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Inventor(s)	Gravelle; Scott et al.

STORAGE AND RETRIEVAL SYSTEMS AND METHODS

Abstract

An improved storage and retrieval system employing a gridded three-dimensional storage structure features workstations served by the same robotic vehicle fleet that serves the storage structure, travel-through workstations using the same robotic vehicles to carry storage units through the workstation without hand-off to any other conveyor or handler, internal sortation using orchestrated navigation of the robotic vehicles to workstation intake points, sensors on the robotic vehicles to confirm proper loading and alignment of storage units thereon, lifting mechanisms for raising the robotic vehicles into shafts of the grid from a lower track thereof, use of markers and scanners to align the robotic vehicles with the grid shafts, and workstation light curtains for hand safety, pick-counting and container content protrusion detection.

Inventors: **Gravelle; Scott (Calgary, CA), Hope; Robert Winston (Calgary, CA), Rousseau; Darin (Calgary, CA)**

Applicant: **ATTABOTICS INC.** (Calgary, CA)

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Background/Summary

INCORPORATION BY REFERENCE TO ANY PRIORITY APPLICATIONS [0001] Any and all applications for which a foreign or domestic priority claim is identified in the Application Data Sheet as filed with the present application are hereby incorporated by reference under 37 CFR 1.57. This application is a continuation of U.S. patent application Ser. No. 16/973,260, filed Dec. 8, 2020, which is the U.S. national phase entry of International Application No. PCT/CA 2019/050815, filed Jun. 10, 2019, which is a continuation-in-part of International Application No. PCT/CA 2019/050404, filed Apr. 3, 2019, which claims benefit of priority under 35 U.S.C. 119 (e) to U.S. Provisional Application No. 62/682,691, filed Jun. 8, 2018, and to U.S. Provisional Application No. 62/770,788, filed Nov. 22, 2018, each of which is incorporated herein by reference in its entirety.

BACKGROUND
Field
[0002] The present invention relates generally to automated storage and retrieval systems useful in order fulfillment environments.
Description of the Related Art
[0003] Applicant's prior PCT application published as WO2016/172793, the entirety of which is incorporated herein by reference, disclosed a goods-to-man storage and retrieval system employing a three-dimensional storage grid structure in which a fleet of robotic storage/retrieval vehicles navigate a three-dimensional array of storage locations in which respective bins or other storage units are held. The storage/retrieval vehicles travel horizontally in two dimensions on both a gridded upper track layout disposed above the three-dimensional array of storage locations, and a gridded lower track layout disposed at ground level below the array of storage locations. The same storage/retrieval vehicles also traverse the structure in the third vertical dimension through vertically upright shafts that join together the upper and lower track layouts. Each column of storage locations is neighboured by one of these upright shafts, whereby each and every storage location in the grid is directly accessible by the storage/retrieval vehicles.
[0004] Continued development has led to numerous improvements in the system design, and novel applications for same, the details of which will become more apparent from the following disclosure.
SUMMARY
[0005] According to a first aspect of the invention, there is provided a storage system comprising: [0006] one or more storage/retrieval vehicles; [0007] a three-dimensional structure comprising: [0008] a gridded lower track layout that occupies a two-dimensional area and on which said one or more storage/retrieval vehicles are conveyable in two directions over said two-dimensional area; and [0009] a plurality of storage columns residing above the gridded lower track layout and distributed over the two-dimensional area of said lower track layout, each column comprising a

plurality of storage locations that are arranged one over another, are each sized to accommodate placement and storage of storage units therein, and are each accessible by the one or more storage/retrieval vehicles to place or remove the storage units to or from said storage locations of said storage column; and [0010] at least one working station residing alongside the three-dimensional structure and outside the two-dimensional area of the lower track layout over which the storage columns are distributed, said working station being linked to the gridded lower track layout by an extension track thereof by which said one or more storage/retrieval vehicles is conveyable between said working station and said lower track layout, whereby conveyance of the storage units between the storage locations and the working station is performable entirely by said one or more storage/retrieval vehicles.

[0011] According to a second aspect of the invention, there is provided a storage system comprising: [0012] one or more storage/retrieval vehicles; [0013] a three-dimensional structure comprising: [0014] a gridded track layout that occupies a two-dimensional area and on which the one or more storage/retrieval vehicles are conveyable in two directions over said two-dimensional area; [0015] a plurality of storage columns residing above or below the gridded track layout and distributed throughout the two-dimensional area of said track layout, each column comprising a plurality of storage locations that are arranged one over another, are each sized to accommodate placement and storage of storage units therein, and are each accessible by the one or more storage/retrieval vehicles to place or remove the storage units to or from said storage locations of said storage column; and [0016] at least one working station residing outside the two-dimensional area of the track layout within which the storage columns are distributed; [0017] wherein conveyance of the storage units between the at least one working station and the storage locations in the three-dimensional structure is performed solely by said one or more storage/retrieval vehicles.

[0018] According to a third aspect of the invention, there is provided a storage system comprising: [0019] one or more storage/retrieval vehicles; [0020] a three-dimensional structure comprising a three-dimensional array of storage locations sized to accommodate placement and storage of storage units therein; and [0021] at least one working station to which selected storage units from the storage locations are conveyable by said one or more storage/retrieval vehicles; [0022] wherein each working station comprises an enclosure through which said one or more storage/retrieval vehicles are conveyable, and an access opening in said enclosure through which a carried storage unit on one of the storage/retrieval vehicles is accessible when said vehicle reaches said access opening of the working station.

[0023] According to a fourth aspect of the invention, there is provided a working station for a goods-to-person fulfillment system, said working station comprising: [0024] a defined pathway through which a retrieved storage unit is conveyed during use of said working station; [0025] an enclosure spanning at least partially around said defined pathway; and [0026] an access opening through said enclosure by which a given storage unit conveyed along the defined pathway is accessible upon arrival at said access opening; and [0027] a sensing mechanism operable to detect insertion of worker hands at said access opening.

[0028] According to a fifth aspect of the invention, there is provided a storage system comprising: [0029] one or more storage/retrieval vehicles; and [0030] a gridded three-dimensional structure comprising: [0031] a gridded track layout that occupies a two-dimensional area and on which the one or more storage/retrieval vehicles are conveyable in two directions over said two-dimensional area; [0032] a plurality of storage columns residing above or below the gridded track layout and distributed within the two-dimensional area of said track layout, each column comprising a plurality of storage locations arranged one over another and sized to accommodate placement and storage of storage units therein; and [0033] a plurality of upright shafts residing above or below the gridded track layout and distributed within the two-dimensional area of said track layout, each storage column being neighboured by a respective one of the upright shafts through which the storage locations of said storage column are accessible by the one or more storage/retrieval vehicles to place or remove the storage units to or from said storage locations of said storage column; and [0034] a set of detectable markers and a set of sensors operable to detect said detectable markers, wherein a first of either said detectable markers or said sensors are supported within the gridded three-dimensional structure at or near spots in the gridded track layout that overlie or underlie the upright shafts, and a second of either said detectable markers or said sensors are carried on said storage retrieval vehicles; [0035] wherein, during arrival of any one of said storage/retrieval vehicles at a respective spot overlying or underlying a targeted shaft for which said one of the storage/retrieval vehicles is destined, detection of the respective marker by the sensor is used to check, and adjust if necessary, alignment of said storage/retrieval vehicle with the targeted shaft before attempting transition of said storage/retrieval vehicle from said gridded track layout into the targeted shaft.

[0036] According to a sixth aspect of the invention, there is provided a method of controlling positioning of one or more storage/retrieval vehicles in a gridded three-dimensional structure in which said one or more storage/retrieval vehicles are conveyable in two dimensions on a gridded track layout and in a third dimension through upright shafts whose upright axes intersect said gridded track layout, said method comprising: [0037] (a) having a first of either a set of detectable markers or a set of sensors supported on the gridded three-dimensional structure at or near spots of the gridded track layout that overlie or underlie the upright shafts, and having a second of either said set of detectable markers or said set of sensors carried on said storage/retrieval vehicles, wherein said sensors are operable to detect said detectable markers; [0038] (b) during arrival of any one of the storage/retrieval vehicles at a respective spot overlying or underlying a targeted shaft for which said one of the storage/retrieval vehicles is destined, using one of the sensors to detect one of the detectable markers; and [0039] (c) using detection of the marker by said one of the sensors to check, and adjust if necessary, alignment of said storage/retrieval vehicle with the targeted shaft before attempting transition of said one of the storage/retrieval vehicles from said gridded track layout into the targeted shaft.

[0040] According to a seventh aspect of the invention, there is provided a storage system comprising: [0041] one or more storage/retrieval vehicles [0042] a three-dimensional structure comprising: [0043] a lower track layout on which one or more storage/retrieval vehicles are conveyable; and [0044] a plurality of storage columns residing above the lower track layout, each column comprising a plurality of storage locations that are arranged one over another, are each sized to accommodate placement and storage of storage units therein, and are each accessible by the one or more storage/retrieval vehicles to place or remove the storage units to or from said storage locations of said storage column; and [0045] at launching spots of the lower track layout from which the storage/retrieval vehicles are to travel upwardly from the lower track layout, respective lifting mechanisms operable to lift any one of the storage/retrieval vehicles upwardly from the lower track layout.

[0046] According to an eighth aspect of the invention, there is provided a storage/retrieval vehicle for carrying storage units in an automated storage system, said storage/retrieval vehicle comprising an upper platform having a landing area of similar size and shape to an underside of one of said storage units, and a set of load status sensors at positions closely adjacent an outer perimeter of said landing area, whereby detection of the underside of said one of the storage units by all of said load status sensors confirms a fully loaded and properly aligned status of said one of the storage units on said platform, while detection of the underside of the one of the storage containers by only a subset of said load status sensors indicates a partially loaded or improperly aligned status of said one of the storage units on said platform.

[0047] According to a ninth aspect of the invention, there is provided a method of presenting retrieved storage units from a storage system to an entrance or intake point of a working station in a sequenced manner, said method comprising: [0048] (a) having a three-dimensional structure comprising: [0049] a gridded track layout that occupies a two-dimensional area and on which one or more storage/retrieval vehicles are conveyable in two directions over said two-dimensional area; and [0050] a plurality of storage columns residing above or below the gridded track layout and distributed within the two-dimensional area of said track layout, each column comprising a plurality of storage locations that are arranged one over another, sized to accommodate placement and storage of storage units therein, and each accessible by the one or more storage/retrieval vehicles to place or remove the storage units to or from said storage locations of said storage column; [0051] (b) having the storage/retrieval vehicles retrieve respective storage units designated for delivery to the working station from respective storage locations; and [0052] (c) within said three-dimensional structure, orchestrating sequenced delivery of the retrieved storage units to the entrance or intake point of the working station.

[0053] According to a tenth aspect of the invention, there is provided a storage system comprising: [0054] a three-dimensional structure comprising: [0055] a gridded track layout that occupies a two-dimensional area and on which one or more storage/retrieval vehicles are conveyable in two directions over said two-dimensional area; and [0056] a plurality of storage columns residing above or below the gridded track layout and distributed within the two-dimensional area of said track layout, each column comprising a plurality of storage locations that are arranged one over another, are each sized to accommodate placement and storage of storage units therein, and are each accessible by the one or more storage/retrieval vehicles to place or remove the storage units to or from said storage locations of said storage column; [0057] at least one working station having an access point that resides outside the two-dimensional area of the track and receives storage units delivered to an entrance or intake point of the working station; and [0058] at least one processor configured to organize sequenced delivery of a group of storage units from the three-dimensional gridded structure to the working station, including: [0059] (a) generating and transmitting signals to instruct a plurality of storage/retrieval vehicles to retrieve the storage units from respective the storage locations; and [0060] (b) generating and transmitting signals to instruct the plurality of storage/retrieval vehicles to navigate the gridded three-dimensional structure in a manner orchestrating arrival of the storage/retrieval vehicles at the entrance or intake point of the working station in a particular sequence.

[0061] According to an eleventh aspect of the invention, there is provided a method of preparing and buffering order shipments, said method comprising: [0062] (a) having a gridded three-dimensional storage system comprising: [0063] a plurality of storage/retrieval vehicles; [0064] a three-dimension structure comprising: [0065] a gridded track layout that occupies a two-dimensional area and on which the storage/retrieval vehicles are conveyable in two directions over said two-dimensional area; and [0066] a plurality of storage columns residing above or below the gridded track layout and distributed within the two-dimensional area of said track layout, each column comprising a plurality of storage locations that are arranged one over another, are sized to accommodate placement and storage of one or more items therein, and are each accessible by the one or more storage/retrieval vehicles to place or remove the items to or from said storage locations of said storage column; and [0067] at least one working station to which items removed from the storage locations and conveyed to the gridded track layout are deliverable by travel of the storage/retrieval vehicles along said gridded track layout to an entrance of said working station; [0068] (b) having a group of the storage/retrieval vehicles retrieve a particular collection of items required to fulfill an order and carry the retrieved items to the gridded track layout and onward to the entrance of the working station; and [0069] (c) at the working station, amalgamating the particular collection of items to form a fully or partially fulfilled order, and placing said fully or partially fulfilled order into a container; and [0070] (d) with said container loaded onto one of the storage/retrieval vehicles at the working station, having said one of the storage/retrieval vehicles travel to one of the storage locations and deposit said container at said one of the storage locations, thereby storing said fully or partially fulfilled order for further completion or shipment at a later time.

[0071] According to a twelfth aspect of the invention, there is provided a sortation/buffering system for shipping containers, said system comprising: [0072] one or more storage/retrieval vehicles having each having a loading area at which said storage/retrieval vehicle is arranged to selectively carry a shipping container; [0073] a gridded three-dimensional structure comprising: [0074] a gridded track layout that occupies a two-dimensional footprint and on which the one or more storage/retrieval vehicles are conveyable in two directions over said two-dimensional area; [0075] a plurality of storage columns residing above or below the gridded track layout in spaced distribution within the two-dimensional footprint of said track layout, each column comprising a plurality of storage locations arranged one over another and sized to accommodate placement and storage of shipping containers therein; and [0076] a plurality of upright shafts residing above or below the gridded track layout in spaced distribution within the two-dimensional footprint of said track layout and through which the one or more storage/retrieval vehicles can travel to and from said gridded track layout in a third dimension, each storage column being neighboured by a respective one of the upright shafts through which the storage locations of said storage column are accessible by the one or more storage/retrieval vehicles to place or remove the shipping containers to or from said storage locations of said storage column.

[0077] According to a thirteenth aspect of the invention, there is provided a method of checking positional accuracy in movement of a vehicle along a path, said method comprising, with a series of detectable markers each situated at a targetable destination along said path, and with an image capture device carried on said vehicle, using said sensor to capture a digital image from a field of view containing said marker upon arrival at one of said targetable destinations, and checking for agreement between a position of said respective marker within the field of view and a predetermined sub-region of the field of view in which the respective marker is expected, whereby said agreement indicates proper alignment of the vehicle relative to the targeted destination.

[0078] According to a fourteenth aspect of the invention, there is provided a track-based conveyance apparatus with positional accuracy monitoring, said apparatus comprising: [0079] a track having a series of detectable markers each situated statically thereon or there adjacent at or adjacent a respective targetable destination along said track; [0080] a vehicle configured for conveyance along said track; and [0081] an image capture device carried on said vehicle and configured to capture a digital image from a field of view containing said marker upon arrival at one of said targetable destinations, and checking for agreement between a position of said respective marker within the field of view and a predetermined sub-region of the field of view in which the respective marker is expected, whereby said agreement indicates proper alignment of the storage/retrieval vehicle relative to the targeted destination.

[0082] According to a fifteenth aspect of the invention, there is provided a method of confirming proper loading of a storage unit onto a robotic storage/retrieval vehicle in an automated storage and retrieval system, said method comprising, as part of a loading routine pulling a storage unit onto the robotic storage/retrieval vehicle, using a local processor of said robotic storage/retrieval vehicle to perform a status check of each of a plurality of load status sensors situated at positions closely adjacent an outer perimeter of a landing area of said robotic storage/retrieval vehicle that is of similar size and shape to an underside of said storage unit, and from said status check, determine whether all of said load status sensors, or only a partial subset thereof, have a positive detection signal, whereby a full set of positive detection signals from all of said load status sensors confirms a fully loaded and properly aligned status of said storage unit, and a partial subset of positive detection signals from only said partial subsect of the load status signals identifies a partially loaded or improperly aligned status of the storage unit.

