., on one or more sets of rails, roads and/or shipping channels, and based on any levels of demand that may be anticipated for such items in regions or areas within a vicinity (e.g., an operating range of an unmanned aerial vehicle carried aboard the intermodal carriers) of the route. Referring to FIG. 8, a view of aspects of operation of one mobile intermodal delivery system in accordance with embodiments of the present disclosure is shown. Except where otherwise noted, reference numerals preceded by the number “5” in FIGS. 8A through 8D, by the number “4” in FIGS. 4A through 4D, by the number “2” in FIG. 2A or FIG. 2B or by the number “1” shown in FIGS. 1A through 1L.

As is shown in FIG. 8, a region 800 (viz., central Connecticut) is serviced by a variety of transportation modes or systems, including a rail line 825. Demand for one or more items within areas in close proximity to the rail line 825 may be predicted. For example, as is shown in FIG. 8, an area 820-1 (viz., East Hartford, Conn.) where a predicted demand for ketchup has been identified is located approximately two miles from the rail line 825 at its shortest distance. Similarly, an area 820-2 (viz., Avon, Conn.) where a predicted demand for cosmetics that has been identified is located approximately seven miles from the rail line 825 at its shortest distance. An area 820-3 (viz., Southington, Conn.) where a predicted demand for milk has been identified is located approximately four miles from the rail line 825 at its shortest distance. Areas 820-4, 820-5 (viz., Middletown, Conn., and Durham, Conn.) where predicted demands for pasta and athletic shoes have been identified are located approximately six and five miles, respectively, from the rail line 825 at their shortest distances.

Therefore, in accordance with some embodiments of the present disclosure, and as is shown in FIG. 8, one or more intermodal carriers (not shown) may be loaded with bottles of ketchup, compact containers, cartons of milk, boxes of pasta and/or pairs of athletic shoes at a fulfillment center 830, along with one or more aerial vehicles (not shown). The intermodal carriers may then be placed onto well cars and coupled to one or more locomotives or other powered vehicles, and caused to travel south along the rail line 825. In anticipation for receiving one or more orders for such items, or after receiving such orders, one or more aerial vehicles may be loaded with the respective items and launched in directions of the areas 820-1, 820-2, 820-3, 820-4, 820-5, or in directions of locations where such items are to be delivered. After the items have been delivered, the aerial vehicles may return to the intermodal carriers and be loaded with one or more additional items for delivery or, alternatively, proceed to an intermodal maintenance vehicle for repairs or other servicing operations.

As is discussed above, the intermodal carrier vehicles and/or the intermodal maintenance vehicles of the present disclosure may be utilized in connection with any transit modes, and are not limited to rail-based systems. Referring to FIGS. 9A and 9B, views of aspects of operation of mobile intermodal delivery systems in accordance with embodiments of the present disclosure are shown. Except where otherwise noted, reference numerals preceded by the number “9” in FIG. 9A or 9B refer to elements that are similar to elements having reference numerals preceded by the number “8” in FIG. 8, by the number “6” in FIG. 6, by the number “5” in FIGS. 5A through 5C, by the number “4” in FIGS. 4A through 4D, by the number “2” in FIG. 2A or FIG. 2B or by the number “1” shown in FIGS. 1A through 1L.

As is shown in FIG. 9A, a mobile intermodal delivery system 940 including a container ship 945 may be configured to receive a plurality of intermodal containers 950-n thereon while in port. For example, as is shown in FIG. 9A, an intermodal container 950-1 may be loaded onto the container ship 945 by a crane 930. Each of the intermodal containers 950-n may be loaded with a plurality of items and/or one or more aerial vehicles, and may include any number of launch and retrieval mechanisms, doors or other access points, environmental controls or engagement systems.

Subsequently, as is shown in FIG. 9B, after the container ship 945 departs from port, orders for one or more items that are stored within the intermodal containers 950-n and to be delivered within a vicinity of the container ship 945 may be fulfilled using aerial vehicles stored therein, while the container ship 945 is underway. For example, an aerial vehicle 970-1 is shown as lifting off from an intermodal container 950-1, while an aerial vehicle 970-2 is shown as returning to an intermodal container 950-2, and an aerial vehicle 970-3 is as traveling away from an intermodal container 950-3. In some embodiments, an aerial vehicle loaded into an intermodal container may be used to deliver items that are also loaded into the same intermodal container to locations that are within a vicinity of the container ship 945. In other embodiments, however, an aerial vehicle that is loaded into a first intermodal container may be used to deliver items that are loaded into a second intermodal container, e.g., by launching the aerial vehicle from the first intermodal container and by landing the aerial vehicle into the second intermodal container, where the aerial vehicle may be loaded with one or more items before being launched therefrom.

