

A GOODS HANDLING SYSTEM

Field of the Invention

5 The present invention relates to a goods handling system of the type wherein goods are stored in and retrieved from a goods storage area in an at least partially automated way.

Background of the Invention

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It is known to provide an at least partially automated goods handling system wherein goods stored in a goods storage area are transported between the goods storage area and operator stations using transportation vehicles, typically in the form of transportation robots. With one such system, the transportation vehicles are navigated
15 through the goods storage area using machine detectable tape that is disposed on the floor of a warehouse along defined movement paths, or by using lasers that interact with reflective material, for example disposed on walls of the warehouse.

However, such existing goods handling systems require relatively complex
20 transportation vehicles and do not control the positions of the transportation vehicles with precision.

Summary of the Invention

25 In accordance with a first aspect of the present invention, there is provided a goods handling system comprising:

a plurality of markers, each marker having associated unique identification information;

at least one vehicle, each vehicle including at least one sensor arranged to
30 detect a marker and obtain the unique identification information associated with the marker, and each vehicle arranged to controllably transport items between defined locations; and

a data storage device including information indicative of each marker and navigation information associated with each marker, the navigation information
35 indicative of the location of at least one defined other marker relative to the marker, and the navigation information usable to control movement of a vehicle between the marker and the at least one defined other marker;

wherein the system is arranged to define a transportation path between defined locations, the transportation path defined by a plurality of selected markers, and the system arranged to control movement of a vehicle between the defined locations by using the navigation information associated with each marker.

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In an embodiment, each marker comprises a machine readable pattern and may include a barcode or QR code.

In an embodiment, each marker comprises a RFID device.

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In an embodiment, the system includes at least one operator station and the system is arranged to controllably move each vehicle to and from an operator station.

In an embodiment, the system includes a plurality of item racks and each vehicle is arranged to controllably transport a rack to and from an operator station.

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In an embodiment, each vehicle includes a contact member and a lifting device arranged to controllably raise or lower the contact member and thereby raise or lower the rack relative to the ground.

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The markers may include rack markers, each rack marker disposed adjacent or under a rack when the rack is disposed at a rack storage location.

The markers may include warehouse markers disposed on a rack, or disposed between a rack storage location and the at least one operator station.

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In an embodiment, the operator station includes a station queue, wherein vehicles arriving at the operator station enter the station queue, and an operator places one or more items on the rack or removes one or more items from the rack when the vehicle is in the station queue. The markers may include at least one queue entry marker disposed adjacent an entry location of the station queue, and at least one queue exit marker disposed adjacent an exit location of the station queue.

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The operator station may include at least one order bin, each order bin for receiving at least one item forming part of an order, and each order bin having an associated visual indicator arranged to provide a visual indication to an operator to indicate to the operator the order bin in which the or each items of an order should be placed.

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The operator station may also include a pointing device arranged to provide a visual indication to an operator to indicate to the operator which item should be picked from a rack or the location on a rack where an item should be placed. The pointing device
5 may include a laser pointer.

In an embodiment, items associated with the system are provided with machine readable identifiers, for example in the form of barcodes, and the operator station may also include a scanner arranged to scan the identifiers so as to obtain item
10 identification information. The item identification information may be used to determine whether an item picked from a rack is correct or whether an item to be placed on a rack is correct.

In an embodiment, the system includes a management system in wireless
15 communication with the vehicles, the management system arranged to provide the instructions to control movement of a vehicle between the defined locations by using the navigation information associated with each marker.

In an embodiment, the system is arranged to transfer control of movement of a vehicle
20 to the operator station when the vehicle is in the station queue.

In an embodiment, the navigation information defines a navigation path between markers in a transportation path, the system is arranged to determine an offset displacement between the vehicle and an adjacent marker, and the system is arranged
25 to use the determined offset displacement to calculate a compensation path, the compensation path modifying the navigation path to produce a compensated navigation path used to control movement of the vehicle between the markers.

In an embodiment, the compensation path is a Bezier curve.
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In an embodiment, the navigation path is divided into a plurality path segments, and the system is arranged such that instructions to control movement of the vehicle are providable at the start of each path segment.

35 In an embodiment, the system is arranged to determine an offset displacement between the vehicle and an adjacent marker by capturing an image that includes the adjacent marker and processing the image to determine the distance between a

centroid of the adjacent marker and a centroid of the captured image. The image may be processed using an OpenCV function such as minAreaRect. In an embodiment, the image is processed so as to determine the coordinates of the corners of the adjacent marker, the corner coordinates being used to determine the angle of rotation of the adjacent marker.

In an embodiment, the velocity of a vehicle is dependent on whether the vehicle is loaded with a rack.

In an embodiment, each vehicle includes a weighing device arranged to weigh a rack when the rack is raised relative to the vehicle, the velocity of the vehicle being dependent on the weight of the rack.

In an embodiment, the weighing device is used to determine a weight distribution profile by using the known centre of gravity of an empty rack, the known weight of each item and the positions of the items on the rack. The weight distribution profile may be used to calculate the centre of gravity of the rack and loaded items, and to determine whether the centre of gravity of the loaded rack is within a defined range.

The navigation information may comprise a displacement value and a bearing value.

In an embodiment, the system is arranged to store information indicative of the locations of all vehicles relative to the markers.

In an embodiment, the system is arranged to store inventory information indicative of all items associated with the goods handling system including the respective racks on which the items are located and the locations on the racks where the items are located.

In an embodiment, the system comprises an order manager arranged to manage timing of order processing, for example based on when an order bin at an operator station becomes free. The order manager may be arranged prioritise order processing based on the expected time taken to fulfil the order.

In an embodiment, the order manager may be arranged to determine a combination of racks to use to fulfil an order using the following heuristic:

$$\text{Heuristic, } H = \text{Distance} / (1 + \text{No of Common Racks})$$

where *Distance* is the combined distance of all racks in a rack combination from an available order bin, and *No of Common Racks* is the number of racks in the rack combination that are common to more than one rack set.