[0083] According to a sixteenth aspect of the invention, there is provided a method of orchestrating presentation of retrieved storage units from a storage system to an entrance or intake point of a working station in a sequenced manner, said method comprising execution of the following automated steps by one of more processors of a computer control system of said storage system: [0084] (a) generating a task assignment for each line item of one or more received orders to be fulfilled at the working station, each task assignment including, at least, specification of a respective storage unit to retrieve from a current storage location thereof in the storage system for delivery to the working station, and identification of a respective storage/retrieval vehicle to retrieve said respective storage unit; and [0085] (b) transmitting command signals to the respective storage/retrieval vehicles of said task assignments to initiate retrieval and delivery of said respective storage unit from the current storage location thereof to the working station; and [0086] (c) determining whether there's an available occupancy at said working station; [0087] (d) in response to confirmation of said available occupancy, identifying from among storage/retrieval vehicles situated outside the working station and assigned to deliver to said working station, a next highest-priority storage/retrieval vehicle to call into the working station; and [0088] (e) commanding said next highest-priority vehicle to travel into the working station.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

[0089] Preferred embodiments of the invention will now be described in conjunction with the accompanying drawings in which:

[0090] FIG. **1** is a perspective view of a three-dimensional grid structure from Applicant's published PCT application WO2016/172793, in which a three-dimensional array of storage units are contained and through which a fleet of robotic storage/retrieval vehicles can travel in three dimensions to access each said storage units.

[0091] FIG. **2** is a perspective view of a modified three-dimensional grid structure according to the present invention.

[0092] FIG. **3** is a simplified partial perspective view of the three-dimensional grid structure of FIG. **2** showing a pair of intersecting outer walls of the grid structure at a corner thereof from which two working stations have been removed to reveal details of said outer walls.

[0093] FIG. **4** is an isolated perspective view of one of the working stations from the three-dimensional grid of FIG. **2** from an outer side thereof that faces outwardly from the grid.

[0094] FIG. **5** is an isolated perspective view of the working station of FIG. **4** from an inner side thereof that inwardly into the grid.

[0095] FIG. **6** is another isolated perspective view of the inner side of the working station of FIG. **5**.

[0096] FIG. **6**A is a partial closeup view of the portion of FIG. **6** marked by detail circle A thereof.

[0097] FIG. **6**B illustrates a control logic routine executed by a computerized control system for combined safety and quantity count purposes at the working station.

[0098] FIG. **6**C illustrated a simplified control logic routine omitting the quantity count functionality of that shown in FIG. **6**B.

[0099] FIG. **7** is a schematic overhead plan view of the working station of FIGS. **4** to **6** and a neighbouring area of a lower track layout of the three-dimensional grid structure at which the working station is installed.

[0100] FIGS. **7**A through **7**H illustrate orchestration of sequenced arrival of storage/retrieval vehicles at the workstation of FIG. **7** by selective parking and advancing of the vehicles on the lower track layout according to priority rankings assigned to storage units carried on said vehicles.

[0101] FIG. **7**I illustrates a control logic routine executed by the computerized control system to perform the sequenced arrival of the storage/retrieval vehicles at the workstation.

[0102] FIG. **8** shows a segment of a lower track of the three-dimensional grid of FIG. **2**, along which one of the robotic storage/retrieval vehicles is travelling.

[0103] FIG. **8**A is a partial closeup view of the portion of FIG. **8** marked by detail circle A thereof.
[0104] FIG. **9**A schematically illustrates scanning of a uniquely coded marker on a track rail in either the grid structure or the working station by a storage/retrieval vehicle travelling therealong in order to assess misalignment between the vehicle and an intended destination thereof.
[0105] FIG. **9**B shows use of the same uniquely coded marker to confirm successful alignment of the storage/retrieval vehicle on the targeted destination spot after correcting the misalignment detected in FIG. **9**A.
[0106] FIG. **9**C illustrates a control logic routine executed by a local processor of the storage/retrieval vehicle to detect the misalignment of FIG. **9**A, and perform appropriate correction to achieve the proper alignment of FIG. **9**B.
[0107] FIG. **10** is an elevational view showing one of the robotic storage/retrieval vehicles on the lower track of the three-dimensional grid at launching spot below a vertical shaft of the three-dimensional grid through which the robotic storage/retrieval vehicle is intended to travel upwardly.
[0108] FIG. **11** is a perspective view of the robot of FIG. **10** at the launching spot of the lower track.
[0109] FIG. **12** is a partial closeup view of the portion of FIG. **10** marked by detail circle A thereof.
[0110] FIG. **13** is a partial closeup view of the portion of FIG. **11** marked by detail circle B thereof.
[0111] FIG. **14** is another closeup of the same robotic storage/retrieval vehicle and lower track intersection point as FIG. **12**, but with the robotic storage/retrieval vehicle raised up to engage with rack teeth on upright frame members of the shaft by a lifting mechanism mounted beneath the lower track.
[0112] FIG. **15** another closeup of the same robotic storage/retrieval vehicle and lower track intersection point as FIG. **13**, but with the robotic storage/retrieval vehicle in the raised position of FIG. **14**.
[0113] FIGS. **16** and **17** are top and bottom perspective views of the robotic storage/retrieval vehicle and lifting mechanism of FIGS. **10** to **13**, but shown in isolation from the lower track and upright shaft members.
[0114] FIGS. **18** and **19** are top and bottom perspective views of the robotic storage/retrieval vehicle and lifting mechanism of FIGS. **14** and **15**, but shown in isolation from the lower track and upright shaft members.
[0115] FIG. **19**A illustrates a control logic routine cooperatively executed between the storage/retrieval vehicle, lifting mechanism and computerized control system initiate and complete launch and travel of the storage/retrieval upwardly through the shaft.
[0116] FIGS. **20** and **21** illustrate one of the robotic storage/retrieval vehicles and a compatible storage unit transportable thereon.
[0117] FIG. **22** illustrates a sortation/buffering grid employing the same three-dimensional grid structure and robotic storage/retrieval vehicles as the storage systems of FIGS. **1** and **2**, but with a different layout of stations serving the grid for use in management of pre-packed shipping containers.
[0118] FIG. **23** is a schematic block diagram illustrating the architecture of a computerized control system responsible for assigning tasks to the storage/retrieval vehicles and working stations, and commanding operation of the storage/retrieval vehicles and lifting mechanisms to manage vehicle navigation throughout the system.

DETAILED DESCRIPTION

[0119] FIG. **1** illustrates the three-dimensional grid structure **17** from Applicant's aforementioned prior PCT application. A gridded upper track layout **10** resides in an elevated horizontal plane well above a matching gridded lower track layout situated in a lower horizontal plane close to ground level. Between these upper and lower track layouts is a three-dimensional array of storage locations, each holding a respective storage unit therein, for example in the form of open-top or openable/closeable storage tray, bin or tote capable of holding any variety of goods therein. The storage locations are arranged in vertical storage columns **11**, in which storage locations of equal footprint are aligned over one another. Each such storage column **11** is neighboured by a vertical shaft **13** through which its storage locations are accessible.

[0120] Each track layout features a set of X-direction rails lying in the X-direction of a horizontal plane and a set of Y-direction rails perpendicularly crossing the X-direction rails in the Y-direction of the horizontal plane. The crossing rails define a horizontal reference grid of the storage system **15**, where each horizontal grid row is delimited between an adjacent pair of the X-direction rails and each horizontal grid column is delimited between an adjacent pair of the Y-direction rails. Each intersection point between one of the horizontal grid columns and one of the horizontal grid rows denotes the position of a respective storage column **11** or a respective upright shaft **13**. In other words, each storage column **11** and each shaft **13** reside at a respective Cartesian coordinate point of the reference grid at a respective area bound between two of the X-direction rails and two of the Y-direction rails. Each such area bound between four rails in either track layout is also referred to herein as a respective “spot” of said track layout. The three-dimensional addressing of each storage location and associated storage unit in the system is completed by the given vertical level at which the given storage location resides within the respective storage column **11**. That is, a three-dimensional address of each storage location is dictated by the horizontal grid row, horizontal grid column and vertical column level of the storage location in the three-dimensional grid structure **17**.

[0121] A respective upright frame member **12** spans vertically between the upper and lower track layouts at each intersection point between the X-direction and Y-direction rails, thereby cooperating with the track rails to define a framework of the three-dimensional grid structure **17** for containing and organizing the three-dimensional array of storage units within this framework. As a result, each upright shaft **13** of the three-dimensional storage array has four vertical frame members spanning the full height of the shaft **13** at the four corners thereof. Each frame member has respective sets of rack teeth **90** arranged in series in the vertical Z-direction of the three-dimensional grid structure **17** on two sides of the frame member **12**. Each shaft **13** thus has eight sets of rack teeth **90** in total, with two sets at each corner of the shaft **13**, which cooperate with eight pinion wheels on the robotic storage/retrieval vehicles **14** to enable traversal of same between the upper and lower track layouts through the shafts **13** of the three-dimensional grid structure **17**. Each robotic storage/retrieval vehicle **14** has a wheeled frame or chassis featuring both round conveyance wheels for conveyance of the robotic storage/retrieval vehicle **14** over the upper and lower track layouts in a track-riding mode, and toothed pinion wheels for traversal of the robotic storage/retrieval vehicle **14** through the rack-equipped shafts **13** in a shaft-traversing mode. The footprint of frame or chassis is less than the horizontal area of each shaft **13** to allow travel of the vehicle **14** through each shaft **13**. Each pinion wheel and a respective conveyance wheel are part of a combined singular wheel unit **68**, **70**, of which at least the conveyance wheel is extendable in an outboard direction from the vehicle for use of the conveyance wheels in a track-riding mode on either track layout, and retractable in an inboard direction of the vehicle for use of the pinion wheels in a shaft-traversing mode engaging the pinion wheels with the rack teeth **90** of the upright frame members **12** of a shaft **13** (for example, see FIGS. **14** and **15** and accompanying description below). Transition of the vehicle **14** from the track-riding mode to the shaft-traversing mode thus converts the vehicle to a smaller overall outer footprint of lesser size than the shaft area to enable the entirety of the vehicle **14** to travel through the shaft **13**.

[0122] The framework of the three-dimensional grid structure **17** includes a respective shelf at each storage location to support the respective storage unit, whereby any given storage unit **16** can be removed from its storage location by one of the robotic retrieval vehicles **14** without disrupting the storage units **16** above and below it in the same storage column. Likewise, this allows a storage unit **16** to be returned to a prescribed location at any level in the array. The lower gridded track layout at the bottom of the three-dimensional grid structure **17** has a number of working stations **18** distributed around its perimeter to which the robotic retrieval vehicles **14** deliver the storage units

16 pulled from the storage columns **11**. Except for differences explicitly described herein, the framework of the three-dimensional grid structure **17**, the robotic storage/retrieval vehicles **14**, their travel over the upper and lower track layouts and through the shafts **13**, and their transition between the track-riding and shaft-traversing modes are the same as described in Applicant's aforementioned prior PCT application.

[0123] FIG. **2** shows a modified form the prior three-dimensional grid structure **17**, which once again features the upper and lower track layouts and the upright frame members **12** that span therebetween to carry shelving at the storage locations for support of the storage units **16** therein, and also carry the rack teeth **90** engageable by the pinion wheels of the robotic storage/retrieval vehicles **14** to enable vertical travel of an entirety of each robotic storage/retrieval vehicle **14** through any of the shafts **13**. The shelving may be in the form of flanged panels or rails at the three sides of the storage column **11** other than the fourth shaft-adjacent side that opens into the neighbouring access shaft from which the robotic storage/retrieval vehicles **14** access the storage units **16** of that column **11**, whereby this fourth open side enables insertion and withdrawal of an extendable/retractable turret arm of each vehicle **14** into the storage column **11** at to pull and push storage units **16** into and out of the storage column **11** through engagement with the undersides of the storage units **16**.

[0124] As outlined in in Applicant's aforementioned prior PCT application, a subset of the vertical shafts **13** located at the outer perimeter may be “up-shafts” that are dedicated for upward travel of the robotic storage vehicles **14** therethrough from the lower track layout to the upper track layout **10** after having delivered a storage unit **16** to one of the working stations **18**, while other vertical shafts **13** are “down-shafts” that are dedicated for downward travel of the robotic storage vehicles **14** therethrough from the upper track layout **10** during either retrieval of a storage unit **16** from the three dimensional storage array, or return of a storage unit **16** back into the three dimensional array after having previously delivered the storage unit **16** to one of the working stations **18** for a picking, re-stocking or other operation.

[0125] The three-dimensional grid structure **17** of FIG. **2** differs from that of FIG. **1** in that cladding panels **20** have been added to the upright frame members **12** at the outer perimeter of the three-dimensional grid structure **17** to create outer side walls that substantially close off all four sides of the three-dimensional grid structure **17**, thus visually concealing the interior thereof, and in that the upright frame members **12** include top segments **22** thereof that stand upright frame the rails of the upper track members at the intersection points thereof, and that obscure the upper track layout **10** from sight in the particular wide-view of the three-dimensional grid structure **17** shown in FIG. **2**. These top segments **22** of the shaft **13** may be used for mounting of charging station hardware by which the robotic storage/retrieval vehicles **14** can be recharged when necessary. However, the structure and purpose of the upper track layout **10** and the form of shafts **13** and storage columns **11** inside the three-dimensional grid structure **17** by the upright frame members **12** are well documented in Applicant's prior PCT application, and thus require no detailed illustration or explanation herein. There may be plurality of working stations **18** on each of one or more perimeter sides of the three-dimensional grid structure **17**, and may be working stations one, two, three or all four sides of the three-dimensional grid structure **17**. FIG. **2** shows distribution of working stations on at least two non-opposing sides of the three-dimensional grid structure **17**. There may also be one or more working stations **18** on each of the two other sides not visible from the vantage point of the figure.

[0126] Turning now to FIGS. **3** to **6**, attention is given to the novel structure of the working stations **18** and the novel interaction therewith by the robotic storage/retrieval vehicles **14**. In the interest of illustrative simplification, FIG. **3** omits much of the three-dimensional grid structure **17**. Shown however are one X-direction rail **24** and one Y-direction rail **26** of the lower track layout **28** that form two outer sides of the lower track layout and intersect at a respective outer corner of the three-dimensional grid structure **17**. Of the remainder of the lower track layout **28**, only the support legs

30 elevating these two particular rails off the ground are shown. Among the upright frame members **12** of the three-dimensional grid structure **17**, only those that stand upright from two illustrated rails **24**, **26** at these two outer sides of the three-dimensional grid structure **17** are shown, and the top segments **22** of these upright frame members **12** are omitted. Around the full perimeter of the three-dimensional grid structure **17**, the cladding panels **20** do not extend fully down to the lower track **28**, but instead terminate in a slightly elevated relation thereover so that bottom segments **32** of the upright frame members **12** that attach to and stand upright from the rails of the lower track layout **28** are left uncladded. This leaves an open space **34** between the bottom segments **32** of every adjacent pair of upright frame members **12**. These open spaces **34** allow the robotic storage/retrieval vehicles **14** to enter and exit the three-dimensional grid structure **17** at the lower track **28** thereof, and thus transition between the three-dimensional grid structure **17** and the working stations **18**.

[0127] As outlined in more detail below, this enables a novel solution for goods-to-man order fulfilment, where a robotic storage/retrieval vehicle capable of travel in three dimensions provides the sole means of storage unit conveyance throughout an entire order picking operation, from the initial retrieval of the storage unit from anywhere in the three dimensional space of the three-dimensional grid structure **17**, through delivery of the storage unit **16** to the working station **18**, including presentation of the storage unit **16** to a human or robot picker at the working station **18**, and subsequent return of the storage unit **16** back into any three dimensional location in the three-dimensional grid structure **17**, without the storage unit **16** ever being offloaded from the robotic storage/retrieval vehicle **14** and conveyed by a separate conveyor, turntable or other transitional mechanism.

[0128] FIGS. **4** through **6** illustrate one of the working stations **18** in isolation from the three-dimensional storage grid **17**. Each working station **18** features a gridded lower track **36** featuring a pair of longitudinal rails **38***a*, **38***b* running a length of the working station **18**. The gridded lower track **36** also features a set of cross rails **40***a*-**40***f* perpendicularly interconnecting the longitudinal rails **38** with one another at regularly spaced intervals therealong. These rails are of the same type used in the gridded upper and lower track layouts of the three-dimensional grid structure **17**, and the spacing between the longitudinal rails matches the spacing between the cross rails and is equal to the inter-rail spacing employed between the rails of the upper and lower track layouts of the grid structure **17** in both the X and Y directions thereof. Accordingly, the lower track of the working station **18** can be traversed by the robotic storage/retrieval vehicles **14** in the same manner as the upper and lower track layouts of the three-dimensional grid **17**. The gridded lower track **36** of the working station **18** is supported in slightly elevated relation above ground level by supports leg **30** depending downward from the gridded lower track **36** at the intersection points of the longitudinal rails **38** and cross rails **40**. These support legs **30** are of the same type and height as those that support the lower track layout of the three-dimensional grid **17**, whereby the gridded lower track **36** of the working station **18** resides at the same elevation as the lower track layout **28** of three-dimensional grid structure **17** to form a coplanar extension track extending therefrom.