Referring to FIG. 10, a view of aspects of operation of one mobile intermodal delivery system in accordance with embodiments of the present disclosure is shown. Except where otherwise noted, reference numerals preceded by the number “10” in FIG. 10 refer to elements that are similar to elements having reference numerals preceded by the number “9” in FIG. 9A or 9B, by the number “8” in FIG. 8, by the number “6” in FIG. 6, by the number “5” in FIGS. 5A through 5C, by the number “4” in FIGS. 4A through 4D, by the number “2” in FIG. 2A or FIG. 2B or by the number “1” shown in FIGS. 1A through 1L.

As is shown in FIG. 10, a mobile intermodal delivery system 1040 includes a road tractor 1045 configured for towing a road trailer 1043 with an intermodal carrier 1050 placed thereon. As is also shown in FIG. 10, the intermodal carrier 1050 may be configured to launch and retrieve one or more aerial vehicles, such as aerial vehicles 1070-1, 1070-2, while the mobile intermodal delivery system 1040 is in motion on a highway or other roadway. In some embodiments, the mobile intermodal delivery system 1040 may therefore be used to fulfill orders for items within the intermodal carrier 1050 using one or more aerial vehicles, e.g., the aerial vehicles 1070-1, 1070-2, or to forward-
deploy inventory to regions where demand for such items is anticipated. Alternatively, or additionally, the road tractor 1045 and/or the road trailer 1043 may be outfitted with an intermodal maintenance vehicle that may perform repairs or other servicing operations on aerial vehicles while the mobile intermodal delivery system 1040 is in motion on a highway or other roadway.

As is also discussed above, an intermodal maintenance vehicle may be configured to receive aerial vehicles therein and to perform one or more repairs or other servicing operations on such aerial vehicles, while the intermodal maintenance vehicle is in motion, before returning the aerial vehicles to service when such operations are complete. The intermodal maintenance vehicles may be strategically directed to one or more regions where aerial vehicles flying overhead may be reasonably expected to require services such as replacements of one or more batteries, propellers and/or motors, or one or more inspection evolutions. Referring to FIG. 11, a flow chart 1100 of one process for operation of a mobile intermodal delivery system in accordance with embodiments of the present disclosure is shown.

At box 1110, a plurality of anticipated unmanned aerial vehicle routes across one or more areas are determined. Such routes may be identified or predicted on any basis, including based on known routes for such vehicles, on predicted demand for one or more commercial goods that may be delivered by unmanned aerial vehicles within such areas, or on any other factor, such as prevailing weather conditions in such areas.

At box 1115, a powered vehicle is coupled to an intermodal maintenance vehicle at a service station. The intermodal maintenance vehicle may include one or more spare parts, supplies or materials, as well as any type or form of engagement systems for inspecting and/or repairing one or more aerial vehicles therein. In some embodiments, the intermodal maintenance vehicle may be provided in association with one or more intermodal containers and placed on a well car configured for pulling or pushing by a locomotive, such as the intermodal maintenance vehicle 160 of FIGS. 1A through 1L. Alternatively, the intermodal maintenance vehicle may be placed on one or more seagoing vessels, road vehicles, or like systems. Likewise, in some embodiments, the service station may be associated with a fulfillment center, a warehouse or another facility associated with the receipt, storage and distribution of items or the operation of one or more aerial vehicles, or may be operated or maintained independent of such facilities.

At box 1120, an intermodal route through or within operating ranges of the areas of the anticipated unmanned aerial vehicle routes is determined. The intermodal route may include travel on one or more sets of rails, on one or more shipping channels, or on one or more highways, or on a combination of rails, shipping channels or highways, or one or more other transportation systems. Additionally, in some embodiments, the powered vehicle to which the intermodal maintenance vehicle is coupled may be selected based on the intermodal route. For example, where the unmanned aerial vehicle routes are determined to cross over one or more bodies of water, the intermodal maintenance vehicle may be coupled to a container ship or other seagoing vessel. Where the unmanned aerial vehicle routes are determined to cross over densely populated land, the intermodal maintenance vehicle may be coupled to a locomotive or other train car during morning and afternoon rush hours, or periods when highway traffic congestion is expected, and coupled to a trailer or other road vehicle during periods when highway traffic congestion is not expected.