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In an embodiment, the system comprises a task manager arranged to determine a set of vehicles to use to fulfil an order.

10 In an embodiment, the system comprises a path calculator arranged to calculate a transportation path for each vehicle in the selected set of vehicles, for example using an A* algorithm.

15 In an embodiment, the system comprises a vehicle navigator arranged to manage movement of each vehicle individually. The vehicle navigator may be arranged to receive the unique identification information associated with a detected marker from a vehicle, and in response to communicate the navigation information associated with the detected marker to the vehicle.

20 In an embodiment, the system is arranged to manage movements of the vehicles so as to avoid collisions between the vehicles, for example by facilitating reservation of markers and/or navigation paths, managing the timing or movements and/or speed of the vehicles, and/or controlling vehicles so as to move temporarily outside the transportation path.

25 In accordance with a second aspect of the present invention, there is provided a method of handling goods, the method comprising:

disposing a plurality of markers in a defined area, each marker having associated unique identification information;

30 providing at least one vehicle, each vehicle including at least one sensor arranged to detect a marker and obtain the unique identification information associated with the marker, and each vehicle arranged to controllably transport items between defined locations; and

35 storing information indicative of each marker and navigation information associated with each marker, the navigation information indicative of the location of at least one defined other marker relative to the marker, and the navigation information usable to control movement of a vehicle between the marker and the at least one defined other marker;

defining a transportation path between defined locations, the transportation path defined by a plurality of selected markers; and

controlling movement of a vehicle between the defined locations by using the navigation information associated with each marker.

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In accordance with a third aspect of the present invention, there is provided a navigation system for navigating a vehicle, the system comprising:

at least one sensor arranged to detect a marker adjacent the sensor;

the system arranged to use navigation information indicative of the location of

10 at least one defined other marker relative to the detected marker to control movement of the vehicle along a navigation path between the detected marker and the other marker; and

the system arranged to determine an offset displacement between the vehicle and the detected marker, and to use the determined offset displacement to calculate a compensation path, the compensation path modifying the navigation path to produce a compensated navigation path used to control movement of the vehicle between the markers;

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wherein the compensation path comprises a Bezier curve.

20 **Brief Description of the Drawings**

The present invention will now be described, by way of example only, with reference to the accompanying drawings, in which:

25 Figure 1 is a block diagram of a goods handling system in accordance with an embodiment of the present invention;

Figure 2 is a diagrammatic representation of a warehouse in which the goods handling system shown in Figure 1 is implemented;

Figure 3 is a diagrammatic representation of a transportation vehicle of the goods handling system shown in Figure 1;

30 Figure 4 is a diagrammatic representation illustrating a transportation vehicle transporting a goods rack of the goods handling system shown in Figure 1;

Figure 5 is a diagrammatic representation of an operator station of the goods handling system shown in Figure 1;

35 Figure 6 is a diagrammatic representation illustrating relationships between markers of the goods handling system according to graph theory;

Figure 7 shows contents of a map database;

Figure 8 is a block diagram illustrating functional components of a management

system of the goods handling system shown in Figure 1;

Figure 9 is a block diagram illustrating functional components of a transportation vehicle of the goods handling system shown in Figure 1;

Figure 10 is a block diagram illustrating functional components of an operator station of the goods handling system shown in Figure 1;

Figure 11 is a flow diagram illustrating steps of a new inventory process;

Figure 12 is a flow diagram illustrating an item picking process;

Figure 13 is a flow diagram illustrating an order fulfilment process; and

Figure 14 is a diagram illustrating methodology used for compensation of a navigation path of a transportation vehicle.

Description of an Embodiment of the Invention

Referring to the drawings, Figure 1 shows a goods handling system 10 diagrammatically, the goods handling system 10 including a plurality of goods racks 12, each of which is capable of containing several goods items that may be included in an order, one or more operator stations 14 and a plurality of transportation vehicles 16 that transport goods racks 12 between a goods storage area 23 and one or more operator stations 14. In this example, the transportation vehicles are transportation robots. Movement of the transportation vehicles 16 is managed by a management system 18 in communication with both the operator station(s) 14 and the transportation vehicles 16, in this example through a wireless communication network 19.

During use, items to be stored in the goods storage area 23 are transported between the operator station(s) 14 and the goods storage area 23 by the transportation vehicles 16, and orders are at least partially automatically fulfilled by transporting racks 12 containing items included in the order from the goods storage area 23 to the operator station(s) 14. The inbound inventory process and outbound order fulfilment process are managed in this example by the management system 18.

An example a warehouse is shown diagrammatically in Figure 2.

As shown, the warehouse includes a plurality of markers 20, in this example disposed on a floor 21 of the warehouse. The racks 12 are stored in a goods storage area 23. In this example, the markers can be categorised as warehouse markers 20a disposed generally between the goods storage area 23 and the operator station(s) 14; rack markers 20b each of which is associated with and disposed under a rack 12 when the

associated rack 12 is disposed at a defined storage location in the goods storage area 23; queue entry markers 20c, each of which is disposed at an entry location of a station queue 22; and queue exit markers 20d, each of which is disposed at an exit location of the station queue 22. It will be understood, however, that markers may in addition or alternatively be disposed elsewhere, such as on the racks 12 themselves or on walls.

In this example, the markers 20 are in the form of machine readable barcodes, although it will be understood that any machine readable markers that are capable of being individually identified are envisaged, for example RFID tags or QR codes.

Each marker 20 is associated with unique identification information that is linked to navigation information usable to control movement of a transportation vehicle between the marker 20 and at least one defined other marker 20. For each marker 20, the navigation information defines the direction and distance between the marker 20 and each other marker that has been associated with the marker, typically other markers that are adjacent the marker 20. Using the navigation information, navigation paths can be defined between markers 20 by identifying each marker as a transportation vehicle 16 passes over or adjacent to the marker, and successively navigating to other markers in sequence using the stored navigation information. In order to navigate a vehicle 16 between a source marker and a destination marker, a transportation path is defined that indicates a sequence of markers between the source and destination markers 20, each of which has associated navigation information defining a navigation path between the marker and a subsequent marker in the transportation path.