[0129] The working station **18** features a chute **42** mounted to the gridded lower track **36** and spanning longitudinally end-to-end thereof from a first one of the cross-rails **40***a* at a first end of the longitudinal rails **38** to a last one of the cross-rails **40***f* at a second opposing end of the longitudinal rails **38**. The chute **42** features a first end wall **44** standing upright from the first cross-rail **40***a*, a second end wall **46** standing upright from the last cross-rail **40***f* in opposing and parallel relation to the first end wall **44**, a longer outer side wall **48** spanning longitudinally between the end walls **44**, **46** in perpendicular relation thereto at an outer one **38***b* of the longitudinal rails, and a top cover panel **50** spanning longitudinally between the end walls and along the top edge of the outer side wall. An underside of the top cover panel **50** defines an interior ceiling of the chute **42**, while an opposing topside of the top cover panel **50** defines an external countertop **50***a* for exploit by human or robotic workers during picking, restocking or other work functions that may be performed at the working station **18**.

[0130] Each square area delimited between the two longitudinal rails **38***a*, **38***b* and any adjacent pair of the cross rails **40***a*-**40***f* is referred to as a respective “spot” along the lower track of the working station. The spot located immediately adjacent the first end wall **44** of the chute **42** and bound between the first and second cross rails **40***a*, **40***b* at the first end of the chute is referred to as an entrance spot S.sub.EN of the working station **18**, as it is here that a robotic storage/retrieval vehicle **14** enters the chute by riding onto these first and second cross rails **40***a*, **40***b* from a respective pair of rails aligned therewith in the lower track layout **28** of the grid structure **17**. At the opposing second end of the chute **42**, the spot located immediately adjacent the second end wall **46** between the second-last and last cross rails **40***e*, **40***f* is referred to as an exit spot S.sub.X, as it is here that the robotic storage/retrieval vehicle **14** exits the chute **42** and re-enters the three-dimensional grid **17** by riding off these last and second-last cross-rails onto another respective pair of rails aligned therewith in the lower track layout **28** of the grid structure **17**.

[0131] Referring to FIG. **3**, the working station **18** on the right side of the figure has its longitudinal direction running in the Y-direction of the grid structure's lower track layout **28**, such that this working station **18** has its longitudinal rails **38***a*, **38***b* of lying in the Y-direction and its cross rails **40***a*-**40***f* lying the X-direction. The first and second cross-rails **40***a*, **40***b* of the working station's gridded lower track **36** form parallel, in-line extensions of a first pair of X-direction rails of the grid structure's lower track layout **28**, and the last and second last **40***e*, **40***f* cross rails likewise form parallel, in-line extensions of a second pair of X-direction rails of the grid structure′ lower track layout **28**. Accordingly, a robotic storage/retrieval vehicle **14** can ride along a pair of X-direction rails of the lower track layout **28** through the uncladded open space **34** between the two upright frame members **12** at the ends of these rails at the outer side of the grid structure **17** at which the working station **18** resides, and onto the first and second cross rails **40***a*, **40***b* at the entrance spot S.sub.EN of the working station **18**. At this entrance spot S.sub.EN, the robotic storage/retrieval vehicle **14** transitions from an X-direction travel mode into a Y-direction travel mode, and can then travel along the working station's longitudinal rails **38***a*, **38***b* in the Y-direction to the exit spot S.sub.X of the working station **18**. Here, the robotic storage/retrieval vehicle **14** then transitions back into its X-direction travel mode to ride atop the last and second last cross rails of the working station **18** back onto the second pair of X-direction rails of the lower track layout **28** of the grid structure **17** through the uncladded open space **34** between the upright frame members **12** at the ends of these rails.

[0132] The working station **18** on the left side of FIG. **3** has its longitudinal direction running in the X-direction of the grid structure's lower track layout **28**, such that this working station **18** has its longitudinal rails **38***a*, **38***b* lying in the X-direction and its cross rails **40***a*-**40***f* lying the Y-direction. The first and second cross-rails **40***a*, **40***b* of the working station's gridded lower track **36** form parallel, in-line extensions of a first pair of Y-direction rails of the grid structure's lower track layout **28**, and the last and second last **40***e*, **40***f* cross rails likewise form parallel, in-line extensions of a second pair of Y-direction rails of the grid structure's lower track layout **28**. Accordingly, a robotic storage/retrieval vehicle **14** can ride along a pair of Y-direction rails of the lower track layout **28** through the uncladded open space **34** between the two upright frame members **12** standing upright from the ends of these rails at the outer side of the grid structure **17** at which the working station **18** resides, and onto the first and second cross rails **40***a*, **40***b* at the entrance spot S.sub.EN of the working station **18**. At this entrance spot S.sub.EN, the robotic storage/retrieval vehicle **14** transitions from the Y-direction travel mode into the X-direction travel mode, and can then travel along the working station's longitudinal rails **38***a*, **38***b* in the X-direction to the exit spot S.sub.X of the working station **18**. Here, the robotic storage/retrieval vehicle **14** then transitions back into its Y-direction travel mode to ride atop the last and second last cross rails of the working station **18** back onto the lower track layout **28** of the grid structure **17** on the second pair of X-direction rails through the uncladded open space **34** between the upright frame members **12** at the ends of these rails.

[0133] Between the second cross rail **40***b* and second last cross rail **40***e* of each working station are a plurality of intermediate spots between the entrance S.sub.EN and exit S.sub.X spots. The illustrated example features three intermediate spots, but this number may vary. One of these intermediate spots, particularly the second last spot immediately neighbouring the exit spot S.sub.X in the illustrated example, is designated as an "access spot" S.sub.A at which the robotic storage/retrieval vehicle **14** is accessible by the human or robotic worker via an access opening **52** penetrating through the top panel **50** of the chute **42** from the countertop surface **50***a* thereof into the interior space of the chute **42**. Accordingly, when the storage/retrieval vehicle **14** travelling longitudinally through the chute **42** arrives and stops at the access spot S.sub.A, the worker can interact with a storage unit **16** carried atop said storage/retrieval vehicle **14**, for example to pick one or more individual items from the storage unit **16** as part of an order fulfilment process withdrawing such items from the grid structure **17**, to instead remove the entire storage unit **16** from the storage/retrieval vehicle **14** as part of such an order fulfillment process, or to instead place one or more individual items into the storage unit **16** as part of a restocking process replenishing the grid structure **17**. Alternatively, a restocking process may involve directing an empty one of the robotic storage/retrieval vehicles **14** (i.e. a vehicle currently unoccupied by a storage unit) to the access spot S.sub.A of the working station **18** to pick up a storage unit **16** from the worker through the access opening **52**.

[0134] The working station **18** is equipped with a hand-sensing mechanism **53** to protect human workers from potential injury as they interact with the storage/retrieval vehicle **14** through the access opening **52**. With reference to FIG. **6**A, first and second sensor bars **54**, **56** are affixed to the underside of top cover panel **50** of the working station **18** in positions lying along opposing perimeter edges of the access opening **52**. The sensor bars **54**, **56** carry optical beam emitters and receivers in opposing relation to one another on the two bars **54**, **56** so that beams emitted by the emitters are received by the opposing receivers unless the beam is interrupted, for example by insertion of a worker's hand(s) into the access opening **52**, or the presence of any other object in the access opening **52**. As opposed to emitters and receivers on opposing sides of the access opening **52**, the sensor configuration may employ emitters and receivers on the same side of the access opening **52**, and reflectors on the opposing side thereof. The sensor bars **54**, **56** communicate, through wired or wireless connection, with a computerized control system that wirelessly communicates with the fleet of robotic storage/retrieval vehicles **14** to control conveyance thereof throughout the grid structure **17** to perform various tasks (picking, restocking, etc.). Continuity of the hand sensor beams, also collectively referred to as a light curtain, generates a "safe" signal, whereas interruption of the sensor beams generates a "stop" signal. Transmission by the computerized control system to a storage/retrieval vehicle **14** of any movement instruction that commands said storage/retrieval vehicle **14** to move into or out of the access spot S.sub.A of a working station **18** is conditional on detection of a "safe" signal from the hand sensing mechanism **53** of that working station **18**. This way, safety procedures can be implemented under which no robotic storage/retrieval vehicle **14** is ever driven along the gridded lower track **36** of the working station **18** while a worker's hand is inside the chute **42**.

[0135] In addition to serving a safety purpose, the hand/object sensing mechanism **53** may also be operable for quality assurance purposes helping ensure human working accuracy in their picking tasks. For a given order for which a predetermined quantity of items is known to be required from a given storage unit **16**, the computerized control system can count the number of times the optical beams are broken while that storage unit **16** is present at the access spot S.sub.A, thus representing a count of how many times the workers hands were inserted through the access opening **52** to access the storage unit **16** and pull a respective item therefrom. The system compares the hand-insertion count against the predetermined quantity of items known to be required from that storage unit **16** (aka, a "line item quantity" from the order being filled), and only permits the storage/retrieval vehicle **14** on which that storage unit **16** is carried to depart the access spot S.sub.A of the working station **18** once the hand-insertion count has reached the predetermined item quantity associated with that storage unit.

[0136] Similar count checks can be performed on other tasks that may be performed at the access opening **52** of the working station **18**, for example during restocking or kitting operations, where instead of picking items from the storage unit **16** parked under the access opening **52**, items are placed or dropped into the parked storage unit **16** through the access opening **52**. Accordingly, each break of the light curtain beams by either a user's hand reaching down to place an item into the storage unit **16**, or by an item dropped into the storage unit **16** from above the light curtain, can likewise be used to count the quantity of items deposited into the storage unit **16**. Accordingly, since the sensing mechanism **53** is operable to detect not only hands, but any objects, the computerized control system can count the number of positive "detections" at the access opening **52**, whether each detection is detected insertion of a user's inserted hand, or detection of another object passing through the opening **52** during placement or retrieval of that object into or from the storage unit **16** parked under the access opening **52**. Either way, the counting of positive detections by the hand/object sensing mechanism **53** is useful to monitor progress and completion of assigned tasks at the working station **18**.

[0137] The hand/object sensing mechanism **53** also serves as a height-check on the storage unit **16** to ensure that no items therein are protruding notably upward from the top of the storage unit **16**, as such protruding items will break the light curtain formed by the optical beams, and such detection of protruding items can thus be used to prevent departure of the storage/retrieval vehicle **14** and the storage unit **16** thereon from the access spot S.sub.A until the protrusion is rectified. This helps ensure that the storage unit **16** will not attempt to re-enter the storage grid **17** with one or more items protruding therefrom and interfering with the available travel spaces between the framework components of the grid structure **17**, thus potential causing damage to the protruding item(s) and/or the storage unit **16**, vehicle **14**, or grid structure **17**.

[0138] In addition to the hand/object sensing mechanism **53**, two movement sensors **58**, **59**, visible in FIG. **6**, are each installed within the workstation **18** for the purpose of detecting movement of a storage retrieval vehicle **14** at or adjacent the access spot S.sub.A. One movement sensor **58** resides just outside the access spot S.sub.A in close adjacency thereto at a side thereof closest to the entrance spot S.sub.EN, and thus resides at a neighbouring lead-in spot S.sub.L from which storage/retrieval vehicles **14** enter the access spot S.sub.A during their travel through the working station **18**. This first movement sensor **58** therefore serves as a lead-in movement sensor operable to detect movement of a storage/retrieval vehicle **14** into the access spot S.sub.A. The other movement sensor **59** resides at or closely adjacent the opposing side of the access spot S.sub.A nearest the exit spot S.sub.X, and therefore serves as a departure movement sensor operable to detect departure of a storage/retrieval vehicle **14** from the access spot S.sub.A into the exit spot S.sub.X, from which it then exits the working station **18** and re-enters the three-dimensional storage grid **17**. Each movement sensor **58**, **59** may be a reflective optical sensor, having an emitter/receiver combination at one side of the working station's gridded lower track **36** so as to be able to detect reflected light off a passing storage/retrieval vehicle **14**. Time of flight calculation (i.e. difference in time between emission of an optical pulse and detection of the reflected optical pulse) may be used to differentiate between reflection off a storage/retrieval vehicle **14** passing by the sensor on the working station's gridded lower track **36**, versus reflection off another object further away. A reflection detected by the receiver within a timed threshold would thus generate a positive "movement detected" output signal from the sensor, whereas a lack of detected reflection within the timed threshold would generate a negative output signal denoting an absence of detected movement. Alternatively, an optical beam sensor may be used to direct a beam across the gridded lower track **36** of the workstation **18** between an emitter at one side and cooperating receiver at the other, or with an emitter/receiver at one side and cooperating reflector at the other. In such instance, an intact status of the beam would denote a negative output signal (absence of movement), and an interrupted status of the beam would denote a positive output signal (detected movement).

[0139] The sensors **58**, **59** are positioned so that a vehicle statically occupying the access spot S.sub.A, lead-in spot S.sub.L, or exit spot S.sub.X will not reflect an optical pulse or break an optical beam, i.e. that pulse reflection or beam interruption at the lead-in sensor **58** will only occur if a vehicle **14** starts transitioning from the lead-in spot S.sub.L to the access spot S.sub.A, and pulse reflection or beam interruption at the departure sensor **59** will only occur if a vehicle **14** starts transitioning from the access spot S.sub.A to the exit spot S.sub.X. This can be seen in FIG. **6**, where each movement sensor **58**, **59** is supported above the gridded lower track **36** at an elevation between the top of the vehicle's wheels, and the underside of an overhanging perimeter portion of the vehicle's upper platform that overhangs the underlying frame or chassis of the vehicle **14**. When a vehicle **14** is parked statically on the lead-in spot S.sub.L or the access spot S.sub.A, the respective lead-in sensor **58** or departure sensor **59** is aimed at an open vertical space between the vehicle wheels and overhanging perimeter portion of the vehicle platform at a respective side of the vehicle chassis, whereby neither movement sensor **58**, **59** is triggered by a statically parked vehicle position. As outlined below, these movement sensors **58**, **59** are useful for the purpose of distinguishing between situations where a positive detection signal from the hand/object sensing mechanism **53** is not problematic due to an absent of vehicle movement under the access opening **52**, versus potentially hazardous situations posing potential injury to a worker or damage to items or equipment by a moving vehicle **14**.

[0140] FIG. **23** shows a block diagram of the computerized control system **500** and cooperating computerized componentry of each robotic storage/retrieval vehicle **14**. The computerized control system comprises a computer network that includes a master control system **502** comprising one or more computers with one or more processors, and non-transitory computer readable memory coupled thereto and on which are stored statements and instructions executable by said one or more processors to logically control various associated tasks described herein, including generation of command signals for the fleet of robotic storage/retrieval vehicles **14**, and for receiving and interpreting feedback communications therefrom. The computer network further includes a plurality of workstation control systems **504**, each installed at a respective one of the working stations **18**. For illustrative convenience, the block diagram shows only a singular workstation control system **504** and singular robotic storage/retrieval vehicle **14**.

[0141] Each workstation control system **504** features a local computer **506**, which may be embodied, for example, in a programmable logic controller (PLC), with an I/O interface by which the local computer **506** can communicate with the hand/object sensing mechanism **53** of the working station **18**, the lead-in and departure movement sensors **58**, **59** of the working station **18**, a respective lifting mechanism **72** described herein further below. The local computer **506** of the working station **18** also has a human-machine interface (HMI) **508** coupled thereto, preferably including at a least a display monitor **510**, which optionally may be a touch screen monitor, thus serving as both a display and input device of the HMI **508**, though other input devices such as a computer keyboard, mouse, trackball, dedicated control buttons, etc. may additionally or alternative be employed. In addition or alternative to a display monitor **510** presenting a graphical user interface (GUI) for the purpose of displaying directive instructions to a human worker of the workstation **18** according to the given task assigned thereto, other worker guidance equipment may be employed, for example a pick-to-light system guiding picking of items from different compartments of compartmentalized storage units **16** having different item types therein during execution of a picking task, a put-to-light system guiding placement of items into different compartments of compartmentalized storage units **16** during execution of an inventory restocking or kitting task, simplified non-GUI displays (e.g. numeric LCD display) for display line item quantities, etc. The local computer **506** of the working station **18** comprises one or more computer processors, non-transitory computer readable memory coupled thereto and on which are stored statements and instructions executable by said one or more processors to perform the various associated tasks described herein in relation to the HMI **508**, hand sensing mechanism **53**, movements sensors **58**, **59**, and a respective one of the lifting mechanisms **72** that neighbours that working station **18**. The local computer **506** of each working station **18** is also communicable with the master control system **502** by way of a wired or wireless connection, to receive details of the tasks to be guided and performed at the working station **18**, and to report back to the master control system **502** on the status of such tasks, and with safety warnings warranting action by the master control system **502**.