In some embodiments, the intermodal maintenance vehicle may be uncoupled from a first powered vehicle and coupled to a second powered vehicle, as necessary, even if the first powered vehicle and the second powered vehicle operate via different transit modes.

At box 1125, the powered vehicle departs from the service station on the intermodal route with the intermodal maintenance vehicle coupled thereto, and at box 1130, the powered vehicle transits along the intermodal route with the intermodal maintenance vehicle. The powered vehicle may travel along one or more sets of rails, roads or shipping channels, and on courses and/or at speeds that may be selected on any basis.

At box 1140, whether an unmanned aerial vehicle requires servicing within one or more of the areas through which the intermodal maintenance vehicle travels is determined. For example, the unmanned aerial vehicle may independently determine that servicing is required, e.g., based on one or more sensed conditions or events that may have occurred while the aerial vehicle is in transit, or in accordance with a predetermined maintenance schedule. Alternatively, the unmanned aerial vehicle may transmit one or more electronic messages to an online marketplace, a fulfillment center, a service station, or to one or more facilities associated with aerial vehicles, including but not limited to ground-based facilities and/or mobile facilities, such as one or more mobile intermodal maintenance vehicles. The electronic messages may include information or data regarding a status of the unmanned aerial vehicle, including but not limited to power levels, operating histories, efficiency metrics or other factors. Upon receiving the electronic messages, one or more servers or other computer devices associated with such facilities may determine whether the unmanned aerial vehicle requires servicing, along with any number of other information or data such as date or time when the servicing is required, or a level of urgency associated with the servicing.

If an unmanned aerial vehicle does not require servicing, then the process returns to box 1130, where the intermodal maintenance vehicle may continue to transit along the intermodal route at any desired courses or speeds. In some embodiments, where confidence in an anticipated level of demand is particularly high, the intermodal maintenance vehicle may be brought to a stop, e.g., on a siding alongside a set of rails, in a rest stop or other roadway that bypasses a highway, or in a port or at anchor on a body of water.

If an unmanned aerial vehicle requires servicing, however, then the process advances to box 1150, where a position of a rendezvous point for the unmanned aerial vehicle and the intermodal maintenance vehicle is determined. The rendezvous point may be selected on any basis, including but not limited to the operability and/or capacities of the unmanned aerial vehicle that requires maintenance, distances between the unmanned aerial vehicle and the intermodal maintenance vehicle, maximum operating speeds, any prevailing weather conditions, or any other relevant factor. At box 1160, a course from the unmanned aerial vehicle and a distance from the intermodal maintenance vehicle to the rendezvous point are determined, and at box 1165, the unmanned aerial vehicle and the intermodal maintenance vehicle proceed to the rendezvous point.

At box 1170, the intermodal maintenance vehicle opens to receive the unmanned aerial vehicle therein for servicing. For example, the intermodal maintenance vehicle may include one or more doors (e.g., a split pair of doors) such as the doors 164A, 164B shown in FIG. 1A, 1D or 1K, or one or more slidable or rollable doors, such as is shown in
Furthermore, although some of the embodiments of the present disclosure depict the distribution or forward-deployment of inventory of items that are made available to customers through online marketplaces, those of ordinary skill in the pertinent arts will recognize that the systems and methods of the present disclosure are not so limited. Rather, mobile intermodal distribution systems may be used to distribute or forward-deploy inventory that may be made available through traditional commercial channels, e.g., by telephone or in one or more bricks-and-mortar stores, and delivered to customers or designated locations rapidly in response to orders for such items by aerial vehicles included in such systems. Moreover, although some of the embodiments of the present disclosure depict intermodal vehicles and/or aerial vehicles that are small in size, those of ordinary skill in the pertinent arts will recognize that the systems and methods of the present disclosure are not so limited. Rather, intermodal vehicles and/or aerial vehicles may be of any size or shape, and may be configured or outfitted with features that enable the distribution, delivery, retrieval or manufacture of items of any type or kind, and of any size or shape, by way of one or more aerial vehicles, in accordance with the present disclosure.