It will be appreciated that since each marker 20 has navigation information associated with it that is used to instruct a vehicle 16 to move from the marker 20 to an adjacent marker 20, the markers 20 do not need to be disposed on the floor 21 of the warehouse in any defined pattern, and the markers 20 may be disposed on the floor 21 at locations that are appropriate for the configuration of the warehouse. In addition, markers 20 may be disposed elsewhere, for example on walls or racks.

A transportation vehicle 16 is shown more particularly in Figure 3. The transportation vehicle 16 includes a body 30, wheels 34, at least some of which are individually controllable so as to control the speed and direction of movement of the transportation vehicle 16, and a contact plate 36 that may be controllably raised or lowered relative to the body 30 in order to raise or lower a goods rack 12 disposed above the

transportation vehicle 16, and thereby facilitate transport of the goods rack 12 between the goods storage area 23 and an operator station 14.

5 A goods rack 12 carried by a transportation vehicle 16 is shown in Figure 4. As shown, the contact plate 36 is disposed in a raised position and consequently the goods rack 12 is raised relative to the floor 21, in this example by about 5cm.

10 The goods rack 12 includes several shelves 40, each of which incorporates several defined item receiving locations that are capable of receiving goods items 42. The item receiving locations may be separated using compartments.

15 An operator station 14 is shown more particularly in Figure 5. The operator station 14 may be referred to as a pick/put station since the operator station 14 is used for both adding new goods items to the goods storage area 23 and retrieving items forming part of an order from the goods storage area 23.

20 The operator station 14 in this example includes a plurality of order bins 46, each order bin 46 being used to receive items that form part of an order as the order is being processed. It will be understood that since retrieval of items in an order is automated, and disposal of the items in the order bins 46 is controlled by the system 10, the system 10 is capable of fulfilling multiple orders at the same time.

25 The operator station 14 is shown during an order fulfilment process wherein goods items 42 forming part of an order are retrieved from the goods storage area 23 and disposed in an order bin 46 by an operator, the order bin 46 being assigned to the order by the system 10.

30 The operator station 14 includes a control unit 48 arranged to control and coordinate operations in the operator station 14, a pointing device 50, in this example in the form of a laser pointer, and a scanner 52, in this example arranged to scan an identifier disposed on a goods item 42. The identifier may be any readable device such as a barcode.

35 During use, when goods items 42 are transported to the operator station 14 by a transportation vehicle 16, an item 42 that forms part of an order currently being fulfilled is identified by the pointing device 50, in this example by directing a laser pointer towards the item 42. After removing the identified item 42 from the rack 12, the

operator at the operator station 14 scans a barcode on the item 42 using the scanner 52, which causes the item 42 to be verified by the control unit 48, thereby ensuring that the correct item 42 for the current order has been removed from the rack 12. The appropriate order bin 46 for the item 42 is then indicated to the operator, for example
 5 by illuminating a light at the order bin 46.

As discussed above, each marker 20 has associated navigation information that identifies how to travel from the marker to one or more other markers, for example that are located adjacent to the marker. In this way, a marker map is defined for all
 10 markers, with each marker 20 having associated information that effectively defines the location of the marker relative to other markers.

Referring to Figure 6, a graph theory representation 60 of the marker map is shown. The graph theory representation 60 includes nodes 62, each of which represents a
 15 marker 20, and edges 66 indicating that a connection exists between two markers 20 because the position of the markers 20 relative to each other has been defined and associated with the markers 20.

The data indicative of each marker 20, the data indicative of the other markers 20
 20 linked to each marker 20, and the navigation information indicative of the positions of the other markers relative to each marker 20 are stored in a database, the contents of which are shown in a table 70 shown in Figure 7.

The table 70 includes a source field 72 containing unique information identifying a
 25 source marker; a destination field 74 specifying a destination marker; a method of traversal field 76 that indicates whether a transportation vehicle is required to travel over relatively flat ground, in an elevator or on an incline between the source and destination markers; and details 78 of the direction, elevation and distance navigation values that define the navigation information required for a transportation vehicle 16 to
 30 move along a navigation path from the source marker to the destination marker; and a cost field 80 that indicates the respective 'cost' of the transportation vehicle moving along the navigation path in terms of the time taken.

In the present example data shown in Figure 7, the goods storage area 23 is disposed,
 35 over several levels of a building and, as such, in order to travel between different levels of the building the transportation vehicle 16 is required to travel in an elevator. For this purpose, a marker may be disposed in the elevator. As shown in the table 70, for a

marker disposed in an elevator, the source and destination fields 72, 74 also include information indicative of the current floor at which the elevator is disposed, and the details field 78 includes information that uniquely identifies the elevator.

5 Functional components 81 of the management system 18 are shown in Figure 8. The functional components 81 may be implemented using any suitable arrangement, for example using a suitable computing device with associated processor(s), memory and data storage.

10 The functional components 81 include a data storage device 82, represented in Figure 8 as a database, although it will be understood that any suitable data storage arrangement is envisaged. The data storage device 82 is arranged to store map data 83 indicative of a marker map of the type represented in Figures 6 and 7, the map data 83 including the unique identifying information associated with each marker 20 and the
15 navigational relationships between each marker 20 and at least one other marker 20 that is associated with each marker.

The functional components 81 also include an inventory manager 84 arranged to manage the process of adding new goods items 42 to the warehouse, and to record
20 the current inventory of goods items 42 in an inventory database 86. The inventory database 86 also includes information indicative of the respective storage locations of the racks 12 in the warehouse and of the locations of the goods items 42 on the racks 12. In this way, the storage locations of all items in the warehouse are known.

25 The functional components 81 also include an order generator 88 arranged to manage receipt of orders from customers, for example received through an on-line checkout system that may be associated with an electronic commerce website. Created orders are managed by an order manager 90 that stores details of the created orders as order entries in a pending orders database 92.