[0142] Each robotic storage/retrieval vehicle **14** has a local computer processor **512** carried onboard thereof, connected to a local onboard transceiver **514** of the vehicle that is wirelessly communicable with a main transceiver **516** of the master control system **502** to enable receipt of command signals therefrom and transmission of feedback communications back thereto. A non-transitory computer readable memory on each robotic storage/retrieval vehicle **14** is connected the onboard local processor **512** thereof for execution of statements and instructions stored in said memory, particularly to execute local functions for the purpose of navigating the storage system **15** and interacting with the storage units **16** thereof, based on commands received from the master control system **502**, and for the purpose of reporting back to the master control system **502** with feedback on the completion of the commanded tasks. To enable the performance of the commanded tasks, the local processor **512** of the vehicle **14** is connected to an onboard I/O interface by which the processor **512** can execute control over various electronic componentry of the vehicle **14** (motors, actuators, sensors, etc.) responsible for travelling movement of the vehicle **14** in the storage grid **17** and working stations **18**, and interactions of the vehicle **14** with the storage units **16**. In the illustrated embodiment, such componentry includes wheel drive motors **524** for driving rotation of the vehicle's wheel units, wheel lifting/lowering motor(s) **526** for controlled raising and lowering of the vehicle's height adjustable wheel set, wheel shifting motors or actuators **528** for controlling inboard/outboard shifting of the wheel units, a turret motor **530** to controlling rotation of the vehicle's turret, an arm actuator **532** for controlling extension/retraction of the extendable/retractable turret arm, a shuttle motor **534** for controlling linear movement of a movable shuttle back and forth along the turret arm, and a set of load status sensors **100** described further below. The local processor **512** is also connected to an onboard scanner **66** of the vehicle **14** for the functions and purpose described in greater detail below.

[0143] FIG. **6**B illustrates cooperative execution of both safety and task monitoring control logic by the processors of the computerized control system **500** and storage/retrieval vehicles **14** in connection with the hand/object sensing mechanism **53**. The local computer **506** (workstation controller **506**, for short) of each working station control system **504** continuously monitors the condition of the hand/object sensing mechanism **53** for a detection signal. A positive detection by the sensing mechanism **53** at Step **1001** generates an input signal to the workstation controller **506** at Step **1002**, in response to which the computerized control system **500**, at Step **1003**, checks for the presence of any storage/retrieval vehicle **14** in the working station **18** at which the detection occurred.

[0144] This check for vehicle presence may be executed by the master control system **502**, which preferably stores dynamically updated location records for all vehicles of the fleet, with the local processor **512** of each vehicle **14** being configured to automatically report back to the master control system **502** successful completion of a vehicle travel task commanded thereby, so that the master control system **502** knows the vehicle reached **14** its targeted destination spot for that travel task, and records this confirmed location in the vehicle's dynamic location record. Travel tasks are commanded in straight line segments (i.e. any required travel from a starting spot to a final destination that requires movement in two or more dimensions is broken down into linear unidirectional travel segments). So, anytime the master control system **502** commands a storage/retrieval vehicle **14** to a working station **18**, this will involve, at some point, a command of

a straight-line travel segment whose targeted destination spot is the entrance spot of that workstation **18**, followed by one or more straight-line travel segments then commanded to advance the vehicle along the lower track of the workstation **18** toward, or fully to, the access spot S.sub.A depending on the occupied or unoccupied state of the access spot S.sub.A and intermediate spots. Once presence of the vehicle **14** is no longer needed at the access spot S.sub.A, the master control system **502** commands another straight-line travel segment to move the vehicle **14** one spot over to the working station's exit spot S.sub.X, followed by another straight-line travel segment in the other direction to move the vehicle **14** from the working's station's **18** exit spot S.sub.X back into the storage grid **17**. Accordingly, to check whether any vehicle **14** is in a workstation **18**, the master control system **502** can search the dynamic location records of all vehicles for a vehicle whose last recorded location was any of the entrance, intermediate, access S.sub.A, or exit spots S.sub.X of the working station **18**. This is only one example however, and other techniques for confirming the presence or absence of a vehicle **14** in the working station **18** may be employed, for example using occupancy sensors in the working station **18**, in which case, checking for the presence of any vehicle **14** in the working station **18** at step **1003** may be performed locally by the workstation control system **504**.
[0145] If it is determined that no vehicle **14** is present in the subject working station **18**, then the positive detection by the hand/object sensing mechanism **53** is ignored at step **1004**, as the lack of vehicle **14** at the working station **18** means that a user's hand inserted in the access opening **52** is not at risk for collision by a vehicle **18**, nor is there a storage unit **16** present at the access opening **52** for which it would be useful to count detections by the hand/object sensing system to track line item quantities being picked or placed in the storage unit **16**. However, if it is determined that one or more vehicles **16** are present in the working station **18**, then at step **1005**, a check is made for static occupation of the access spot S.sub.A of the working station **18** by a vehicle **14**, for example by checking the status of the movement sensors **58**, **59** installed in the working station **18** adjacent the access spot S.sub.A thereof, and checking the dynamic vehicle location records of the vehicles **14** in the workstation **18**. If those dynamic vehicle location records include one whose currently stored value is a unique identifier of that working station's **18** access spot S.sub.A, and there is no detected movement from the movement sensors **58**, **59**, then a positive determination is made that a vehicle **14** is statically parked at the access spot S.sub.A.
[0146] In response, at step **1006**, the computer control system **500** checks for whether the workstation control system **504** has an open task (whether a picking, replenishment, or kitting task) for which a remaining quantity of items to be picked from or placed in the parked storage unit **16** (a remaining “line item quantity” of the picking, kitting or restocking order) is greater than zero. If yes, then at step **1007** the computer control system **500** decrements the remaining line quantity by one, based on which a dynamically displayed line quantity shown on the HMI **508** to the human worker is likewise decremented by one in synchronous fashion, so that the worker is visually informed of how many additional items are to be picked from or placed in the parked storage unit **16**. If the line item quantity was already zero, then at step **1008**, the computer control systems **500** displays an error message on the HMI **508**, thereby notifying the worker that they may have made an error by exceeding the prescribed line item quantity to be picked from, or placed in, the storage unit **16** parked at the access spot S.sub.A. The worker can thus double check the actual item quantity they picked or placed, and make appropriate correction to match the assigned line quantity of the order.
[0147] If the determination at Step **1005** is that there is no vehicle **14** parked statically at the access spot S.sub.A, then at Step **1009**, the movement sensors **58**, **59** of the working station **18** are monitored for detected vehicle movement. Absent any movement, operation of the system continues in normal fashion. However, once the movement sensors **58**, **59** detect movement near the access spot S.sub.A at Step **1010**, thus representing a risk of injury to a workers hand by a storage bin entering or departing the access spot S.sub.A, or risk of damage to items or equipment

by due to an item protruding upward from a storage bin trying to depart the access spot S.sub.A, an emergency stop signal is instantly transmitted from the workstation control system **504** to the master control system **502**, which in turn transmits an emergency stop command to the vehicle(s) **14** in the working station **18** at Step **1011**. Accordingly, any vehicle **14** about to move into the access spot S.sub.A, if previously unoccupied, or any vehicle **14** attempting to depart the access spot S.sub.A from its previously static position parked thereat, is immediately stopped at Step **1012** to prevent injury or damage. The vehicle **14** reports its successful emergency stop back to the master control system **502**, in response to which the master control system **502** may halt all vehicle travel commands to the vehicle(s) **14** at the subject working station **18** until such time as the workstation control system **504** reports that light curtain is re-established to an unbroken state, and an appropriate worker-performed reset action is undertaken and confirmed, for example requiring a two-handed input at the HMI **508** of the working station **18** to ensure that neither hand of the worker is in peril once vehicle travel is reinitiated. After this reset, normal operation is reinitiated, and the FIG. **6**B procedure can be repeated. At any time when a positive detection signal from the hand/object sensing mechanism is present, the master control system **502** will not command or allow any storage retrieval vehicle **14** travel into, or out of, the access spot S.sub.A of the working station **18**.

[0148] While FIG. **6**B illustrates a procedure combining both safety check and quantity count functionality, it will be appreciated that other embodiments need not necessarily use the hand/object sensing mechanism **53** for quantity counting, as illustrated by the simplified safety procedure in FIG. **6**C, which simply omits steps **1005-1008** of FIG. **6**B. As an extra precaution, the movement detection actions of steps **1009** and **1010** may also be performed between steps **1002** and **1003**, with a negative “no movement detected” determination leading onward to step **1003**, and with a positive “movement detected” determination leading to the emergency stop steps **1011-1013**. This way, the combination of a positive hand or object detection at the access opening **52** together with movement detection inside the workstation **18** at or adjacent the access spot S.sub.A will always result in an emergency stop, even if the control system **500** doesn't currently indicate the presence of a vehicle **14** in the workstation **18**. It will be appreciated that the same safety functionality and/or quantity counting functionality using a light curtain or other hand/object sensing mechanism **53** in an access opening **52** of a working station **18** through which storage units **16** are travelling could similarly be employed in working stations **18** in which the travel of the storage units **16** through the working station **18** is not necessarily effected by robotic storage/retrieval vehicles **14** from the storage grid **17**, and for example could be employed in workstations **18** using conveyor-based through-routing of the storage units **16** past an access spot S.sub.A underlying a similarly equipped access opening **52**.

[0149] While FIGS. **4** through **6** show the inner longitudinal rail **38***a* as part of the isolated working station **18**, it will be appreciated that this rail is shared with the lower track layout **28** of the grid structure **17** when the working station **18** is installed at the grid structure **17**. With reference to FIG. **3**, the inner longitudinal rail **38***a* of the working station **18** on the right side of the figure is an in-line section of the Y-direction perimeter rail **26** at the respective side of the grid structure's lower track layout **28**. The outer rail of that working station **18** lies parallel to the Y-direction perimeter rail of the grid structure's lower track layout **28**, and the cross-rails of the working station **18** connect the Y-direction perimeter rail **26** of the lower track layout **28** to the outer longitudinal rail **38***b* of the working station **18** at positions in-line with and joined to the X-direction rails of the lower track layout **28**. Likewise, the inner longitudinal rail **38***a* of the working station **18** on the left side of the figure is an in-line section of the X-direction perimeter rail **24** at the respective side of the grid structure's lower track layout **28**. The outer rail **38***b* of that working station **18** lies parallel to the X-direction perimeter rail of the grid structure's lower track layout **28**, and the cross-rails of the working station **18** connect the X-direction perimeter rail of the lower track layout **28** to the outer longitudinal rail **38***b* of the working station **18** at positions in-line with and joined to the Y-direction rails of the lower track layout **28**.

[0150] The gridded lower track **36** of each working station **18** is thus an extension track connected to the lower track layout **28** of the three-dimensional grid structure **17** in a position running alongside the lower track layout **28** to allow seamless transition of the robotic storage/retrieval vehicles **14** between the three-dimensional grid **17** and the working station **18** situated outside the two-dimensional footprint occupied by the upper and lower track layouts and the columns **11** and shafts **13** spanning therebetween. The transition of the vehicles **14** between the lower track layout **28** of the three-dimensional grid **17** and the working station **18** takes place through the working station **18** entrance spot S.sub.EN situated at one end of the working station's **18** gridded lower track **36** and the working station **18** exit spot S.sub.X situated at an opposing second end of the working station's **18** gridded lower track **36**. By way of the computerized control system **500**, the robotic storage/retrieval vehicles **14** are driven through the working stations **18** in a unidirectional manner from the dedicated entrance to the dedicated exit, which allows multiple vehicles **14** to be queued inside the working station **18**, thus reducing traffic obstruction on the lower track layout **28** of the three-dimensional grid **17**. In the illustrated example, the use of separate entrance spots S.sub.EN and exit spots S.sub.X and inclusion of one or more intermediate spots in each working station between the entrance spots S.sub.EN and exit spots S.sub.X thereof increases this internal queueing capacity of each working station **18**.

[0151] However, the use of separate entrance spots S.sub.EN and exit spots S.sub.X, inclusion of one or more intermediate spots between the entrance spots S.sub.EN and exit spots S.sub.X, and placement of the access opening **52** at a dedicated spot other than the entrance spots S.sub.EN or exit spots S.sub.X are optional features, and may be omitted altogether or in various combinations. For example, in one alternative embodiment, the gridded lower track **36** of the working station **18** may be as simple as two cross-rails extending from the lower track layout **28** to define a single spot over which the access opening **52** resides, thus serving as an entrance spot S.sub.EN, exit spot S.sub.X, and access spot S.sub.A of the working station **18** all at one singular spot on the track layout. The robotic storage/retrieval vehicle **14** would ride forwardly onto this single-spot extension track in the X or Y direction perpendicular to the perimeter rail at the side of the lower track layout **28**, receive interaction with the worker through the access opening **52**, and then exit the working station **18** in a reverse direction back onto the lower track layout **28** of the three-dimensional grid **17**. Accordingly, the extension track need not necessarily be elongated along the perimeter of the lower track layout **28** of the grid structure **17** like in the illustrated embodiment, and the enclosure need not necessarily be an elongated chute having spaced apart entrance and exit points at longitudinally spaced locations of the working station's lower track. In another example, an elongated extension track like that of the illustrated embodiment may be used together with a chute **42** that is open along the entire inner side thereof, as shown in in the drawings, thus allowing any of the multiple spots along the extension track to serve as an entrance spot S.sub.EN and/or exit spot S.sub.X.

[0152] FIG. **7** schematically shows an overhead plan view of one of the working stations **18**, and a neighbouring area of the lower track layout **28** of the three-dimensional grid **17**. As with the working station **18** gridded lower track **36**, the square area denoted between two adjacent X-direction rails and two adjacent Y-direction rails of the lower track layout **28** is referred to as a respective “spot” therein. Each spot underlying a respective down-shaft (a type of shaft **13**) of the three-dimensional grid **17** is designated as a landing spot S.sub.LND at which the robotic storage/retrieval vehicles **14** land on the lower track layout **28** after having travelled vertically downward through the down-shaft. Each spot underlying a respective up-shaft (also a type of shaft **13**) at the outer perimeter the three-dimensional grid **17** is designated as a launching spot S.sub.LCH from which the robotic storage/retrieval vehicles **14** travel upwardly through the up-shaft to the upper track layout **10**. The spot in the lower track layout **28** of grid structure **17** that neighbours the entrance spot S.sub.EN of the working station **18** is referred to as an emergence spot

S.sub.EM from which the robotic travel vehicle **14** exits the lower track layout **28** of the three-dimensional grid **17** and enters the working station **18** at the entrance spot S.sub.EN thereof. The spot in the lower track layout **28** of grid structure **17** that neighbours the exit spot S.sub.X of the working station **18** is referred to as a re-entry spot S.sub.R from which the robotic travel vehicle **14** re-enters the three-dimensional grid **17** from the exit spot S.sub.X of the working station **18**. Arrows in the figure show the travel path followed by a robotic storage/retrieval vehicle **14**, first travelling outward from the emergence spot S.sub.EM of the lower track layout **28** into the entrance spot S.sub.EN of the working station **18**, then travelling longitudinally through the access spot S.sub.A for interaction with the worker, before moving longitudinally into the exit spot S.sub.X and then transitioning back into the lower track layout **28** at the re-entry spot S.sub.R thereof.

[0153] One or both of the emergence spot S.sub.EM and re-entry spot S.sub.R may be a multi-purpose spot, for example also serving as a landing spot S.sub.LND or launching spot S.sub.LCH under a respective down-shaft or up-shaft, as shown in the illustrated example where the re-entry spot S.sub.R is also a landing spot S.sub.LND. All other spots in the area of the lower track layout **28** neighbouring the working station **18** underlie respective storage columns **11** of the three-dimensional grid structure **17** in which the storage units **16** are shelved. These spot serve as available parking spots S.sub.P in which a robotic storage/retrieval vehicle **14** carrying a respective storage unit **16** can be selectively parked after landing on the lower track layout **28** at the landing spot S.sub.LND at the bottom of the down-shaft from which the robotic storage/retrieval vehicle **14** retrieved said storage unit **16** in the event that there is another robotic storage/retrieval vehicle **14** that is destined for the same working station **18** and whose travel to said working station **18** has been assigned, by the computerized control system **500**, a greater priority ranking than the robotic storage/retrieval vehicle **14** being parked. Selection by the computerized control system **500** of a particular spot at which to park one of the storage/retrieval vehicles **14** may be based on an available least-distance travel path to the working station entrance from a particular one of the designated landing spots S.sub.LND at which the parking storage/retrieval vehicle **14** arrived at the lower track layout **28**.