Although some embodiments of the present disclosure show the distribution or forward deployment of items that are available for purchase from an online marketplace to one or more locations based on known, observed or predicted demand using mobile intermodal delivery systems having aerial vehicles stored therein, the systems and methods of the present disclosure are not so limited. Rather, the systems and methods of the present disclosure may be utilized in any environment where the improved distribution of items, or the efficient retrieval and reuse of items or materials, is desired. For example, in one embodiment, the mobile intermodal delivery systems and aerial vehicles may be utilized in trash hauling or recycling systems.

It should be understood that, unless otherwise explicitly or implicitly indicated herein, any of the features, characteristics, alternatives or modifications described regarding a particular embodiment herein may also be applied, used, or incorporated with any other embodiment described herein, and that the drawings and detailed description of the present disclosure are intended to cover all modifications, equivalents and alternatives to the various embodiments as defined by the appended claims. Moreover, with respect to the one or more methods or processes of the present disclosure described herein, including but not limited to the flow charts shown in FIG. 3, 7 or 11, orders in which such methods or processes are presented are not intended to be construed as any limitation on the claimed inventions, and any number of the method or process steps or boxes described herein can be combined in any order and/or in parallel to implement the methods or processes described herein. Additionally, it should be appreciated that the detailed description is set forth with reference to the accompanying drawings, which are not drawn to scale. In the drawings, the use of the same or similar reference numbers in different figures indicates the same or similar items or features. Except where otherwise noted, leftmost digit(s) of a reference number identify a figure in which the reference number first appears, while the two right-most digits of a reference number identify a component or a feature that is similar to components or features having reference numbers with the same two right-most digits in other figures.

Conditional language, such as, among others, “can,” “could,” “might,” or “may,” unless specifically stated otherwise, or otherwise understood within the context as used,
is generally intended to convey in a permissive manner that certain embodiments could include, or have the potential to include, but do not mandate or require, certain features, elements and/or steps. In a similar manner, terms such as "include," "including" and "includes" are generally intended to mean "including, but not limited to." Thus, such conditional language is not generally intended to imply that features, elements and/or steps are in any way required for one or more embodiments or that one or more embodiments necessarily include logic for deciding, with or without user input or prompting, whether these features, elements and/or steps are included or are to be performed in any particular embodiment.

The elements of a method, process, or algorithm described in connection with the embodiments disclosed herein can be embodied directly in hardware, in a software module stored in a memory device and executed by one or more processors, or in a combination of the two. A software module can reside in RAM, flash memory, ROM, EPROM, EEPROM, registers, a hard disk, a removable disk, a CD-ROM, a DVD-ROM or any other form of non-transitory computer-readable storage medium, media, or physical computer storage known in the art. An example storage medium can be coupled to the processor such that the processor can read information from, and write information to, the storage medium. In the alternative, the storage medium can be integral to the processor. The storage medium can be volatile or nonvolatile. The processor and the storage medium can reside in an ASIC. The ASIC can reside in a user terminal. In the alternative, the processor and the storage medium can reside as discrete components in a user terminal.

Disjunctive language such as the phrase "at least one of X, Y, or Z," or "at least one of X, Y and Z," unless specifically stated otherwise, is otherwise understood with the context as used in general to present that an item, term, etc., may be either X, Y, or Z, or any combination thereof (e.g., X, Y, and/or Z). Thus, such disjunctive language is not generally intended to, and should not, imply that certain embodiments require at least one of X, at least one of Y, or at least one of Z to each be present.

Unless otherwise explicitly stated, articles such as "a" or "an" should generally be interpreted to include one or more described items. Accordingly, phrases such as "a device configured to" are intended to include one or more recited devices. Such one or more recited devices can also be collectively configured to carry out the stated recitations. For example, "a processor configured to carry out recitations A, B and C" can include a first processor configured to carry out recitation A, working in conjunction with a second processor configured to carry out recitations B and C.

Language of degree used herein, such as the terms "about," "approximately," "generally," "nearly" or "substantially" as used herein, represent a value, amount, or characteristic close to the stated value, amount, or characteristic that still performs a desired function or achieves a desired result. For example, the terms "about," "approximately," "generally," "nearly" or "substantially" may refer to an amount that is within less than 10% of, within less than 5% of, within less than 1% of, within less than 0.1% of, and within less than 0.01% of the stated amount.

Although the invention has been described and illustrated with respect to illustrative embodiments thereof, the foregoing and various other additions and omissions may be made therein and thereto without departing from the spirit and scope of the present disclosure.