30 The order manager 90 also manages the timing of fulfilment of the pending orders in the orders database 92, and in this example the order manager 90 is arranged to instigate processing of a pending order when a trigger signal is generated to indicate that an order bin 46 at an operator station 14 is available to fulfil an order. The order
35 manager 90 manages the sequence of fulfilment of pending orders by calculating a 'cost' of each pending order and instigating fulfilment of orders based on minimum 'cost'. The order 'cost' is related to the time taken to transport all of the required racks

for an order to a designated operator station 14.

For each order selected for processing, an operator station 14 is selected, a rack 12 or set of racks 12 that include the items 42 required for the order are reserved, and an
5 order bin at the operator station 14 is reserved.

In order to calculate the cost of a pending order, for each item all racks 12 that could potentially provide the item are first identified and a rack set listing the identified racks for the item is defined.

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A rack combination comprising a rack selected from each rack set is then selected from the determined rack sets by calculating the following heuristic for each rack combination:

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$$\text{Heuristic, } H = \text{Distance} / (1 + \text{No of Common Racks})$$

where *Distance* is the combined distance of all racks in a rack combination from an available order bin 46, and *No of Common Racks* is the number of racks in the rack combination that are common to more than one rack set.

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The heuristic H is calculated for all free order bins of the operator stations 14.

The rack combination with the minimum heuristic H value is selected and the 'cost' associated with the selected rack combination is the time required for all racks in the
25 combination to move to the operator station 14 of the selected order bin 46.

The racks 12 that are included in the selected rack combination are reserved and identified as such in a reserved database 94. Similarly, the selected operator station 14 and the selected order bin 46 at the operator station 14 are also reserved by
30 specifying the selected operator station 14 and order bin 46 in the reserved database 94.

The functional components 81 also include a task manager 96 arranged to select at least one transportation vehicle 16 for fulfilment of an order when the order is selected
35 for processing. The transportation vehicles 16 are selected based on availability, task priority and 'cost'. Firstly, the available transportation vehicles 16 are identified, and within the identified available transportation vehicles 16 a set of transportation vehicles

are selected based on proximity of the transportation vehicles 16 to the racks 12 in the selected rack combination for the order. Each selected transportation vehicle 16 is assigned a task to retrieve a particular rack 12 from the goods storage area 23. The transportation vehicles 16 selected for the order are stored in an assigned vehicles database 98.

The functional components 81 also include a planner 100 arranged to control and coordinate planning of navigation paths for the selected transportation vehicles, and manage implementation of the movements of the transportation vehicles to and from the selected operator station 14, including control over vehicle start/stop actions and vehicle pausing/unpausing actions. The planner 100 also manages charging of the transportation vehicles 16, including checking the charge state of the vehicles 16 and movement of the vehicles 16 requiring charging to a vehicle charging station.

The planner 100 includes a path calculator 102 arranged to calculate transportation paths for each of the transportation vehicles 16 in the set of transportation vehicles selected for fulfilment of an order. Each transportation path defines a sequence of markers 20 that a transportation vehicle 16 will follow in order to transport a rack 12 to a rack storage location in the goods storage area 23 and between the rack storage location and the operator station 14. Calculated transportation paths for each transportation vehicle 16 are stored in a defined paths database 103. The 'cost' of each defined transportation path is based on the time taken to travel from source to destination.

In the present example, the transportation paths for the transportation vehicles 16 are calculated using an A* algorithm. This type of algorithm uses the relationship between the markers 20, in this example defined according to graph theory and represented in Figure 6, to calculate an efficient path through the markers 20 from a source marker to a destination marker.

The planner 100 also includes a vehicle navigator 104 arranged to manage movements of each transportation vehicle 16 individually according to the respective transportation paths defined for the vehicles 16. The vehicle navigator 104 is responsible for controlling movement of a vehicle 16 along the sequence of markers in the transportation path, and handling communications received from the vehicles 16.

As a vehicle 16 arrives at a marker 20, the marker is detected by the transportation

vehicle 16 and unique identification information associated with the detected marker 20 is communicated to the vehicle navigator 104 through the wireless communication network 19. Based on the received information, the vehicle navigator 104 verifies that the identified marker 20 corresponds to the expected marker in the transportation path, and communicates navigation information to the vehicle 16 in order to direct the vehicle 16 to a subsequent marker 20 in the transportation path. In this example, the navigation information is in the form of a bearing value and a distance value derived from the navigation information stored in the map database 83 and shown in tabular form in Figure 7.

The vehicle navigator 104 also calculates the position of a centroid of the vehicle 16 relative to a marker 20, and the orientation of the vehicle 16 relative to the marker 20 using the image captured by the sensor/camera 134, and thereby the offset position of the vehicle 16 relative to a detected marker 20.

The current positions of the transportation vehicles 16 are stored in a vehicle location database 105, and in this way, the planner is aware of the locations of all vehicles 16 in the system 10 at all times.

The vehicle navigator 104 may also be arranged to manage movements of the vehicles 16 so that collisions are avoided.

In one arrangement, collision management is achieved by managing the path and marker reservations, for example such that each navigation path between 2 markers is reserved shortly before the vehicle 16 arrives, but movement in a subsequent navigation path is not allowed until the navigation path is reserved. If the navigation path is already reserved by another vehicle, then the vehicle wishing to reserve the navigation path will need to wait.

However, because the full transportation path for each vehicle is not reserved, this arrangement may result in a deadlock situation because 2 vehicles may wish to move in opposite directions along similar paths, but in order to do so, one of the vehicles will need to move out of the way.

In order to overcome a deadlock situation, the vehicle navigator 104 may be arranged to actively control one of the vehicles involved in the deadlock situation to move away from the designated path, thereby allowing the other vehicle in the deadlock situation

to move according to its designated transportation path.