[0154] Accordingly, the computerized control system **50** responsible for assigning tasks to the robotic storage/retrieval vehicles **14** and controlling navigation thereof through the three-dimensional grid **17** and working stations **18** can orchestrate arrival of a group of occupied vehicles (i.e. vehicles **14** carrying respective storage units **16** thereon) to the assigned working station **18** for which those storage units **16** are destined in a sequence that doesn't necessarily match the sequence in which the task were assigned (i.e. the assignment sequence), the sequence in which those storage units **16** were retrieved (i.e. the retrieval sequence) from their respective storage locations, the sequence in which the occupied vehicles landed at the lower track layout **28** (i.e. the landing sequence), and/or the sequence in which the occupied vehicles initially arrived into a vicinity of the emergence spot S.sub.EM adjacent the assigned working station **18** (i.e. the arrival or approach sequence)

[0155] In one illustrative example, a picking operation is executed by the computerized control system **500**, and involves assigning a first group of one or more vehicles **14** to retrieve one or more respective storage units **16** each containing a different item for a first customer order and deliver said storage units **16** to a particular working station **18**, and a second group of one or more vehicles **14** assigned to retrieve one or more storage units **16** each containing a different item for a second customer order for delivery to the same working station **18**. Due to differences in travel distance from the initial location of each vehicle **14** to the assigned working station **18** via an available retrieval location at which a storage unit **16** containing the appropriate item is stored (of which there may be multiple options, in which case priority may be given based on shortest overall travel path from the robotic storage/retrieval vehicle's current location to the assigned working destination via the different retrieval location options), vehicles **14** from the two groups may arrive at the lower track layout **28** with their retrieved storage units **16** and approach the assigned working station **18** in a mixed order. Here, the computerized control system **500** can assign priority rankings on which to sequence the entry of the two groups of vehicles **14** into the working station **18**, and instruct lower priority vehicles **14** to park themselves at currently unoccupied parking spots S.sub.P of the lower track layout **28**.

[0156] The assigned priority ranking may be based at least partly on a “grouped delivery” basis so that all items for one order are delivered prior to any item for the other order. Further weighting may be based on a “first landing” or “first arrival” basis, where the first vehicle **14** landing at the lower track layout **28** or approaching the assigned working station **18** dictates which of the two vehicle groups is prioritized over the other in the “grouped delivery” sequence, or on an “order priority” basis where the orders are ranked by priority due to size (i.e. picking larger orders before smaller ones), shipment destination (picking orders destined for more remote destination before more local destinations), delivery deadlines, customer types, shipment vehicle availability, etc. So, depending on the ranking criteria selected, all items of the first order may be delivered to the access spot S.sub.A of the working station **18** before any item of the second order, or vice versa, regardless of the particular sequence in which the two orders were received by the system. Alternatively, a large order requiring a high number of storage units **16** for complete fulfillment may have its queue of robotic storage/vehicles **14** interrupted by one or more robotic storage/retrieval vehicles **14** assigned to a small order in order to pick the entire small order at the working station **18** before returning to continued picking of the larger order.

[0157] Referring again to FIG. **23**, the executable statements and instructions of the software at the master control system **502** includes an order processing module **518**, which receives the details of orders to be fulfilled, for example from a warehouse management system (WM S) or other host system **519**. The received orders may have pre-assigned priority rankings already applied thereto by the WM S or other host system **519**, for example based on customer type, delivery deadlines, order size, distance to shipping destination, scheduled or estimated availably of transport vehicle, etc. One by one in sequential order from highest to lowest priority ranking of the orders, the order processing module **518** breaks each order down into line item tasks that each containing identification (UPC, SKU or other unique identifier) of a particular line item from the order, and the quantity of that item to be picked (i.e. line item quantity). These line item tasks of each order are communicated to a planning module **520**. The planning module **520** compares the unique identifier from each line item task against dynamically updated inventory records of the master control system **502** which contain the currently stored location of each storage unit **16** and the quantity and type of items stored therein. Based on this comparison, the planning module identifies the location in the storage grid **17** at which a storage unit **16** containing that line item is currently stored. The planning module also selects which working station **18** to assign to the current order to, and identifies available storage/retrieval vehicles **14** to which the line item tasks can be assigned, and compiles this information, together with the line item quantities, into a respective a task assignment for each line item task. These task assignments are shared with a task transmission module **522**, which converts the task assignments of the processed order into recognizable commands wirelessly transmitted to vehicles **14** for execution thereby to carry out the assigned tasks. The task assignments are also shared with the workstation control system **506** of the working station **18** to which the processed order was assigned. In addition to the line item quantity, each task assignment may also include identification of the particular item(s) to pick from the storage unit, for example as required in instances where the storage unit is one that contains multiple item types therein.

[0158] On top of the order-based priority ranking, further item-based priority ranking may be applied to the different line items of an individual order, in which case each task assignment also contains an item priority ranking for the line item thereof. Such item-based priority ranking may be based on any of a variety of different item attributes, including style, size, weight, color, ingredients, liquids vs. dry goods, allergens, contaminants, etc. For example, fulfillment of a retail order may require style, color, size runs, etc. that are to be packaged together for sorting convenience at the recipient retailer. Heavier items or liquid goods can be given higher priority so that their earlier delivery to the working station enables packing of the heavier/liquid items into the bottom of a shipping container, followed by placement of subsequently delivered lightweight/dry-good items on top to prevent crushing or liquid contamination of the bottom packed goods. Likewise, allergenic foods can be presented first and packed before non-allergenic foods ever reach the working station **18** to avoid cross-contamination.

[0159] One particular example of orchestrating sequenced delivery of storage units **16** by priority ranking, whether order-based among storage units **16** of different orders or item-based among storage units **16** of a same order, is illustrated in FIGS. **7**A through **7**H, where four storage/retrieval vehicles V.sub.1, V.sub.2, V.sub.3, V.sub.4 are carrying respective storage units, U.sub.1, U.sub.2, U.sub.3, U.sub.4 whose priorities have been ranked by the computerized control system **500** in sequentially decreasing order, such that storage unit U.sub.1 on vehicle V.sub.1 is of greatest priority, and storage unit U.sub.4 on vehicle V.sub.4 is of lowest priority, but whose arrival into proximity with the working station **18** has occurred non-matching sequence to this priority ranking. Referring to FIG. **7**A, vehicle V.sub.4 is the first to land on the lower track layout **28** and approach the emergence spot S.sub.EM thereof. Due to its lowest priority ranking, vehicle V.sub.4 is parked close to the working station **18** entrance spot S.sub.EN, for example at a parking spot S.sub.P adjacent the emergence spot S.sub.EM of the lower track layout **28**. Turning to FIG. **7**B, vehicle V.sub.2 is the next to land on the lower track layout **28** and approach the emergence spot S.sub.EM, and due to its non-highest priority ranking, is also parked at an open parking spot S.sub.P close to the working station **18** entrance spot S.sub.EN, for example adjacent to previously parked vehicle V.sub.4. Turning to FIG. **7**C, vehicle V.sub.3 is the next to land on the lower track layout **28** and approach the emergence spot S.sub.EM, and due to its non-highest priority ranking, is also parked at an open parking spot S.sub.P close to the working station **18** entrance spot S.sub.EN, for example adjacent to previously parked vehicle V.sub.2. Turning to FIG. **7**D, vehicle V.sub.1 is the next to land on the lower track layout **28** and approach the emergence spot S.sub.EM, and due to its highest priority ranking, travels straight into the entrance spot S.sub.EN of the working station **18**, as enabled by the non-obstructive relationship of the parked vehicles V.sub.2, V.sub.3, V.sub.4 to the working station **18** entrance spot S.sub.EN. Turning to FIG. **7**E, vehicle V.sub.1 travels onwardly through the working station chute **42** atop the extension track, and parks at the access spot S.sub.A thereon, thereby delivering the highest ranked storage unit U **1** to the access spot S.sub.A for interaction therewith by a human or robotic worker.

[0160] Turning to FIG. **7**F, having delivered the highest-ranking storage unit U.sub.1 to the access spot S.sub.A of the working station **18**, vehicle V.sub.2 carrying the next-highest ranking storage unit U.sub.2 is then commanded out of its parking spot S.sub.P to the emergence spot S.sub.EM of the lower track layout **28**, onward therefrom to the working station **18** entrance spot S.sub.EN, and onward therefrom toward the working station access spot S.sub.A where vehicle V.sub.1 is current parked. Vehicle V.sub.2 is parked adjacent to the access spot S.sub.A currently occupied by vehicle V.sub.1. Turning to FIG. **7**G, vehicle V.sub.3 carrying the next-highest ranking storage unit U.sub.3 is then commanded out of its parking spot S.sub.P to the emergence spot S.sub.EM of the lower track layout **28**, onward therefrom to the working station **18** entrance spot S.sub.EN, and onward therefrom toward the working station **18** access spot S.sub.A where vehicle V.sub.1 is current parked, and beside which vehicle V.sub.2 is already queued. Vehicle V.sub.3 is parked adjacent the intermediate spot currently occupied by vehicle V.sub.2. Turning to FIG. **7**H, final vehicle V.sub.4 carrying the lowest-ranking storage unit U.sub.4 is then commanded out of its parking spot S.sub.P to the emergence spot S.sub.EM of the lower track layout **28**, and onward therefrom into the working station **18** entrance spot S.sub.EN, next to which vehicles V.sub.2 and V.sub.3 are already queued behind vehicle V.sub.1. Vehicle V.sub.4 is parked at the entrance spot S.sub.EN of the workstation so as to reside adjacent the intermediate spot currently occupied by vehicle V.sub.3. Through the forgoing orchestration of vehicles **14** and their carried storage units **16** by selective parking and advancement of vehicles **14** on the lower track layout **28** according to their priority rank, the four storage units are now queued inside the working station **18** for properly sequenced advancement to the access spot S.sub.A of the working station **18**.

[0161] FIG. **7**I illustrates cooperative execution of control logic by the processors of the computerized control system **500** and storage/retrieval vehicles **14** to perform such orchestration of the vehicles **14** and their carried storage units **16** within the three-dimensional storage grid **17** to achieve the sequenced arrival thereof at the working station **18**. At step **2001**, the master control system **502** generates the task assignments from the line items of a new order of highest priority ranking among those in queue to be processed, then forwards the task assignments to the workstation controller **506**, and transmits the task commands to the storage/retrieval vehicles **14**. At step **2002**, upon receipt of said commands, the vehicles **14** begin their task-prescribed travel paths through the storage grid **17** to retrieve the respective storage units **16** from their storage locations, and carry the retrieved storage bins down to the lower track layout **28** of the three-dimensional storage grid **17**, upon which they subsequently approach the assigned working station **18**. Meanwhile, the workstation controller **506** has stored thereat the task assignments of the new order, together with any remaining as-yet incomplete task assignments of an earlier order, collectively referred to as pending tasks. With such tasks pending, at step **2003**, the computerized control system **500** checks if there is any open spot in the workstation **18** among the entrance spot S.sub.EN, intermediate spots, and access spot S.sub.A thereof. To do this, the workstation controller **506** may query the dynamic vehicle location records of the master control system **502** for the vehicles **14** assigned to the pending tasks, and search these for records for vehicles **14** whose last confirmed location is one of these spots in the workstation **18**. If the query turns up no vehicle match for one or more of these spots, then the workstation **18** knows there is an available spot to fill. Accordingly, this initiates a procedure for the workstation controller **506** to “call” for a next vehicle **14** to enter the workstation **18** in view of the available occupancy therein. Identification of which vehicle **14** to call is performed by the workstation controller **506** based on the order and item priority rankings of the pending tasks.

[0162] The instant example contemplates a scenario where fulfillment of the earlier order is already underway at the working station **18**, and the order priority of the new order is not one that outranks the earlier order. The same approach would also apply where the system is set to follow a “no interruption” workflow, where an order fulfillment already underway is not to be interrupted by another order, even if of greater priority ranking. At step **2004**, the workstation controller **506** determines whether or not all vehicles **14** of the earlier order have already entered the workstation **18**. To do this, the workstation controller **506** may check the pending tasks of the earlier order to identify any vehicles **14** among those assigned to these tasks that have not yet been confirmed to have entered the workstation **18**, for example by querying the master control system's **502** dynamic location records of these vehicles **14** for any whose last confirmed location doesn't match the unique identifier of any of the entrance spot S.sub.EN, intermediate spots, and access spot S.sub.A on the working station's **18** gridded lower track **36**. If the master control system **502** reports back to the workstation controller **506** that the last confirmed locations of all the queried pending-task vehicles **14** of the earlier order are spots in the working station **18**, then the working station controller **506** has confirmed at Step **2004** that all vehicles **14** of the earlier order have already entered the workstation **18**. Having made this positive determination at Step **2004**, Step **2005** is to then call on the vehicle **14** of the highest priority ranked task assignment in the new order. To do so, the workstation controller **506** identifies the pending task assignment of highest priority among the new order's task assignments, and submits a “call request” to the master controls system **502** that identifies the vehicle **14** specified in this identified task assignment. In response, the master control system **502** flags this vehicle **14** as having been summoned or called by the working station **18**.

[0163] As mentioned previously, vehicle travel is commanded in segmented fashion, meaning the overall travel plan used by a vehicle **14** to pick a storage unit **16** and deliver it to the working station **18** is broken down into linear segments. Accordingly, the task commands sent to the vehicles **14** are not one-time commands containing a full set of travel instructions to complete the entire task of retrieval and delivery of a storage unit **16** to a workstation **18**. Instead, the travel instructions are commanded in piecemeal, segment by segment, and the next segment to be commanded can be dynamically selected or reconfigured by the planning module before transmission to the vehicle **14**. Each time a vehicle **14** reaches the end of a commanded segment, it returns a confirmation signal to the master control system **502** that it has completed the last commanded travel segment, in response to which a further command with the instructions for the next linear travel segment are transmitted to the vehicle **14**. The flagging of a vehicle **14** as having been called by the workstation **18** means that when the vehicle **14** sends confirmation of a completed travel segment sometime after having already retrieved the assigned storage unit **16** and landed at the lower track layout **28**, the master control system **502** recognizes that the vehicle **14** should be commanded with a travel route of one or more linear segments leading into the entrance spot S.sub.EN of the workstation **18** that called for this vehicle **14**, and so the planning module **520** calculates such a workstation-destined route, the commands for which are then transmitted to the vehicle **14**. These commands are again transmitted in piecemeal fashion segment-by-segment if the route involves more than one linear segment from the vehicle's **14** last confirmed position on the lower track layout **28** to the entrance spot S.sub.EN of the working station **18**. For example, upon receiving a confirmation signal that a robotic storage/retrieval vehicle **14** has arrived at a landing spot S.sub.LND on the lower track layout **28**, the master control system **502** may use this at the check-point to see whether the vehicle **14** has been flagged/called, and accordingly decide whether to calculate and command a workstation-destined travel route for that vehicle **14**. However, spots on the lower track layout **28** other than the landing spots S.sub.LND may alternatively serve as the check point where this routing decision is made to dynamically update the vehicle's **14** overall travel path to the workstation **18** depending on whether is has yet been called, or should be temporarily parked.

[0164] Once having called the highest-ranking vehicle **14** of the new order, any other vehicle **14** assigned to that same order, but not yet flagged by a call request from the working station **18**, must be parked at Step **2006** to await entry to the working station **18** once another spot opens up. Any such uncalled vehicle **14**, instead of a workstation-destined travel route, is commanded with a holding-pattern travel route dynamically generated by the planning module to instead terminate at an available parking spot S.sub.P outside the working station **18**, but preferably nearby the entrance thereof, where it awaits assignment of called-for status before being re-routed into the workstation **18**. For a parked vehicle **14**, awaiting its turn to enter the workstation **18**, later receipt of the call request for that vehicle **14** by the master control system **502** will trigger immediate calculation and command of its workstation-destined travel route from the parking spot S.sub.P. Steps **2003** to **2005** are then repeated, followed by a check at step **2007** with each repetition on whether all vehicles **14** of the new order have yet been called, for example in the same fashion described above for the earlier order at Step **2004**. Once all vehicles **14** have been called, the process terminates until a subsequent order is tasked to that working station **18**. If determination at Step **2004** was that all vehicles **14** from the earlier order were not yet in the working station **18**, then calling of the highest ranked vehicle **14** of that earlier order and parking of any other landed vehicles **14** in that order, along with parking of all landed vehicles **14** in the new order, are performed at Steps **2008** and **2009** in the same manner described for Steps **2005** and **2006** for the new order, followed by repetition of steps **2003** and **2004**. By using the very same grid structure **17** in which the storage units **16** are arrayed and by which the robotic vehicles **14** navigate the storage array, this internally performed sequence orchestration enables complex sequencing or sortation during order picking operations while avoiding the space and material inefficiencies associated with prior art techniques, such as space intensive sortation conveyors, where the retrieval step is performed by one fleet of machines, and then sortation is performed downstream at a second stage of different machinery or equipment type, before delivering sorted items to assigned working stations **18** situated remotely of the storage structure.