What is claimed is:

1. A mobile system comprising:

   a locomotive;

   a first well car, wherein the first well car is coupled to the locomotive;

   a first intermodal maintenance vehicle disposed on the first well car, wherein the first intermodal maintenance vehicle comprises a plurality of batteries, at least one robotic arm and at least one system for launching an aerial vehicle or retrieving the aerial vehicle within a compartment of the first intermodal maintenance vehicle;

   at least one computer system in communication with at least the locomotive, the first intermodal maintenance vehicle and a first aerial vehicle, wherein the at least one computer system is configured to execute a method comprising:

   - determining that a power level of a first battery aboard the first aerial vehicle is below a predetermined threshold at a first time, wherein the locomotive and the first well car are traveling in the predetermined direction on the first set of rails at the first time;
   - determining a position of the first aerial vehicle;
   - determining a rendezvous point for the first aerial vehicle and the first intermodal maintenance vehicle on the first set of rails based at least in part on at least one of the position of the first aerial vehicle or the power level;
   - determining a first course and a first speed for the first aerial vehicle based at least in part on the power level and the rendezvous point;
   - causing the first aerial vehicle to travel to the rendezvous point at the first course and the first speed;
   - causing the locomotive and the first well car to travel to the rendezvous point at a second speed on the first set of rails;
   - retrieving the first aerial vehicle within the compartment of the first intermodal maintenance vehicle by the at least one system while the locomotive is in motion on the first set of rails;
   - removing the first battery from the first aerial vehicle within the compartment of the first intermodal maintenance vehicle by the at least one robotic arm;
   - installing a second battery into the first aerial vehicle within the compartment of the first intermodal maintenance vehicle by the at least one robotic arm.

2. The mobile system of claim 1, wherein the method further comprises:

   - after installing the second battery into the first aerial vehicle, launching the first aerial vehicle from the compartment of the first intermodal maintenance vehicle by the at least one system.

3. The mobile system of claim 1, further comprising:

   a second well car, wherein the second well car is coupled to at least one of the locomotive or the first well car; and

   a first intermodal carrier disposed on the second well car, wherein the first intermodal carrier vehicle comprises a plurality of items, at least one robotic arm and at least one system for launching an aerial vehicle or retrieving the aerial vehicle within a compartment of the first intermodal carrier vehicle, wherein the at least one computer system is in communication with at least the first intermodal carrier, and...
A method comprising:

1. identifying a subset of the plurality of intermodal maintenance vehicles, wherein each of the intermodal maintenance vehicles of the subset is configured to perform the first servicing operation on an aerial vehicle; and

2. selecting the one of the subset of the plurality of intermodal maintenance vehicles, wherein the first intermodal maintenance vehicle is the selected one of the subset of the plurality of intermodal maintenance vehicles.

3. determining, based at least in part on the at least one electronic message, that the first aerial vehicle requires the first servicing operation.

4. determining that the first intermodal maintenance vehicle is capable of performing the first servicing operation on the first aerial vehicle within the first compartment of the first intermodal maintenance vehicle; and

5. causing the first intermodal maintenance vehicle to travel to the rendezvous point of the intermodal maintenance vehicle, wherein the maximum range of the first intermodal maintenance vehicle is the selected one of the plurality of intermodal maintenance vehicles.

6. identifying a plurality of intermodal maintenance vehicles, wherein the first intermodal maintenance vehicle is the selected one of the plurality of intermodal maintenance vehicles.

7. receiving, over a network, at least one electronic message from the first aerial vehicle, wherein the at least one electronic message comprises information regarding a status of the first aerial vehicle; and

8. determining, based at least in part on the at least one electronic message, that the first aerial vehicle requires the first servicing operation.

9. determining that the first intermodal maintenance vehicle is capable of performing the first servicing operation on the first aerial vehicle within the first compartment of the first intermodal maintenance vehicle; and

10. causing the first intermodal maintenance vehicle to travel to the rendezvous point of the intermodal maintenance vehicle, wherein the maximum range of the first intermodal maintenance vehicle is the selected one of the plurality of intermodal maintenance vehicles.

11. wherein the method further comprises:

   - receiving, at a second time, a request for a delivery of one of the plurality of items to a location, wherein the second time precedes the first time, wherein the maximum range of the first intermodal maintenance vehicle is the selected one of the plurality of intermodal maintenance vehicles; and

   - identifying a plurality of intermodal maintenance vehicles, wherein each of the intermodal maintenance vehicles of the subset is configured to perform the first servicing operation on an aerial vehicle; and

   - selecting the one of the subset of the plurality of intermodal maintenance vehicles, wherein the first intermodal maintenance vehicle is the selected one of the plurality of intermodal maintenance vehicles.