Alternatively, the vehicle navigator 104 may be arranged to actively prevent deadlock situations from occurring. When the vehicle navigator 104 attempts to reserve a
5 marker 20 for a vehicle 16, the vehicle navigator 104 checks whether another vehicle 16 also has a transportation path defined that passes through the marker 20, and if so, then the vehicle navigator 104 reserves markers 20 for the vehicle 16 as safety reservations. For markers 20 reserved as safety reservations, another transportation vehicle 16 cannot reserve a marker 20 in the safety reservations unless a marker is
10 also reserved that enables the other vehicle 16 to exit the safety reserved marker 20. In other words, after safety reservation, no other vehicle will be allowed to remain in the safety reserved region.

Collisions and deadlocks may be prevented by managing movements of the
15 transportation vehicles based on the reserved markers and navigation paths, and by controlling the timing of movements of the vehicles 16. Collisions may then be avoided by causing a vehicle 16 to wait, or by actively modifying the speed of movement of a vehicle 16. Should any deadlock situations arise, the above procedure may be followed.

20 The planner 100 also includes a reservation manager 106 arranged to manage reservations of markers and navigation paths between markers 20, for example in order to avoid collisions between vehicles 16, and to store information indicative of the reserved markers and navigation paths in a reserved paths and markers database 108.

25 The planner 100 also includes a vehicle manager 110 arranged to control vehicle start and stop instructions, and movement of the contact plate 36 between raised and lowered positions. The vehicle manager 110 also manages the charge level of the vehicles 16, including checking the charge state of the vehicles 16 and managing
30 movement of the vehicles 16 requiring charging to a vehicle charging station.

The functional components 81 of the management system 18 also include a network interface 112 arranged to facilitate networked communications between the management system 18, the transportation vehicles 16 and the operator stations 14.

35 Functional components 118 of a transportation vehicle 16 are shown in Figure 9.

The functional components 118 include a network interface 120 arranged to facilitate networked communications between the vehicle 16 and each of the management system 18 and the operator stations 14, and a microcontroller 122 arranged to control and coordinate operations in the transportation vehicle 16, and in particular to perform
5 dedicated tasks including managing detection of markers 20, managing control of vehicle movement according to instructions received from the vehicle navigator 104, and applying a compensation path to the determined transportation path between markers 20.

10 The microcontroller 122 communicates with a motor driver 124 that controls motors 126 associated with the vehicle wheels 34, and in this way the speed and direction of the vehicle 16 is controlled.

The functional components 118 also include a lifting device 130 arranged to
15 controllably raise or lower a contact plate 36 in response to instructions from the microcontroller 122 that are generated in response to instructions received from the vehicle manager 110.

The functional components 118 also include at least one sensor 134, for example that
20 includes a camera, arranged to detect a marker 20 when the vehicle 16 travels close to the marker 20 and to obtain from the marker 20 the unique identification information that is associated with the marker 20. The obtained unique identification information is communicated to the planner 100 by the microcontroller 122 so that the current location of the vehicle 16 is communicated to the planner 100.

25 The sensor(s)/camera 134 are also used to determine an offset between the location of the vehicle 16 and the location of the detected marker 20, the offset being used to modify the transportation path defined between the detected marker 20 and a subsequent marker 20 in the transportation path. This is achieved by capturing an
30 image including the marker and forwarding the image to the planner 100 for processing. Since the location and orientation of the captured image relative to the vehicle 16 is known, it is possible to determine the location and orientation of the marker relative of the vehicle 16.

35 The functional components 118 also include a weigher 138 arranged to produce a weight measurement when the vehicle 16 is transporting a rack 12, the weight measurement being used by the microcontroller 122 to calculate movement

parameters for a loaded vehicle 16, for example appropriate acceleration and deceleration parameters in consideration of the weight of the rack 12 being transported by the vehicle 16. The movement parameters may also be calculated based on whether the contact plate 36 is in a raised or lowered position.

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The weigher 138 is also used to determine a weight distribution profile by using the known centre of gravity of an empty rack 12, the known weight of each item and the positions of the items on the rack 12. The weight distribution profile is used to calculate the centre of gravity of the rack and loaded items, which is then used to ensure that the centre of gravity of the loaded rack 12 is within a defined range. This ensures that the loaded rack does not bounce too much during transportation.

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The z component of the centre of gravity of a loaded rack 12 is managed by managing the locations of the items on the rack 12 so that the centre of gravity is not too high. In addition, in relation to the x-y component of the centre of gravity, a cost value is calculated for all item receiving locations on the rack 12 each time an item is added to or removed from a rack 12, the cost value representing the amount that the loaded rack will deviate from the centre of gravity.

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The microcontroller 122 is arranged to implement defined functionality in the vehicle 16, including control of the motors 126 in response to instructions from the planner 100, control of the lifting device 130 in response to instructions from the planner 100, management of communications with the sensors/camera 134 and the weigher 138, and management of communications to and from the network interface 120..

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Functional components 139 of an operator station 14 are shown in Figure 10.

The functional components 139 include a network interface 140 arranged to facilitate networked communications between the operator station 14, the management system 18 and the vehicles 16, and a control unit 142 arranged to control and coordinate operations in the operator station 14.

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The control unit 142 is arranged to implement defined functionality, and in this example the control unit 142 implements an inward item process 144 and an outward items process 146.

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The inward items process 144 manages reception of new items of inventory into the

goods handling system 10, both in a physical sense wherein a new item 42 is disposed on a selected rack 12 and the rack 12 transported to a storage location in the goods storage area 23, and in an electronic sense wherein the presence and location of the item is recorded in the inventory database 86.

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The outward items process 146 manages retrieval of items from the goods handling system 10, both in a physical sense wherein an item forming part of an order is retrieved from a rack 12 in the good storage area 23, and in an electronic sense wherein a record of the retrieved item is removed from the inventory database 86.