[0165] While the forgoing example specifically uses dedicated up-shafts, dedicated down-shafts, and designated parking spots S.sub.P specifically on the lower track layout **28** for the purpose of selectively parking vehicles **14** after storage unit **16** retrieval on their way to assigned lower level working stations **18** without interfering with flow of other unparked vehicles **14** moving through the three dimensional grid **17**, it will be appreciated that other locales in the three dimensional grid **17** may be used to temporarily park retrieved storage units **16** during the orchestration of sequenced delivery to the working stations **18**. Accordingly, any of the square spots between the X and Y direction rails **24**, **26** of the upper track layout **10** may likewise be used as a temporary parking spot S.sub.P for occupied vehicles **14** during delivery sequence orchestration, just as they may be used to park inactive vehicles **14** awaiting activation by way of operational assignment and instruction from the computerized control system **500**. In such instance, the spots overlying the up-shafts and down-shafts are preferably reserved as drop-down spots for entry to the down-shafts and climb-out spots for exit from the up-shafts, and thus not employed for temporary parking purposes so as not to hinder traffic flow of unparked vehicles **14** through the three-dimensional grid **17**. Likewise, the sequenced delivery orchestration may employ parking of vehicles **14** at any level in the down-shafts and/or up-shafts for the purpose of delaying the arrival of such parked vehicles **14** to the working stations **18** in view of higher priority rankings assigned to the other occupied vehicles **14**, though again, it may be preferable to avoid such obstruction to shaft travel by other vehicles **14**. While select embodiments have specific up-shafts dedicated to only upward traffic flow of the robotic storage/retrieval vehicles **14** and separate down-shafts dedicated to only downward traffic flow, it will be appreciated that other embodiments need not restrict each shaft **13** to a particular direction of traffic flow. Accordingly, the spot on the lower track layout **28** beneath such a two-way shaft would serve as both a launching spot S.sub.LCH and landing spot S.sub.LND, and the spot on the upper track layout **10** above the two-way shaft would serve as both a drop-down and climb-out spot for that shaft **13**. Also, while the illustrated example has working stations **18** at the lower level for service from the lower track layout **28**, the same concepts concerning working stations **18** served by extension tracks, and in-grid orchestration of sequenced delivery of storage units **16** to the working stations **18**, may similarly be employed in instances where working stations **18** are instead served from the upper track layout **10**.

[0166] The same inventive in-grid orchestration of sequenced delivery of storage units **16** to the working stations **18** entirely within the two-dimensional footprint of the track layouts, can also be employed regardless of whether the working stations **18** are the inventive “travel-through” workstations disclosed herein, where the same robotic storage/retrieval vehicles **14** responsible for retrieving and returning storage units **16** to the three-dimensional storage grid **17** also carry the storage units **16** through the working stations **18**, or are “drop off” workstations where the robotic storage/retrieval vehicles **14** drop off the storage units **16** at an intake point of the working station **18**, which may for example be a turntable, elevator, conveyor or other handling equipment responsible for transitioning the dropped off storage unit **16** to an access point of the working station **18** where a human or robotic worker then interacts with the storage unit **16** outside the three-dimensional grid **17**. The intake point at which the storage units **16** are dropped off may reside within, or just outside, the two-dimensional footprint of the track layouts, while the access point (e.g. access opening **52** over an access spot S.sub.A) resides outside the two-dimensional footprint of the track layouts, i.e. outside the storage grid structure **17**.

[0167] While many of the forgoing examples focus on picking operations used to fulfill an order by delivering storage units **16** containing items for that order to a working station **18** where a human or robotic worker can remove such items from the storage units **16** and compile them into a shipping container for delivery to a customer, the working stations **18** can also be used for re-stocking or order buffering operations, where items are placed into the storage unit **16** presented by the robotic storage/retrieval vehicle **14** at the access spot S.sub.A of the working station **18**, from which the robotic storage/retrieval vehicle **14** then re-enters the three-dimensional grid **17** to place that storage unit **16** in an available storage location in the three-dimensional grid **17**. In the re-stocking operation, the items placed in the robotic storage/retrieval vehicle-carried storage unit are new inventory items of a type not previously stored in the structure, or inventory replenishment items replacing previously picked items. Accordingly, it will be appreciated reference herein to performance of tasks at the working station **18** to fulfill an order is not necessarily limited specifically to fulfillment of customer orders, where customer-ordered items are picked from storage units **16** for shipment to the customer, and that an order being fulfilled may be any variety of work order similarly requiring interaction with a storage unit **16** at the access opening **52** of the workstation **18**, whether for picking of items therefrom or placement of items therein, for example for re-stocking or kitting purposes (the latter referring to placement of mixed items of different types into a singular storage unit from bulk inventory storage units **16** each containing only a singular item type).

[0168] An order buffering operation first involves a picking operation, in which the computerized control system **500** assigns and instructs a group of storage/retrieval vehicles **14** to different retrieve storage units **16** containing a particular collection of items required to fulfill an order, and to carry the retrieved items in their respective storage units **16** down to the lower track layout **28** and onward to the entrance spot S.sub.EN of the working station **18** assigned to this buffering operation. As the assigned group of vehicles **14** move through the working station **18**, the worker extracts one or more items of the order from the storage unit **16** on each vehicle **14** when said vehicle **14** arrives at the access spot S.sub.A of the working station **18**, and these extracted items are amalgamated together in order to form a full or partial fulfillment of the order.

[0169] This fully or partially fulfilled order is placed into a container of compatible size with the storage spaces in the three-dimensional grid structure **17**. This container may be the same as the rest of the storage units **16**, for example an openable/closeable storage bin, or may be a shipment container of different type from the storage units **16** (e.g. cardboard shipping box, optionally sealed closed and having a shipping label already placed thereon, for example if the amalgamated order contents fulfill the entire order). The computerized control system **500** sends an unloaded vehicle **14** to the same working station **18**, where the container with the amalgamated order contents is placed atop this vehicle **14** at the access spot S.sub.A of the working station **18**. The computerized control system **500** then sends this order-carrying vehicle **14** back into the three-dimensional grid structure **17** with instructions to store the fully or partially fulfilled order in an available storage location in the three-dimensional grid structure **17**. The same three-dimensional storage grid **17** used to store inventory items can therefore also be used to buffer partially prepared or fully-ready shipments until a later date or time, for example a future pickup time at which a shipping vehicle is expected to arrive to pick up a fully completed order for delivery, or in the case of a partially fulfilled order requiring additional items currently not in stock, an future time at which the out of stock inventory will be replenished to enable completion of the order.

[0170] When it comes time for the pickup or inventory replenishment, a buffered-order retrieval operation is performed by the computerized control system **500**, sending a robotic storage/retrieval vehicle **14** to retrieve the order container from its storage location, and deliver the order container to one of the working stations **18**, for retrieval of the container, or the individual items contained therein, through the access opening **52** of the working station **18**. If the buffered order was only a partial order, then the previously missing items are then amalgamated with the retrieved items, either by addition to the same container if useable as a shipment container, or by amalgamation into a new shipping container.

[0171] Having summarized the novel working stations **18** of the present invention, novel uses thereof, and novel use of the three-dimensional grid structure **17** itself for workstation delivery sequencing and order buffering, attention is now turned to other points of novelty in the three-dimensional grid structure **17**, robotic vehicle fleet and cooperative operation therebetween.

[0172] FIG. **8** illustrates an isolated section of the lower track layout **28** of the three-dimensional grid structure **17**, with parallel first and second longitudinal rails **60***a*, **60***b* running in the X-direction of the lower track layout **28**, and a parallel set of additional cross-rails **62***a*-**62***f* perpendicularly interconnecting the first and second longitudinal rails **60***a*, **60***b* at regularly spaced intervals therealong in the Y-direction of the lower track layout **28**. As mentioned above, a respective spot of the lower track layout **28** is denoted by the square area between the two longitudinal rails **60***a*, **60***b* and each adjacent pair of cross-rails **62***a*-**62***f*. The cross-rail on the same side of each spot (on the right side of each spot in the illustrated example) carries a visually detectable location marker **64** thereon at a mid-point of the cross-rail's topside. The visually detectable location marker **64** may be applied as a separate sticker or label, or etched into the rail of the track itself. Each robotic storage/retrieval vehicle **14** carries a scanner **66** on a side of the robotic storage/retrieval vehicle **14** that matches the side of the spots on the track layout on which the visually detectable location markers **64** are positioned. The scanner **66** comprises an image capture device with a downwardly angled field of view oriented to capture imagery of the marked cross-rails as the robotic storage/retrieval vehicle **14** travels the lower track layout **28**. The field of view is aimed so that the frame size thereof at the marked topsides of the rails exceeds the size of the visually detectable location markers **64**. The scanner **66** and the visually detectable location markers **64** are positioned relative to one another such that when the robotic storage/retrieval vehicle **14** is properly centered between the two longitudinal rails **60***a*, **60***b* and two cross-rails bounding a given spot of the lower track layout **28**, the respective visually detectable location marker **64** on one of the cross-rails **62** will occupy a predetermined subregion of the scanner's **66** field of view (e.g. a central area thereof). As the robotic storage/retrieval vehicle **14** arrives at a targeted destination spot of the lower track layout **28**, the scanner **66** captures images from its current field of view and a software module executed by a local computer processor **512** of the robotic vehicle **14** compares the position of the visually detectable location marker **64** within the larger viewing frame of the scanner **66** to check for agreement between the visually detectable location marker **64** position in the viewing frame and expected viewing frame sub-region in which the visually detectable location marker **64** is expected. So where the sub-region is a central area of the viewing frame, the software is checking whether the marker is properly centered in the viewing frame. The relative agreement or disagreement thus reflects the relative alignment between the robotic storage/retrieval vehicle **14** and the targeted spot on the lower track layout **28**.

[0173] As described in Applicant's aforementioned prior PCT application, the robotic storage/retrieval vehicle **14** features a set of X-direction wheels **68** on two opposing sides of the robotic storage/retrieval vehicle **14**, and a set of Y-direction wheels **70** on the other two opposing sides of the robotic storage/retrieval vehicle **14**. The X-direction wheels **68** are raiseable and lowerable relative to a frame or chassis of the robotic storage/retrieval vehicle **14** into an out of engagement with the X-direction rails **60***a*, **60***b* of the lower track layout **28**, just as the Y-direction wheels **70** are raiseable and lowerable relative to a frame of the robotic storage/retrieval vehicle **14** into an out of engagement with the Y-direction rails **62** of the lower track layout **28**. Raising of the X-direction wheels **68** out of contact with the X-direction rails **60***a*, **60***b* is performed when the robotic storage/retrieval vehicle **14** is to travel in the Y direction by driven rotation of the Y-direction wheels **70** on the Y-direction rails **62**, while raising of the Y-direction wheels **70** out of contact with the Y-direction rails **62** is performed when the robotic storage/retrieval vehicle **14** is to travel in the X direction by driven rotation of the X-direction wheels **68** on the X-direction rails **60***a*, **60***b*.

[0174] FIG. **8** shows the example where the robotic storage/retrieval vehicle **14** is riding in the X-direction of the lower track layout **28** toward a targeted destination spot thereon, and is scanning

the visually detectable location markers **64** on the Y-direction rails as it does so. Each visually detectable location marker **64** may embody a scannable code containing a unique ID of the respective spot it designates within the two-dimensional grid map of the lower track layout **28**, whereby this unique ID together with detected alignment of the visually detectable location marker **64** of the targeted destination spot can be used to both confirm arrival of the robotic storage/retrieval vehicle **14** at the correct targeted destination spot, and achieve proper centering of the robotic storage/retrieval vehicle **14** on this spot. Such alignment ensures that 1) the robotic storage/retrieval vehicle **14** does not interfere with travel of other vehicles **14** travelling in the other direction through neighbouring spots in the lower track layout **28**; and 2) the robotic storage/retrieval vehicle **14** is properly aligned with the vertical shaft **13** above it if the targeted destination spot is a launching spot S.sub.LCH from which the robotic storage/retrieval vehicle **14** is intended to travel upwardly through the shaft **13** above it.
[0175] The engagement of wheels on opposing sides of the robotic storage/retrieval vehicle **14** with the corresponding rails of the lower track layout **28** automatically ensures alignment of the robotic storage/retrieval vehicle **14** on the targeted spot of the lower track layout **28** in the track direction perpendicular to these rails. So in the illustrated example of FIG. **8**, the X-direction wheels **68** are engaged with the X-direction rails **60***a*, **60***b*, thus automatically aligning the robotic storage/retrieval vehicle **14** with the targeted spot in the Y-direction. During arrival of the robotic storage/retrieval vehicle **14** at the targeted spot in the X-direction, the scanner **66** captures imagery from its viewing frame and the software executed by the local processor **512** on the robotic storage/retrieval vehicle **14** checks the position of the visually detectable location marker **64** image within the viewing frame, and uses any deviation between the actual and expected visually detectable location marker **64** position in the viewing frame as feedback signals to dynamically adjust the drive signals to the motors of the X-direction wheels **68** so as to drive the robotic storage/retrieval vehicle **14** into properly centered alignment on the targeted spot. The same alignment procedure is used to provide feedback-governed control over the Y-direction wheels **70** when travelling into a targeted spot in the Y-direction. Since the robotic storage/retrieval vehicles **14** never change orientation on the track layout, the particular selection of which set of rails the markers are placed on (either X-direction or Y direction rails) is of no consequence, provided that the scanner **66** is placed on the appropriately cooperative side of each vehicle **14**.
[0176] FIGS. **9**A and **9**B illustrate performance of the alignment procedure in the Y-direction, where the vehicle has just finished travelling along a Y-direction rail **62**. The outer rectangular box drawn over the rail **62** represents an outer boundary Brov of the scanner's **66** field of view (FOV), the center point of which is marked at C. The FOV subregion S.sub.FOV in which the visually detectable location marker **64** is expected to reside in the vehicle's **14** properly aligned position on the targeted spot of the gridded track is visible in FIG. **9**A, which represents a misaligned state of the vehicle **14** on the targeted spot in the grid, where the visually detectable location marker **64** is clearly offset to one side of the subregion. In FIG. **9**B, the visually detectable location marker **64** can be seen to be accurately centered in the FOV, thus perfectly occupying the central subregion S.sub.FOV at which is expected, and thus representing a properly aligned position of the vehicle **14** on the targeted spot of the gridded track. The only difference in images captured for X-direction alignment check purposes would be that instead of the visually detectable location marker **64** being offset from center in the left-right direction of FIG. **9**A in a misaligned scenario, it would be offset from center in the up-down direction of the figure.
[0177] The wheel drive motors of each vehicle **14** are encoded, and the unidirectional travel commands received from the master control system **502** are expressed only in terms of the direction of travel and the number of grid spots to travel in that direction. The local processor **512** translates this travel command into an appropriate drive signal for the wheel drive motors **524**, based on a stored proportionality factor representing the predetermined relationship between the conveyance wheel diameter and the uniform width shared by all of the square grid spots. The

encoded motors give the processor feedback that the appropriate number of wheel rotations equivalent to the commanded travel length have been performed. So when the processor **512** receives feedback confirmation from the encoded wheel motors that the prescribed rotation has been completed, the processor **512** triggers an image capture by the scanner **66**, and then performs a visual analysis on the captured image to identify whether there is an offset between the expected and actual position of the visually detectable location marker **64** within the scanners FOV, calculated as a pixel offset value V.sub.PO.

[0178] If the calculated offset is either zero, or within a permissible threshold, then the processor **512** has confirmed proper alignment of the vehicle **14** on the targeted spot of the gridded track. If the offset is nonzero, or exceeds a permissible threshold, then the vehicle **14** is known to be misaligned. In response, the processor **512** initiates a corrective wheel rotation action by transmitting a drive signal to the wheel drive motors **524** that is proportional to the calculated amount of pixel offset V po in the image, and in appropriate direction determined by the direction of offset in the image. After performance of this corrective drive action by the wheel drive motors **524**, an updated image is captured, and is subjected to the same offset determination process to assess whether proper alignment has been achieved, or whether further corrective action is needed to correct an overshoot or undershoot in the last corrective attempt. Once proper alignment is achieved, the vehicle processor **512** sends a “position accomplished” confirmation signal to the master control system **502**, which includes the unique identifier encoded in the visually detectable location marker **64** and read by the scanner **66** as feedback to the master control system **502** to confirm that the targeted destination spot specific by the commanded vehicle task has been reached. This confirmation of aligned arrival at the targeted destination of the commanded linear travel segment, the master control system **502** can update the dynamic location record of the vehicle **14** with the unique identifier of the spot at which the vehicle **14** has now arrived. The gridded lower tracks **36** of the working stations **18** use the same visually detectable location marker **64** arrangement thereon for the same arrival confirmation, alignment check/correction, and location update purposes.