   - determining, for each of the plurality of intermodal maintenance vehicles, a rendezvous point for the intermodal maintenance vehicle and the first aerial vehicle; and

   - determining, for each of the plurality of intermodal maintenance vehicles, a net distance between the first position and the rendezvous point of the intermodal maintenance vehicle; and

   - determining, for each of the plurality of intermodal maintenance vehicles, a net time for the performance of the first servicing operation by the intermodal maintenance vehicle; or

   - determining, for each of the plurality of intermodal maintenance vehicles, a net cost for the performance of the first servicing operation by the intermodal maintenance vehicle; and

   - selecting the one of the plurality of intermodal maintenance vehicles based at least in part on the at least one of the net distance, the net time, or the net cost, wherein the second position is the position of the selected one of the plurality of intermodal maintenance vehicles.

   - wherein determining the second position comprises:

     - determining, for each of the plurality of intermodal maintenance vehicles, a position of the intermodal maintenance vehicle, wherein the at least one powered vehicle is one of: Dijkstra’s Algorithm, Bellman-Ford Algorithm, Floyd-Warshall Algorithm, Johnson’s Algorithm or a hub labeling technique.

   - wherein selecting the one of the plurality of intermodal maintenance vehicles further comprises:

     - identifying a subset of the plurality of intermodal maintenance vehicles, wherein each of the intermodal maintenance vehicles of the subset is configured to perform the first servicing operation on an aerial vehicle; and

     - selecting the one of the subset of the plurality of intermodal maintenance vehicles, wherein the first intermodal maintenance vehicle is the selected one of the subset of the plurality of intermodal maintenance vehicles.

   - receiving, over a network, at least one electronic message from the first aerial vehicle, wherein the at least one electronic message comprises information regarding a status of the first aerial vehicle; and

   - determining, based at least in part on the at least one electronic message, that the first aerial vehicle requires the first servicing operation.

   - determining that the first intermodal maintenance vehicle is capable of performing the first servicing operation on the first aerial vehicle within the first compartment of the first intermodal maintenance vehicle; and

   - causing the first intermodal maintenance vehicle to travel to the rendezvous point of the intermodal maintenance vehicle, wherein the maximum range of the first intermodal maintenance vehicle is the selected one of the plurality of intermodal maintenance vehicles.

   - identifying a plurality of intermodal maintenance vehicles, wherein each of the intermodal maintenance vehicles of the subset is configured to perform the first servicing operation on an aerial vehicle; and

   - selecting the one of the subset of the plurality of intermodal maintenance vehicles, wherein the first intermodal maintenance vehicle is the selected one of the subset of the plurality of intermodal maintenance vehicles.

   - determining, for each of the plurality of intermodal maintenance vehicles, a rendezvous point for the intermodal maintenance vehicle and the first aerial vehicle; and

   - determining, for each of the plurality of intermodal maintenance vehicles, a net distance between the first position and the rendezvous point of the intermodal maintenance vehicle; and

   - determining, for each of the plurality of intermodal maintenance vehicles, a net time for the performance of the first servicing operation by the intermodal maintenance vehicle; or

   - determining, for each of the plurality of intermodal maintenance vehicles, a net cost for the performance of the first servicing operation by the intermodal maintenance vehicle; and

   - selecting the one of the plurality of intermodal maintenance vehicles based at least in part on the at least one of the net distance, the net time, or the net cost, wherein the second position is the position of the selected one of the plurality of intermodal maintenance vehicles.

   - wherein determining the second position comprises:

     - determining, for each of the plurality of intermodal maintenance vehicles, a position of the intermodal maintenance vehicle, wherein the at least one powered vehicle is one of: Dijkstra’s Algorithm, Bellman-Ford Algorithm, Floyd-Warshall Algorithm, Johnson’s Algorithm or a hub labeling technique.

   - wherein selecting the one of the plurality of intermodal maintenance vehicles further comprises:

     - identifying a subset of the plurality of intermodal maintenance vehicles, wherein each of the intermodal maintenance vehicles of the subset is configured to perform the first servicing operation on an aerial vehicle; and

     - selecting the one of the subset of the plurality of intermodal maintenance vehicles, wherein the first intermodal maintenance vehicle is the selected one of the subset of the plurality of intermodal maintenance vehicles.