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The functional components 139 also include the pointing device 50 and the scanner 52. The pointing device 50 cooperates with the inward and outward items processes 144, 146 to coordinate retrieval of the correct item(s) 42 from the rack(s) 12 and placement of items 42 at the correct locations on the rack(s). The scanner 52 is used to scan identifiers on the items 42, for example barcodes on the items, as they are picked from a rack 12 during order fulfilment or placed onto a rack 12 during addition of new inventory, the scanned barcodes enabling the operator station 14 to check and verify whether the scanned item 42 is correct.

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20 Referring to Figure 11, a flow diagram 160 is shown illustrating steps 162 to 180 of a new inventory process implemented by the system 10.

The new inventory process commences when items 42 of new inventory arrive 162 at the warehouse. For each item 42, an operator at an operator station 14 scans 164 an identifier, in this example a barcode on the item 42, using the scanner 52, and in response the operator station 14 communicates information indicative of the item 42 to the inventory manager 84 of the management system 18. The inventory manager 84 then adds a record of the item to the inventory database 86 and communicates the desired location of the item 42 in the goods storage area 23 to the operator station 14, in particular the rack 12 on which the item 42 should be stored and the location of placement of the item on the rack 12. Based on the location communication received from the management system 18, the inward items process 144 instructs a transportation vehicle 16 to retrieve 166 the relevant rack 12 from the goods storage area 23. After the rack 12 has been transported 168 to the operator station 14, the pointing device 50 indicates the location on the rack where the item should be placed, in this example by directing 170 a laser pointer at the location on the rack 12. If a further item is to be placed on the same rack 12, the further item is scanned 174 and

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placed on a particular location on the rack indicated to the operator using the pointing device 50. If no further items 42 are to be placed on the same rack 12, the rack is transported back 176 to a defined storage location in the goods storage area 23. The process then repeats for each other new item to be stored in the goods storage area 23.

Referring to Figure 12, a flow diagram 190 is shown illustrating steps 192 to 212 of an item picking process implemented by the system 10.

The item picking process commences 192 when an order is triggered for processing by the order manager 90 of the management system 18. For an item 42 forming part of the order, the vehicle navigator 104 instructs 194 a vehicle 16 to retrieve 196 the selected rack 12 from the goods storage area 23 by successively communicating navigation instructions to the vehicle 16 indicative of successive navigation paths to travel along between markers in the transportation paths in order for the vehicle 16 to travel to the selected rack 12, and for the vehicle to travel from the selected rack 12 to the operator station 14. When the selected rack 12 arrives 198 at the operator station 14, the pointing device 50 indicates the location on the rack where the item to be picked is located, in this example by directing 200 a laser pointer at the location on the rack 12.

The operator at an operator station 14 picks 202 the identified item 42 from the rack 12 and scans an identifier, in this example a barcode, on the item 42 using the scanner 52. In response, the operator station 14 communicates information indicative of the item 42 to the operator station 14 which uses the scanned information to verify 204 whether the correct item 42 has been picked. If the item is verified as correct, the information indicative of the item 42 is also communicated to the inventory manager 84 of the management system 18, which removes a record of the item from the inventory database 86. If a further item is to be picked from the same rack 12, the pointing device 50 indicates the location on the rack where the further item to be picked is located, and the above process repeats.

If no further items 42 are to be picked from the same rack 12, the rack is transported back 208 to a defined storage location in the goods storage area 23. The process then repeats for each other new item in the order that is to be retrieved from the goods storage area 23.

Referring to Figure 13, a flow diagram 220 is shown illustrating steps 222 to 278 of an order fulfilment process including steps for controlling movements of the transportation vehicles 16.

- 5 Orders are received 222 at the management system 18 using an order generator 88, for example through an electronic commerce website, and the received orders are recorded in the orders database 92 by the order manager 90 and placed 224 in an order queue. When an order is triggered 226 for fulfilment, the task manager 96 determines 228 the preferred rack combination 12 for fulfilment of the order based on
- 10 the heuristic described above, and the task manager 96 determines 230 the best transportation vehicle 16 to carry out retrieval of each of the determined racks 12 based on the locations of the vehicles 16 relative to the racks 12.

- 15 For each rack 12 in the rack combination, the path calculator 102 at the management system 18 calculates 232 the transportation path to be followed by a vehicle 16 during retrieval of the rack and transportation of the rack 12 back to the goods storage area 23. In this example, the transportation path is calculated using an A* algorithm. The transportation path defines the sequence of markers 20 through which a vehicle 16 will pass in order to travel from its current location to the relevant rack 12 in the goods
- 20 storage area 23, or the sequence of markers 20 through which a vehicle 16 will pass in order to travel from the goods storage area 23 to the operator station 14.

- 25 For each vehicle 16 assigned to retrieve a rack 12 from the goods storage area 23, the vehicle navigator 104 communicates navigation instructions to the vehicle 16, which indicates to the vehicle how to travel from the current marker 20 to a subsequent marker 20 in the defined transportation path. Such navigation information includes direction information, for example in the form of a bearing, and distance information indicative of the distance between the current marker and the subsequent marker. When the vehicle 16 arrives at the subsequent marker 20, the vehicle 16 reads the
- 30 unique identification information associated with the subsequent marker 20 using the sensors 134, and communicates the information indicative of the subsequent marker 20 to the vehicle navigator 104. If the subsequent marker 20 is not a rack marker 20b, then the vehicle navigator 104 communicates further navigation instructions to the vehicle 16, which indicates to the vehicle how to travel from the current marker 20 to a
- 35 further subsequent marker 20 in the defined transportation path. This process continues until the subsequent marker 20 is a rack marker 20b.

When the vehicle 16 arrives at the rack marker 20b disposed underneath the rack 12 to be retrieved, the position of the vehicle 16 relative to the rack 12 is determined using the sensors 134, and if necessary the vehicle 16 moves 240 relative to the rack in order to properly align the vehicle 16 with the rack 12. After alignment, if necessary,
 5 the vehicle manager 110 sends a communication to the vehicle 16 to instruct 242 the vehicle 16 to raise the rack 12 from the ground by raising the contact plate 36 from the lowered position to the raised position.