[0179] The above alignment check/correction process is generally summarized in FIG. **9**C, where at step **3001**, the computerized control system **500** commands unidirectional travel of the vehicle **14** along the gridded track layout of the grid structure **17**, or along the gridded lower track **36** of a workstation **18**, by a select whole number of grid squares or spots. At step **3002**, in response to receipt of such command, the vehicle **14** drives itself the commanded number of spots in the commanded direction according to the known proportionality between the vehicle's conveyance wheel diameter and the standardized width of the grid and spots track layout. At step **3003**, the local processor **512** of the vehicle **14** triggers capture of a digital image by the scanner **66**, and at step **3004** analyzes the captured image to check for proper alignment of the uniquely coded visually detectable location marker **64** on the rail by measuring, in the same X or Y direction as the vehicle's commanded unidirectional travel, any pixel offset between the coded visually detectable location marker **64** and its anticipated position in the image. If the visually detectable location marker **64** is properly aligned in the image (i.e. if there is no offset, at least not beyond any prescribed threshold limit), then at Step **3005** the vehicle's processor **512** wirelessly transmits a confirmation signal to the master control system **502**, which contains the unique identifier read from uniquely coded visually detectable location marker **64** scanned by the vehicle **14**, so that the master control system **502** uses this to confirm the vehicle's arrival at the targeted destination spot prescribed by the travel command. If the visually detectable location marker **64** is found not to be properly aligned in the image, then at step **3006**, the vehicle **14** attempts self-correction of its alignment by sending a drive signal to the wheel drive motors **524** that is proportional to the measured pixel offset value V po from the image analysis, and repeats step **3004** again until alignment is confirmed.

[0180] In addition to such adjustment of the vehicle position as it arrives at the targeted spot on the track layout, earlier dynamic adjustment of the vehicle's travel may take place upstream of such

arrival by scanning the other visually detectable location markers **64** past which the vehicle **14** is travelling on its way to the targeted spot beneath the targeted shaft (i.e. a shaft **13** for which the vehicle **14** is destined). The original travel instructions assigned and transmitted to the storage/retrieval vehicle **14** by the computerized control system **500** are based on actual physical distance to the targeted shaft **13** based on the known grid dimensions of the gridded three-dimensional structure **17**. Where the vehicle **14** is travelling through more than one pass-through spot to reach the targeted grid spot below the targeted shaft **13**, the scanner **66** can perform a scan as it moves through each pass-through spot use the results to dynamically correct the travel instructions on the fly to account for differences between the originally assigned travel distance and the true-remaining travel distance from the vehicle's current location to the targeted spot, thus co-ordinating more precisely aligned arrival of the storage/retrieval vehicle at the targeted spot to avoid or reduce the need for fine-tuning of the alignment during final arrival at the targeted spot.
[0181] While the illustrated embodiment employs static visually detectable location markers **64** located in the gridded three-dimensional structure **17** at fixed positions relative to the targetable spots on the lower track layout **28**, and moving scanners **66** carried on the travelling storage/retrieval vehicles **14**, this arrangement may be reversed by having statically positioned scanners in the three-dimensional grid structure **17** and detectable markers on the robotic storage/retrieval vehicles **14**, though having the scanning and associated image processing carried out on the robotic storage/retrieval vehicle **14** whose wheels are being controlled is likely preferable. While the forgoing description of the scanner/marker alignment confirmation tool is made with reference to the lower track layout **28** to ensure that a vehicle **14** is properly aligned at a targeted launching spot of the lower track layout **28** before the robotic storage/retrieval vehicle **14** is lifted up into the shaft **13** above such launching spot S.sub.LCH, the same tool may also be employed on the upper track layout **10** to ensure alignment of a vehicle **14** at a targeted drop-down spot overtop of a respective shaft **13** before lowering of the robotic storage/retrieval vehicle **14** down into said shaft **13**.
[0182] FIGS. **10** through **15** illustrate one of the robotic storage/retrieval vehicles **14** at a launching spot S.sub.LCH of the lower track layout **28** of the three-dimensional grid structure **17** just outside one of the working stations **18** in neighboring relation to the exit spot S.sub.X thereof. A majority of the three-dimensional grid structure **17** is omitted for illustrative purpose, leaving only the four rails of the lower track layout that delimit this particular launching spot S.sub.LCH (of which one X-direction rail is labelled **60**, and one Y-direction rail is labelled **62**), the four support legs **30** supporting the rails at the intersection points therebetween at the corners of the launching spot S.sub.LCH, and two of the four upright frame members **12** that stand upright from the four corners of the launching spot S.sub.LCH to define the four corners of the respective vertical up-shaft **13** above the launching spot S.sub.LCH. The other two upright frame members are omitted to provide improved visibility of the robotic storage/retrieval vehicle **14** to demonstrate interaction thereof with a novel lifting mechanism **72** for raising the storage/retrieval vehicle **14** up into the overlying up-shaft **13**.
[0183] The lifting mechanism **72** is seated atop the same ground surface as the support legs **30** of the lower track layout **28** within the rectangular footprint of the launching spot S.sub.LCH. Shown in isolation from the lower track layout **28** in FIGS. **16** through **19**, the lifting mechanism **72** features a base frame having four vertically upright corner legs **74** interconnected by horizontal cross-braces **76**, and an upper panel **78** mounted atop the base frame at the top ends of the corner legs **74**. A lifting platform **80** resides above the upper panel **78** of the base frame, and is movably carried thereon in a raiseable/lowerable manner by a suitable actuator, which in the illustrated example is an electric linear actuator **81** whose electric motor **82** is mounted to the underside of the base frame's upper panel **78** with the output rod **84** of the actuator **81** reaching upwardly through a central opening in the upper panel **78** to connect to the underside of the lifting platform **80**. Accordingly, extension of the linear actuator **81** raises the lifting platform **80** upwardly from the

upper panel **78**, and retraction of the linear actuator **81** lowers the lifting platform **80** back down into contact or close adjacency to the upper panel **78** of the base frame. A set of four linear guide rods **86** are affixed to the underside of the lifting platform **80** near the corners thereof, and pass down through a set of bushings or bearings in the upper panel **78** of the base frame for sliding movement upwardly and downwardly through the upper panel **78** during extension and retraction of the linear actuator **81**. The rod guides **86** thus help stabilize the lifting platform **80** to maintain a horizontally level orientation thereof.

[0184] The base frame is of a lesser height than the lower track layout **28** so that the upper panel **78** of the base frame resides at an elevation below the topsides of the rails of the lower track layout **28**, and for example slightly below the undersides of these rails so that when the lifting platform **80** is in the lowered position adjacent the upper panel **78** of the base frame, it does not protrude above the rails of the lower track layout **28**. In the followed position of the lifting platform **80**, the robotic storage/retrieval vehicles **14** can thus travel freely over the launching spot S.sub.LCH in either track direction. Mounting brackets **88** reach outward from the upper panel **78** of the base frame of the lifting mechanism **72** at two or more sides thereof and are fastened to the rails of the lower track layout **28**, for example at the undersides thereof, thus fixing the position of the lifting platform **80** in a properly squared relation to the lower track layout **28** and in properly centered position within the square area of the launching spot S.sub.LCH.

[0185] The lifting mechanism **72** is communicable with the computerized control system **500** via wired or wireless connection thereto, for example as shown in FIG. **23** where the lifting mechanism **72** is wired to the local computer **506** of the workstation **18**. When a robotic storage/retrieval vehicle **14** travelling along the lower track layout **28** reaches a targeted launching spot S.sub.LCH under an up-shaft **13** through which the robotic storage/retrieval vehicle **14** is destined to travel, or more typically when a robotic storage/retrieval vehicle **14** just having exited the workstation **18** rides onto this launching spot S.sub.LCH just outside the working station **18** exit spot S.sub.X, the vehicle **14** is accurately aligned with the up-shaft **13** using the above described visually detectable location markers **64** and cooperating scanners **66**, and the wireless transceiver **514** of the robotic storage/retrieval vehicle **14** signals the computerized control system **500** of the confirmed arrival of the robotic storage/retrieval vehicle **14** at the targeted launching spot S.sub.LCH.

[0186] This process is shown in FIG. **19**A, where, at Step **4001**, the master control system **502** commands the vehicle **14** to move to the launching spot S.sub.LCH from the neighbouring exit spot S.sub.X of a working station **18**, in response to which the vehicle **14** self drives the commanded one-spot unidirectional distance onto the launching spot S.sub.LCH in Step **4002**. At step **4003**, the vehicle **14** performs the alignment checking/correction procedure and positional confirmation reporting process documented in FIG. **9**C. In response to this confirmation, the master control system **502** instructs the workstation control system **504** to send an activation signal to the lifting mechanism **72** at Step **4004**, in response to which the actuator **80** thereof is activated in the extension direction to raise the lifting platform **80** up into contact with an underside of the robotic storage/retrieval vehicle's frame or chassis just above the rails of the lower track layout **28**, thereby lifting the conveyance wheels of the vehicle **14** up off the lower track layout **28**. At Step **4005**, raising of the lifting mechanism **72** to this wheel-lifting height is completed, and confirmed by transmission of a first-stage lift-confirmation signal from the lifting mechanism **72** to the local computer **506** of the workstation control system, which in turn reports this first-stage lift-confirmation onward to the master control system **504**. In other embodiments, the lifting mechanism **72** may be controlled directly by, and report confirmations directly back to, the master control system **502**.

[0187] With the weight of the robotic storage/retrieval vehicle **14** now borne by the lifting mechanism **72** rather than by riding of the robotic storage/retrieval vehicle's conveyance wheels on the rails of the lower track layout **28**, the master control system **502** now sends a mode-transition command to the storage/retrieval vehicle **14** at Step **4007**, in response to which the local processor

512 thereof initiates a transition of the storage/retrieval vehicle **14** from track-riding mode to the shaft traversing mode. As part of this transition, the vehicle's local processor **512** drives the wheel-shifting motor(s) or actuator(s) **528** in the appropriate direction to draw the conveyance wheels of the robotic storage/retrieval vehicle **14** inwardly in a horizontally inboard direction to reduce the overall robotic storage/retrieval vehicle **14** footprint to a reduced size capable of entering the shaft so that the pinion wheels can engage with the rack teeth **90** on the upright frame members **12** at the corners of the up-shaft **13**, thereby enabling climbing of the storage/retrieval vehicle **14** therethrough. The transition may further involve raising of the vehicle's height adjustable wheel set via activation of the wheel lifting/lowering motor(s) or actuator(s) **526**, if these height adjustable wheels were previously in the lowered track-riding position. This way, all eight wheel units will be high enough to engage with the rack teeth **90** when the vehicle **14** is fully raised by the lifting mechanism **72** is completed. Only one lower set of rack teeth **90** is shown the bottom segment **32** of one of the two illustrated upright frame members **12** in FIGS. **10** through **15**, but it will be appreciated that such rack teeth **90** are provided on all eight inwardly facing sides of the four upright frame members **12** of the up-shaft **13**, and span a substantially full height of the shaft **13** to near the upper track layout **10**. Moreover, pinion wheels are toothed for corresponding engagement with rack teeth **90**, however, for illustrative simplicity, the figures are shown in simplified form without teeth on the pinion wheels.

[0188] After such retraction of the wheels, and raising of the height-adjustable wheels if necessary, the vehicle **14** sends a confirmation to the master control system **502** at Step **4008** that the transition of the vehicle **14** from track-riding mode to shaft-traversing mode has been successfully completed. In response, at Step **4009**, the master control system **502** instructs the workstation controller **506** to command further extension of the lifting mechanism actuator to lift the robotic storage/retrieval vehicle **14** into a raised position in which the teeth (not shown) of the robotic storage/retrieval vehicle's pinion wheels are brought into engagement or immediate adjacency with lowermost rack teeth **90** on the upright frame members **12** of the three-dimensional grid structure **17**. On completion of this further extension at Step **4010**, the lifting mechanism **72** sends a full-stage extension confirmation signal to the local workstation computer **506**, which is reported onward to the master control system **502** as confirmation that the vehicle **14** is now in fully raised position to ascend the up-shaft. In response, at Step **4011**, the master control system **502** commands the vehicle to climb through the up-shaft to the upper track layout **10**, in response to which, at Step **4012**, the local processor **512** of the vehicle **14** activates the wheel drive motors **524** to drive the vehicle's pinion wheels and thereby initiate climbing of the robotic storage/retrieval vehicle **14** upwardly through the up-shaft of the three-dimensional grid structure **17**.

[0189] The lifting mechanism **72**, being powered by a mains power supply, thus reduces the overall energy load consumed by the on-board power supplies of the storage/retrieval vehicle **14** in its travel from the lower track layout **28** up the upper track layout **10**, as the storage/retrieval vehicle's on-board power supply is not used to lift the robot up to an engageable position with the rack teeth **90**. To maintain the robotic storage/retrieval vehicle **14** in alignment with the up-shaft **13** during lifting, the lifting platform **80** and underside of the vehicle chassis may have mateable male and female features laid out in matching pattern to one another to automatically align with one another when the vehicle **14** is properly centered on the launching spot S.sub.LCH of the track, whereby raising of the lifting platform **80** mates the male/female features thereon with the matching female/male features on the underside of the vehicle chassis. The mated features prevent the vehicle chassis from sliding around on the lifting platform **80** as it is raised. In on example, four male nipples protrude upwardly from the topside of the lifting platform **80** near the outer corners thereof to mate with four mating recesses in the underside of the vehicle chassis.

[0190] FIG. **20** shows one of the robotic storage/retrieval vehicles **14** and a storage unit **92** receivable on the robotic storage/retrieval vehicle **14** for transport thereby within the three-dimensional grid structure **17** and the working stations **18**. In the illustrated example, the storage unit **92** to and from which smaller individual items can be inserted and removed is an open-top tray, though as mentioned elsewhere herein above, an openable/closeable box, bin or tote may alternatively be used. In other embodiments, the storage unit **92** may be the packaging of an individual item, as opposed to a container for storing multiple items therein. In other embodiments, where the grid dimensions and working stations **18** are of larger scale, a storage unit **92** may be a pallet on which one or items are received, whether one relatively large individual item, or a plurality of items. In the example of multiple palleted items, the items may be distributed among multiple containers (e.g. boxes, trays, bins, or totes) placed or stacked on the pallet, with one or more items stored in each such container.

[0191] As disclosed in Applicant's aforementioned prior PCT application, the robotic storage/retrieval vehicle **14** features an upper support platform **94** on which the storage unit **92** is receivable for carrying by the robotic storage/retrieval vehicle **14**, and which may feature a rotatable turret **96** surrounded by a stationary outer deck surface **98**. As disclosed in Applicant's aforementioned prior PCT application, the turret may once again have an extendable/retractable arm (not shown), which together with the rotatable function of the turret **96** allows pulling of storage units **92** onto the support platform **94** and pushing of storage units **92** off the support platform **94** at all four sides of the robotic storage/retrieval vehicle **14** so that each vehicle **14** can access a storage unit **92** on any side of any shaft **13** in the three-dimensional grid structure **17**. That is, each robotic storage/retrieval vehicle **14** is operable in four different working positions inside any of the shafts **13** to enable access to any of the storage locations on any of the shaft's four different sides. In the presently illustrated embodiment, the turret **96** and deck surface **98** are shown in simplified form without detail for illustrative simplicity. While the use of a rotatable turret **96** with a single extendable/retractable arm is one example of a robotic storage/retrieval vehicle **14** operable in four different working positions to access any side of any shaft **13**, including fully-surrounded shafts **13** of the three-dimensional storage grid **17** that have storage locations on all four sides thereof, it will be appreciated that other vehicles **14** may be able to likewise accomplish four different working positions enabling interaction on all sides thereof, for example having a plurality of extendable arms respectively extendable from the four different sides of the vehicle **14**.

[0192] The turret **96** and surrounding deck surface **98** collectively define a square landing area atop which the storage unit **92** is seated when carried on the robotic storage/retrieval vehicle **14**. This landing area is equal or similar in size and shape to the underside of each storage unit **92** in the three-dimensional grid structure **17**, as shown by FIG. **21** where the seated position of the storage unit **92** occupying an entirety of the landing area. For the purpose of ensuring that the storage unit **92** is fully received and properly aligned on the landing area of the robotic storage/retrieval vehicle **14**, the upper support platform **94** has a set of load status sensors **100** situated in close proximity to the outer perimeter thereof at spaced apart positions along said perimeter. In the illustrated example, the load status sensors **100** are optical sensors recessed into the upper surface of the landing area, and provided in a quantity of four, each positioned proximate a respective one of the four outer corners of the landing area. As part of a loading routine pulling a storage unit **92** onto the robotic storage/retrieval vehicle **14** from a storage location in the three-dimensional grid **17** using retraction of the extendable/retractable arm, the local processor **512** on the vehicle **14** then checks the status of the four load status sensors **100** for detected presence of the underside of the storage unit **92** above the load status sensors **100**. A positive detection signal from all four load status sensors **100** thus confirms the presence of the storage unit **92** at all four corners of the landing area, thereby confirming that the storage unit **92** is fully received on the landing area and is in properly squared alignment therewith.

[0193] One embodiment uses reflective optical sensors for load status detection, where light energy transmitted by an optical beam emitter of the load status sensor **100** is reflected off the underside of the storage unit **92** back to an optical receiver of the load status sensor **100** when the storage unit **92** is present thereover, thus successfully determining said presence. Time of flight calculation (i.e.

difference in time between emission of an optical pulse and detection of the reflected optical pulse) may be used to differentiate between a reflection off the underside of a storage bin seated on the landing area of the robotic storage/retrieval vehicle **14** vs. a reflection off another surface further away. It will be appreciated that sensor types other than optical sensors may be employed, for example including limit switches mechanically actuated by contact with the underside of the storage unit **92**, or magnetic sensors actuated by presence of cooperating magnetic elements emitting detectable magnetic fields at the underside of the storage unit **92**. However, optical sensors may be preferable to avoid moving parts or need for magnetic integration or other specialized configuration of the storage units **92**.