   - receiving, over a network, at least one electronic message from the first aerial vehicle, wherein the at least one electronic message comprises information regarding a status of the first aerial vehicle; and

   - determining, based at least in part on the at least one electronic message, that the first aerial vehicle requires the first servicing operation.

   - determining that the first intermodal maintenance vehicle is capable of performing the first servicing operation on the first aerial vehicle within the first compartment of the first intermodal maintenance vehicle; and

   - causing the first intermodal maintenance vehicle to travel to the rendezvous point of the intermodal maintenance vehicle, wherein the maximum range of the first intermodal maintenance vehicle is the selected one of the plurality of intermodal maintenance vehicles.

   - identifying a plurality of intermodal maintenance vehicles, wherein each of the intermodal maintenance vehicles of the subset is configured to perform the first servicing operation on an aerial vehicle; and

   - selecting the one of the subset of the plurality of intermodal maintenance vehicles, wherein the first intermodal maintenance vehicle is the selected one of the subset of the plurality of intermodal maintenance vehicles.

   - determining, for each of the plurality of intermodal maintenance vehicles, a rendezvous point for the intermodal maintenance vehicle and the first aerial vehicle; and

   - determining, for each of the plurality of intermodal maintenance vehicles, a net distance between the first position and the rendezvous point of the intermodal maintenance vehicle; and

   - determining, for each of the plurality of intermodal maintenance vehicles, a net time for the performance of the first servicing operation by the intermodal maintenance vehicle; or

   - determining, for each of the plurality of intermodal maintenance vehicles, a net cost for the performance of the first servicing operation by the intermodal maintenance vehicle; and

   - selecting the one of the plurality of intermodal maintenance vehicles based at least in part on the at least one of the net distance, the net time, or the net cost, wherein the second position is the position of the selected one of the plurality of intermodal maintenance vehicles.

   - wherein determining the second position comprises:

     - determining, for each of the plurality of intermodal maintenance vehicles, a position of the intermodal maintenance vehicle, wherein the at least one powered vehicle is one of: Dijkstra’s Algorithm, Bellman-Ford Algorithm, Floyd-Warshall Algorithm, Johnson’s Algorithm or a hub labeling technique.

   - wherein selecting the one of the plurality of intermodal maintenance vehicles further comprises:

     - identifying a subset of the plurality of intermodal maintenance vehicles, wherein each of the intermodal maintenance vehicles of the subset is configured to perform the first servicing operation on an aerial vehicle; and

     - selecting the one of the subset of the plurality of intermodal maintenance vehicles, wherein the first intermodal maintenance vehicle is the selected one of the subset of the plurality of intermodal maintenance vehicles.

   - receiving, over a network, at least one electronic message from the first aerial vehicle, wherein the at least one electronic message comprises information regarding a status of the first aerial vehicle; and

   - determining, based at least in part on the at least one electronic message, that the first aerial vehicle requires the first servicing operation.

   - determining that the first intermodal maintenance vehicle is capable of performing the first servicing operation on the first aerial vehicle within the first compartment of the first intermodal maintenance vehicle; and

   - causing the first intermodal maintenance vehicle to travel to the rendezvous point of the intermodal maintenance vehicle, wherein the maximum range of the first intermodal maintenance vehicle is the selected one of the plurality of intermodal maintenance vehicles.

   - identifying a plurality of intermodal maintenance vehicles, wherein each of the intermodal maintenance vehicles of the subset is configured to perform the first servicing operation on an aerial vehicle; and

   - selecting the one of the subset of the plurality of intermodal maintenance vehicles, wherein the first intermodal maintenance vehicle is the selected one of the subset of the plurality of intermodal maintenance vehicles.

   - determining, for each of the plurality of intermodal maintenance vehicles, a rendezvous point for the intermodal maintenance vehicle and the first aerial vehicle; and

   - determining, for each of the plurality of intermodal maintenance vehicles, a net distance between the first position and the rendezvous point of the intermodal maintenance vehicle; and

   - determining, for each of the plurality of intermodal maintenance vehicles, a net time for the performance of the first servicing operation by the intermodal maintenance vehicle; or

   - determining, for each of the plurality of intermodal maintenance vehicles, a net cost for the performance of the first servicing operation by the intermodal maintenance vehicle; and

   - selecting the one of the plurality of intermodal maintenance vehicles based at least in part on the at least one of the net distance, the net time, or the net cost, wherein the second position is the position of the selected one of the plurality of intermodal maintenance vehicles.