The vehicle then starts to move towards the operator station 14 along a further defined
 10 transportation path. As with movement towards the rack 12, the vehicle navigator 104 communicates navigation instructions to the vehicle 16, which indicates to the vehicle how to travel from the current rack marker 20b to a subsequent marker 20 in the defined transportation path. Such navigation information includes direction information, for example in the form of a bearing, and distance information indicative of
 15 the distance between the current marker and the subsequent marker. This process continues until the subsequent marker 20 is a queue entry marker 20c.

When the vehicle 16 arrives at a queue entry marker 20c, control over vehicle movement is transferred 250 from the management system 18 to the operator station
 20 14, which then causes the vehicles 16 and associated racks 12 in the station queue 22 to move sequentially 252 towards a pick point adjacent an operator. When a vehicle with a rack 12 arrives at the pick point, the pointing device 50 indicates the location on the rack where the item to be picked is located, in this example by directing 256 a laser pointer at the location on the rack 12, and the operator picks the item 42. The operator
 25 then scans the item 42 and the system verifies whether the item that has been picked from the rack 12 is correct. If the item 42 is correct, the operator places the item in the assigned order bin 46. The process repeats for all further items to be picked from the same rack 12. When no further items 42 are to be picked from the rack 12, the vehicle 16 and rack 12 are controlled by the operator station so as to move 264 toward a
 30 queue exit marker 20d at an exit of the station queue 22. When the vehicle detects the queue exit marker 20d, control over vehicle movement is transferred back 266 from the operator station 14 to the management system 18, and the vehicle 16 transports the rack 12 back to the relevant storage location in the goods storage area 23. At the storage location in the goods storage area 23, the vehicle manager 110 sends a
 35 communication to the vehicle 16 to instruct 274 the vehicle 16 to lower the rack 12 to the ground by lowering the contact plate 36.

If further items 42 are included in the order, the process repeats for transportation of each other rack 12 from the goods storage area 23 to the operator station 14 and back to the goods storage area 23 until all items 42 in the order are disposed in the order bin 46.

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Referring to Figure 14, a vehicle 16 is shown diagrammatically adjacent a first marker 282. The vehicle 16 is travelling towards a second subsequent marker 284 and the navigation path 285 in this example is a straight line between the first and second markers 282, 284.

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As shown, the vehicle 16 centroid 286 is offset from the first marker 282 by a distance ΔX , ΔY . In order to compensate for the offset, a correction path 288 is defined that extends between the centroid 286 and the navigation path 285.

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In the present embodiment, the correction path 288 to apply to the uncorrected navigation path 285 is calculated using the offset distance ΔX of the centroid 286 from the first marker 282 along the x axis, the offset distance ΔY of the centroid 286 from the first marker 282 along the y axis, and the difference in the direction vectors of the transportation vehicle 16 and the uncorrected navigation path 285. In this example, the correction path 288 is a Bezier curve formed using this information.

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It will be understood that the speed of turns experienced by the vehicle 16 as the vehicle 16 moves along the correction path may take into account whether the vehicle 16 is loaded with a rack 12 or not and, if so, the weight of the rack 12.

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A velocity profile is determined for the uncorrected navigation path 285, the velocity profile including an acceleration profile, a constant velocity profile and a deceleration profile, the velocity profile is modified using the correction path.

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The navigation path between adjacent markers 282, 284 is divided into a plurality of segments, in this example 500 segments, and as movement of the vehicle 16 commences a timer and a wheel counter are started. A segment counter maintains a record of the current segment. The respective velocities of the wheels 34 can be set at the start of each segment. After every 500 μ s, the timer is interrupted and the count read. If the count is at least equal to an expected count, the segment number is incremented.

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After a defined proportion of the corrected navigation path, for example approximately 95% of the corrected navigation path, the transportation vehicle 16 is instructed by the vehicle navigator 104 to attempt to detect the second marker 284.

- 5 The offset distances ΔX , ΔY of the centroid 286 from the first marker 282 are calculated, in this example by the vehicle navigator 104, based on the image including the first marker that is captured by the sensor/camera 134 in the vehicle 16.

10 The location and orientation of the sensor/camera 134 relative to the vehicle 16 is determined, in this example using a jig, and a permanent offset calculated that represents the default distance between the centre of the vehicle 16 and the centre of the image captured by the sensor/camera 134.

15 The location and orientation of the first marker 282 in the captured image is then determined using image processing techniques, the centroid of the first marker 282 calculated and the offset between the first marker 282 and the centre of the vehicle 16 determined.

20 In the present example, the location and orientation of the first marker 282 is determined using OpenCV image processing algorithms, although it will be understood that any suitable image processing techniques are envisaged.

25 In this example, the coordinates of the corners of the first marker 282 and the coordinate of the centre of the first marker 282 are determined using OpenCV function `minAreaRect`, and the corner coordinates used to determine the angle of rotation of the first marker 282. The distance between the centre of the first marker 282 and the centre of the captured image represents the offset distances ΔX , ΔY .

30 As an alternative, the offset distance may be determined using suitable sensors such as a plurality of lasers that are used to measure distance, with the position of the centroid of the vehicle 16 relative to the marker 20 calculated using triangulation techniques. However, other relative position determining arrangements are envisaged.

35 The planner 100, for example the vehicle navigator 104, may also be arranged to calculate speed and acceleration information for movement of the vehicle 16 based on the transportation path to be followed by the vehicle 16 and based on the offset position of the vehicle 16 from the detected marker 20. The calculated speed,

acceleration and direction information are communicated to the motor driver 124 during movement of the vehicle 16.

Modifications and variations as would be apparent to a skilled addressee are deemed
5 to be within the scope of the present invention.