[0194] As disclosed above, the three-dimensional grid structure **17** used to store inventory items in an order fulfillment center can also be used to buffer fully or partially completed orders within the same three-dimensional inventory storage grid structure **17**. FIG. **22** illustrates a separate three-dimensional sortation/buffering grid that can supplement an inventory storage grid of the type shown in FIG. **2**. For example, palletized incoming supply inventory can be depalletized and induced into the inventory storage grid of FIG. **2**, from which orders are then picked and packaged into shipping containers, which are then induced into the sortation/buffering grid structure **200** of FIG. **22**. the sortation/buffering grid structure **200** features the same three-dimensional framework as the three-dimensional inventory storage grid **17**, thus having matching upper **10** and lower track layouts **28**, and the array of upright frame members **12** therebetween for delimiting storage columns **11** and upright shafts **13** between the two track layouts to enable a fleet of the robotic storage/retrieval vehicles **14** to horizontally traverse each track layout, and vertically traverse the shafts **13** between the two track layouts **10**, **28** to access the shelved storage locations therebetween. However, the storage locations in the sortation/buffering grid **200** contain previously packed shipment containers containing the orders picked from the three-dimensional inventory storage grid **17**. The robotic fleet is once again wirelessly controlled via a central computerized control system **500**, for example the same computerized control system **500** shared by the three-dimensional inventory storage grid **17**.

[0195] In the illustrated example of FIG. **22**, the upper track layout of the sortation/buffering grid **200** is served by a plurality of intake stations **202** co-operably installed therewith for the purpose of loading incoming shipping containers **204** onto robotic storage/retrieval vehicles **14** on the upper track layout. Each intake station may comprise an intake conveyor **206** on which a series of incoming shipping containers **204** can be queued for induction into the sortation/buffering grid **200**, with an outlet end of each intake conveyor **206** elevated slightly above the upper track layout of the sortation/buffering grid **200** at the outer perimeter thereof by an elevated distance equal to or slightly exceeding the heights of the robotic storage/retrieval vehicles **14**. This way, the outlet of each intake conveyor **206** resides at or above an upper horizontal reference plane occupied by the landing areas of the robotic storage/retrieval vehicles **14** when riding on the upper track layout. The intake conveyor **206** can thus slide or drop an incoming shipping container **204** onto the landing area of one of the robotic storage/retrieval vehicles **14** situated at a pick-up spot aligned with the outlet end of the intake conveyor **206** at the outer perimeter of the upper track layout.

[0196] One or more intake stations **202** may be provided at any one or more perimeter sides of the upper track layout, though as illustrated, the intake stations **202** may all reside at a common side of the upper track layout that's nearest to an on-site three-dimensional inventory storage grid **17** from which the packed shipping containers are arriving, or nearest to one or more intermediate packing stations at which order items amalgamated at the three-dimensional inventory storage grid **17** working stations **18** are subsequently packaged before being forwarding on to the sortation/buffering grid **200**. However, it will be appreciated that the two grids need not necessary be located in a shared facility.

[0197] The lower track layout of the sortation/buffering grid **200** is served by a plurality of output stations **208** co-operably installed therewith for the purpose of unloading outgoing shipping containers **210** off of robotic storage/retrieval vehicles **14** on the lower track layout. Each output station **208** may comprise an output conveyor **212** on which a series of outgoing shipping containers **210** can be queued for transfer to a further downstream location of the facility, for example a final packing area or loading bay at which the containers will be loaded onto a shipping vehicle when available. An inlet end of each output conveyor **212** is situated at or slightly below a lower horizontal plane in which the landing areas of the robotic storage/retrieval vehicles **14** reside when riding on the lower track layout. This way, a robotic storage/retrieval vehicle **14** at a drop-off spot situated at the outer perimeter of the lower track layout in alignment with the inlet end of the output conveyor **210** can slide or drop a shipping container from said robotic storage/retrieval vehicle **14** onto the inlet end of the output conveyor **210**. One or more output stations **208** may be provided at any one or more perimeter sides of the upper track layout. The illustrated example features output stations on at least two opposing sides of the lower track layout, for example to respectively feed a pair of loading bays or packing areas optionally situated on opposing sides of the sortation/buffering grid **200**.

[0198] Each incoming shipping container may be picked up from one of the intake stations **202** by a robotic storage/retrieval vehicle **14** assigned to this pickup task by the computerized control system **500**, and then carried to an available (i.e. currently unoccupied) storage location in the sortation/buffering grid **200** via the respective shaft **13** from which this storage location is accessible, and left at this storage location for later retrieval. Alternatively, instead of commanding the assigned robotic storage/retrieval vehicle **14** to store the incoming shipping container, the computerized control system **500** may command the robotic storage/retrieval vehicle **14** to deliver the shipping container directly to one of the output stations **208** in view of a need or availability at the loading bay or packing area for that shipping container on an urgent basis.

[0199] In selecting between these storage and direct output options for the picked-up shipping container, the computerized control system **500** may consult an order priority ranking of an order associated with that shipping container, relative to other orders whose constituent containers have already been inputted to the sortation/buffering grid **200**. Additionally or alternatively, if the picked-up shipment container is only a partial component of a larger overall order, then the determination of whether to store the shipping container or deliver it straight to an output station **208** is based at least partly on whether the other shipment containers fulfilling the remainder of the larger overall order are also present, or imminently expected, at the sortation/buffering grid **200**. If the entire order is present or imminently present, and there are not any other orders of higher priority ranking, then the currently picked-up container may be put directly through to the appropriate output station **208** to which the order is assigned by the computerized control system **500**. The other constituent containers of that same order are retrieved from respective storage locations in the sortation/buffering grid **200**, if already present therein, and delivered to that same assigned output station **208**, or are assigned for imminent pickup and straight delivery to that output station if said other constituent containers are currently at, or imminently expected at, the intake stations **202**.

[0200] One particular example of a useful application for the combination of the two three dimensional grids is aisle-based or similar location-based kitting operations, for example where different retail items destined for a retailer are picked in groups from the three-dimensional inventory storage grid **17** according to a particular aisle section or other identifiable sub-region of the retailer's store layout for which the particular items are destined. The different groups are packed into different shipping containers, and then fed individually into the sortation/buffering grid **200** for temporary storage (i.e. buffering) as each such picked group of items is picked and packaged. Exiting the three-dimensional inventory storage grid **17**, the connected working stations **18** thereof, or subsequent packing station(s) located further downstream from the three-dimensional inventory storage grid **17** at different times, the shipping containers arrive at the sortation/buffering grid **200** at staggered points in time, with one or more initially received containers potentially arriving much earlier than a subsequently received remainder of said containers, and so the earlier received packages are temporarily stored (i.e. buffered) in the sortation/buffering grid **200**, at least until such time as the remainder of containers are received by or imminently approaching the sortation/buffering grid **200**. At such time, the previously-buffered initially-received shipping containers are retrieved from their respective storage locations in the sortation/buffering grid **200** and delivered to a common output station **208** by one or more of the robotic storage/retrieval vehicles **14** for amalgamation (e.g. palletization) into the completed order ready for shipment to the retailer.

[0201] This however, is only one non-limiting example of the usefulness of the sortation/buffering grid **200**, the use of which is not specifically limited to use with an inventory storage solution specifically using the three-dimensional grid structure **17** employed in the present invention and Applicant's aforementioned prior PCT application. Also, aisle-based kitting for retailers is only one example, and non-retail customers similarly having an aisle-based or similarly mapped organizational layout with different identifiable sub-regions may likewise benefit from kitted delivery. This may include manufacturers with organized storage for incoming raw materials or pre-fabricated componentry from outside suppliers, where kitted shipment containers are destined for such on-site manufacturer storage, from which the raw materials or pre-fabricated componentry are distributed to one or more manufacturing stations in the facility. The kitting approach may also be used where the manufacturing stations themselves are the different identifiable sub-regions for which the kitted materials or componentry are destined according to the supply needs of such stations, whether these stations are different stages within one product line, or full or partial assembly stations for two different product lines.

[0202] In another example, such manufacturing facilities could have the inventory storage grid **17** of FIG. **2** on site for kitting of raw materials and/or componentry, either with or without the downstream sortation/buffering grid **200**, to feed kit-populated storage units to the manufacturing stations at the same facility.

[0203] As outlined above, the computerized control systems referenced herein may comprise one or more computer processors, non-transitory computer readable memory coupled thereto and on which are stored statements and instructions executable by said one or more processors to perform the various associated tasks described herein, including generation and transmission of command and communication signals to the fleet of robotic storage/retrieval vehicles **14** to control the navigation thereof through the gridded three-dimensional storage structure **17**, and through the working stations **18** connected thereto, and control the deposit and retrieval of the storage units to and from the storage locations within the gridded three-dimensional storage structure **17** by the robotic storage/retrieval vehicles **14**, and the generation and assignment of priority rankings to the storage units being retrieved based on order data accessed by said one or more processors from one or more databases of the computerized control system.

[0204] Since various modifications can be made in my invention as herein above described, and many apparently widely different embodiments of same made, it is intended that all matter contained in the accompanying specification shall be interpreted as illustrative only and not in a limiting sense.

Claims

1. A storage system comprising: one or more storage/retrieval vehicles; a three-dimensional structure comprising: a gridded lower track layout that occupies a two-dimensional area and on which said one or more storage/retrieval vehicles are conveyable in two directions over said two-dimensional area; and a plurality of storage columns residing above the gridded lower track layout and distributed over the two-dimensional area of said lower track layout, each column comprising a plurality of storage locations that are arranged one over another, are each sized to accommodate

placement and storage of storage units therein, and are each accessible by the one or more storage/retrieval vehicles to place or remove the storage units to or from said storage locations of said storage column; and at least one working station residing alongside the three-dimensional structure and outside the two-dimensional area of the lower track layout over which the storage columns are distributed, said working station being linked to the gridded lower track layout by an extension track thereof by which said one or more storage/retrieval vehicles is conveyable between said working station and said lower track layout, whereby conveyance of the storage units between the storage locations and the working station is performable entirely by said one or more storage/retrieval vehicles.
2. The storage system of claim 1 wherein the working station is served solely by the extension track and the one or more storage/retrieval vehicles conveyable thereon.
3. The storage system of claim 1 wherein said extension track is connected to the lower track layout of the three-dimensional structure at two opposing ends of said extension track, whereby each storage/retrieval vehicle can traverse the extension track in a direction emerging from the three-dimensional structure at one end of the extension track and re-entering the three-dimensional structure at the other end of the extension track.
4. The storage system of claim 1 wherein the extension track is at least partially enclosed.
5. The storage system of claim 1 wherein the extension track passes through the working station from an entrance situated at or adjacent one end thereof to an exit situated at or adjacent an opposing end thereof.
6. The storage system of claim 1 wherein the working station comprises an enclosure into which the extension track extends from the gridded lower track layout.
7. The storage system of claim 1 any preceding claim wherein the working station comprises an access opening served by the extension track and through which a carried storage unit on one of the storage/retrieval vehicles is accessible when said vehicle reaches said access opening of the working station.
8. The storage system of claim 7 wherein said working station comprises a countertop penetrated by the access opening, and said extension track runs underneath said countertop.
9. The storage system of claim 7 comprising a sensing mechanism operable to detect insertion of worker hands at said access opening.
10. The storage system of claim 9 wherein said sensing mechanism is operable to prevent travel of the storage/retrieval vehicles on the track extension at the access opening during a detected presence in said access opening.
11. The storage system of claim 9 wherein said sensing mechanism is operable to prevent departure of a given storage/retrieval vehicle from the access opening until a detection counter equals a quantity associated with a current task to which the given storage/retrieval vehicle has been assigned.
12. The storage system of claim 1 wherein said at least one working station comprises a plurality of working stations each linked to the gridded lower track layout by a respective extension track.
13. The system of claim 1 comprising at least one processor configured to organize sequenced delivery of a group of storage units from the three-dimensional structure to the working station, including: (a) generating signals to instruct a plurality of storage/retrieval vehicles to retrieve the storage units from respective the storage locations; and (b) generating signals to instruct the plurality of storage/retrieval vehicles to navigate the three-dimensional structure in a manner orchestrating arrival of the storage/retrieval vehicles at the extension track in a particular sequence.
14. The system of claim 13 wherein the at least one processor is configured such that step (b) comprises identifying from among the plurality of storage/retrieval vehicles a first storage/retrieval vehicle of a higher ranked sequence priority than a second storage/retrieval vehicle, and generating signals instructing the second storage/retrieval vehicle to park itself in the three-dimensional structure at a parking spot of non-obstructive relation to the extension track while the first

storage/retrieval vehicle is conveyed along the gridded lower track layout to said extension track.

15. The system of claim 1 wherein the three-dimensional structure further comprises a plurality of upright shafts residing above the gridded lower track layout in spaced distribution over the two-dimensional area of said lower track layout, each storage column being neighboured by a respective one of the upright shafts, through which the storage locations of said storage column are accessible by the one or more storage/retrieval vehicles.

16. A storage system comprising: one or more storage/retrieval vehicles; a three-dimensional structure comprising: a gridded track layout that occupies a two-dimensional area and on which the one or more storage/retrieval vehicles are conveyable in two directions over said two-dimensional area; a plurality of storage columns residing above or below the gridded track layout and distributed throughout the two-dimensional area of said track layout, each column comprising a plurality of storage locations that are arranged one over another, are each sized to accommodate placement and storage of storage units therein, and are each accessible by the one or more storage/retrieval vehicles to place or remove the storage units to or from said storage locations of said storage column; and at least one working station residing outside the two-dimensional area of the track layout within which the storage columns are distributed; wherein conveyance of the storage units between the at least one working station and the storage locations in the three-dimensional structure is performed solely by said one or more storage/retrieval vehicles.

17. The system of claim 16 comprising at least one processor configured to organize sequenced delivery of a group of storage units from the three-dimensional structure to the working station, including: (a) generating signals to instruct a plurality of storage/retrieval vehicles to retrieve the storage units from respective the storage locations; and (b) generating signals to instruct the plurality of storage/retrieval vehicles to navigate the three-dimensional structure a manner orchestrating arrival of the storage/retrieval vehicles at the working station in a particular sequence.

18. The system of claim 17 wherein the at least one processor is configured such that step (b) comprises identifying from among the plurality of storage/retrieval vehicles a first storage/retrieval vehicle of a higher ranked sequence priority than a second storage/retrieval vehicle, and generating signals instructing the second storage/retrieval vehicle to park itself in the three-dimensional structure at a parking spot of non-obstructive relation to travel of the first storage/retrieval vehicle to said working station.

19. The system of claim 16 wherein the three-dimensional structure further comprises a plurality of upright shafts residing above or below the gridded track layout in spaced distribution within the two-dimensional area of said track layout, each storage column being neighboured by a respective one of the upright shafts, through which the storage locations of said storage column are accessible by the one or more storage/retrieval vehicles.

20. A storage system comprising: one or more storage/retrieval vehicles; a three-dimensional structure comprising a three-dimensional array of storage locations sized to accommodate placement and storage of storage units therein; and at least one working station to which selected storage units from the storage locations are conveyable by said one or more storage/retrieval vehicles; wherein each working station comprises an enclosure through which said one or more storage/retrieval vehicles are conveyable, and an access opening in said enclosure through which a carried storage unit on one of the storage/retrieval vehicles is accessible when said vehicle reaches said access opening of the working station.

21. The storage system of claim 20 wherein said enclosure comprises an entrance and an exit at opposite ends thereof by which said one of the storage/retrieval vehicles can travel past said access opening during travel between said entrance and said exit.

22. The storage system of claim 20 wherein said working station comprises a countertop penetrated by the access opening, and said enclosure runs underneath said countertop.

23. The storage system of claim 20 comprising a sensing mechanism operable to detect insertion of worker hands at said access opening.

24. The storage system of claim 23 wherein said sensing mechanism is operable to prevent travel of the storage/retrieval vehicles at the access opening during detected presence at said access opening.
25. The storage system of claim 23 wherein said sensing mechanism is operable to prevent departure of a given storage/retrieval vehicle from the access opening until a detection counter equals a quantity associated with a current task to which the given storage/retrieval vehicle has been assigned.
26. The storage system of claim 20 wherein conveyance of the storage units between the at least one working station and the storage locations is performed solely by said one or more storage/retrieval vehicles.
27. The storage system of claim 20 wherein the storage system is free of any conveyors operating between the three-dimensional structure and the at least one working station.
28. The storage system of claim 16 wherein the storage units are conveyed through the at least one working station by the one or more storage/retrieval vehicles.