   - wherein determining the second position comprises:

     - determining, for each of the plurality of intermodal maintenance vehicles, a position of the intermodal maintenance vehicle, wherein the at least one powered vehicle is one of: Dijkstra’s Algorithm, Bellman-Ford Algorithm, Floyd-Warshall Algorithm, Johnson’s Algorithm or a hub labeling technique.
18. A repair vehicle comprising:
a first intermodal container having an upper face, a forward face, a left face, a right face and an aft face; a second intermodal container stacked atop the first intermodal container, wherein the second intermodal container has a forward face, a left face, a right face, an aft face and a lower face, and wherein the first intermodal container and the second intermodal container define a compartment; a slidable door provided on the upper face of the first intermodal container, wherein the slidable door is configured for motion along a longitudinal axis between at least an open position and a closed position, wherein the slidable door has a free end in contact with the aft face of the first intermodal container when the slidable door is in the closed position, and wherein the free end is configured to translate in the longitudinal direction toward the forward face when the slidable door is moved from the closed position to the open position; an intake duct provided on at least one of the forward face of the first intermodal container or the forward face of the second intermodal container, wherein the intake duct extends between an exterior of the compartment and an interior of the compartment; an outlet duct provided on at least one of the aft face of the first intermodal container or the aft face of the second intermodal container, wherein the outlet duct extends between an exterior of the compartment and an interior of the compartment; 
a retrieval system comprising at least one conveyor, wherein the retrieval system is mounted to the lower face of the second intermodal container, and wherein the retrieval system is configured for motion along a vertical axis with respect to the upper face of the first intermodal container and the lower face of the second intermodal container; and a robotic arm mounted within the compartment, wherein the robotic arm is configured to automatically perform at least one servicing operation on an aerial vehicle disposed within the compartment.

19. The repair vehicle of claim 18, wherein each of the left face of the second intermodal container and the right face of the second intermodal container has a length of approximately fifty-three feet, wherein each of the forward face and the aft face of the second intermodal container has a width of approximately eight-and-one-half feet, wherein each of the left face of the second intermodal container, the right face of the second intermodal container, the forward face of the second intermodal container and the aft face of the second intermodal container has a height of approximately nine-and-one-half feet, wherein the lower face of the second intermodal container is coupled to a well car, wherein the well car is coupled to a locomotive, and wherein each of the locomotive and the well car is configured for travel on a common pair of rails.

20. The repair vehicle of claim 18, wherein at least one servicing operation is at least one of:
   a battery replacement;
   a motor repair;
   a motor replacement; or
   a propeller replacement.
A dedicated network delivery system may avoid congestion experienced by traditional transportation networks and enable the delivery of objects from an origin to a destination using one or subterranean or aboveground elements. The network delivery system may be specifically configured to transport a particular type of object, such as an item, or a parcel or container having one or more items therein, in both vertical and horizontal directions along one or more of such elements, and in one or more item carriers such as carts, bags or boxes. The elements may be driven by or along one or more conveyors or rails, and may comprise one or more pressure-controlled carriers within a vacuum environment or among any type of fluid, including liquids or gases. A path between the origin and destination may be defined based on any factor, including travel time or cost, and any actual or predicted congestion.

16 Claims, 15 Drawing Sheets

OTHER PUBLICATIONS


* cited by examiner

Primary Examiner — Yolanda Cumbess
(74) Attorney, Agent, or Firm — Athorus, PLLC

ABSTRACT

A dedicated network delivery system may avoid congestion experienced by traditional transportation networks and enable the delivery of objects from an origin to a destination using one or subterranean or aboveground elements. The network delivery system may be specifically configured to transport a particular type of object, such as an item, or a parcel or container having one or more items therein, in both vertical and horizontal directions along one or more of such elements, and in one or more item carriers such as carts, bags or boxes. The elements may be driven by or along one or more conveyors or rails, and may comprise one or more pressure-controlled carriers within a vacuum environment or among any type of fluid, including liquids or gases. A path between the origin and destination may be defined based on any factor, including travel time or cost, and any actual or predicted congestion.

16 Claims, 15 Drawing Sheets