The invention claimed is:

1. A method for path correction of a vehicle travelling from a first marker to a second marker, the method comprising:
 - computing, by circuitry of an information processing apparatus, an offset in a location of the vehicle with respect to the first marker;
 - dividing a distance between the first marker and the second marker into a predetermined number of segments;
 - computing a speed profile of the vehicle based on the distance between the first marker and the second marker;
 - generating a compensation curve based on the computed offset and a plurality of interpolation points; and
 - modifying, upon each segment being traversed by the vehicle, the speed profile of the vehicle.
2. The method according to claim 1, wherein the offset is computed based on a first displacement of the vehicle with respect to the first marker along a first reference axis, and a second displacement of the vehicle with respect to the first marker along a second reference axis, and wherein the offset has a magnitude corresponding to a displacement between a predetermined reference point of the vehicle at the location and a center of the first marker.
3. The method according to claim 2, wherein the first reference axis lies along a line connecting the center of the first marker to a center of the second marker, and wherein, the second reference axis is perpendicular to the first reference axis.
4. The method according to claim 1, further comprising:
 - computing by the circuitry, for each interpolation point of the plurality of interpolation points, coordinates along a first reference axis and a second reference axis, the coordinates being computed based on an angular deviation of the vehicle with respect to the first marker.
5. The method according to claim 1, wherein the compensation curve is a polynomial curve.

6. The method according to claim 1, wherein the modifying step further comprises:
 - receiving, an image captured by the vehicle, when the vehicle is disposed within a predetermined range of the first marker;
 - processing, by the circuitry, the received image to compute the offset; and
 - transmitting, an instruction to control a motion of the vehicle at each segment.
7. The method according to claim 1, wherein the vehicle includes a weighing device arranged to weigh items transported by the vehicle, the speed profile of the vehicle being modified based on at least one of the weight of the items and a reading of a wheel counter disposed on the vehicle.
8. The method according to claim 1, wherein the computing the speed profile step comprises:
 - computing based on a distance between the first marker and the second marker, an acceleration distance, a deceleration distance, and a maximum speed of traversal of the vehicle.
9. An information processing apparatus, the information processing apparatus comprising:
 - circuitry configured to compute an offset in a location of a vehicle with respect to a first marker, divide a distance between the first marker and a second marker into a predetermined number of segments, compute a speed profile of the vehicle based on the distance between the first marker and the second marker, generate a compensation curve based on the computed offset and a plurality of interpolation points, and modify, upon each segment being traversed by the vehicle, the speed profile of the vehicle.
10. The information processing apparatus according to claim 9, wherein the offset is computed based on a first displacement of the vehicle with respect to the first marker along a first reference axis, and a second displacement of the vehicle with respect to the first marker along a second reference axis, and wherein the offset has a magnitude corresponding to a displacement between a predetermined reference point of the vehicle at the location and a center of the first marker.

11. The information processing apparatus according to claim 10, wherein the first reference axis lies along a line connecting the center of the first marker to a center of the second marker, and wherein, the second reference axis is perpendicular to the first reference axis.
12. The information processing apparatus according to claim 9, wherein the circuitry is further configured to: compute, for each interpolation point of the plurality of interpolation points, coordinates along a first reference axis and a second reference axis, the coordinates being computed based on an angular deviation of the vehicle with respect to the first marker.
13. The information processing apparatus according to claim 9, wherein the compensation curve is a polynomial curve.
14. The information processing apparatus according to claim 9, wherein the circuitry is further configured to receive an image captured by the vehicle, when the vehicle is disposed within a predetermined range of the first marker;
process the received image to compute the offset; and
transmit an instruction to control a motion of the vehicle at each segment.
15. The information processing apparatus according to claim 9, wherein the vehicle includes a weighing device arranged to weigh items transported by the vehicle, the speed profile of the vehicle being modified based on at least one of the weight of the items and a reading of a wheel counter disposed on the wheel.
16. The information processing apparatus according to claim 9, wherein the circuitry is further configured to compute, based on a distance between the first marker and the second marker, an acceleration distance, a deceleration distance, and a maximum speed of traversal of the vehicle.
17. A non-transitory computer readable medium having stored thereon a program that when executed by a computer, causes the computer to execute a method for path correction of a vehicle travelling from a first marker to a second marker, the method comprising:

computing an offset in a location of the vehicle with respect to the first marker;
dividing a distance between the first marker and the second marker into a predetermined number of segments;
computing a speed profile of the vehicle based on the distance between the first marker and the second marker;
generating a compensation curve based on the computed offset and a plurality of interpolation points; and
modifying, upon each segment being traversed by the vehicle, the speed profile of the vehicle.

18. The non-transitory computer readable medium according to claim 17, wherein the offset is computed based on a first displacement of the vehicle with respect to the first marker along a first reference axis, and a second displacement of the vehicle with respect to the first marker along a second reference axis, and wherein the offset has a magnitude corresponding to a displacement between a predetermined reference point of the vehicle at the location and a center of the first marker.

19. The non-transitory computer readable medium according to claim 18, wherein the first reference axis lies along a line connecting the center of the first marker to a center of the second marker, and wherein, the second reference axis is perpendicular to the first reference axis.

20. The non-transitory computer readable medium according to claim 17, the method further comprising:

computing, for each interpolation point of the plurality of interpolation points, coordinates along a first reference axis and a second reference axis, the coordinates being computed based on an angular deviation of the vehicle with respect to the first marker.

21. The non-transitory computer readable medium according to claim 17, wherein the compensation curve is a polynomial curve.

22. The non-transitory computer readable medium according to claim 17, wherein the modifying step further comprises:

receiving, an image captured by the vehicle, when the vehicle is disposed within a predetermined range of the first marker;

processing the received image to compute the offset; and

transmitting, an instruction to control a motion of the vehicle at each segment.

23. The non-transitory computer readable medium according to claim 17, wherein the vehicle includes a weighing device arranged to weigh items transported by the vehicle, the speed profile of the vehicle being modified based on at least one of the weight of the items and a reading of a wheel counter disposed on the vehicle.

24. The non-transitory computer readable medium according to claim 17, wherein the computing the speed profile step comprises:

computing based on a distance between the first marker and the second marker, an acceleration distance, a deceleration distance, and a maximum speed of traversal of the vehicle.