CLAIMS

What is claimed is:

1. A manufacturing system, said manufacturing system comprising:

a storage arrangement, said storage arrangement comprising:

an automated storage and retrieval system (ASRS) structure comprising a three-dimensional array of storage locations distributed throughout a two-dimensional footprint of the ASRS structure at a plurality of storage levels within the ASRS structure;

a supply of workpieces, tool pieces, and workpiece supports stored within the storage locations of the ASRS structure for use in manufacturing goods; and

a fleet of robotic storage/retrieval vehicles, wherein each of the robotic storage/retrieval vehicles is navigable within the ASRS structure in three dimensions to access the storage locations in the three-dimensional array, each of the robotic storage/retrieval vehicles configured to carry storage units of compatible size and shape for storage in the storage locations of the ASRS structure, the storage units configured to hold at least the workpieces and the tool pieces;

a plurality of manufacturing cells configured in a continuous arrangement outside the ASRS structure, wherein the storage units are configured to be transferred to and from the storage locations of the ASRS structure and between the manufacturing cells, free of identification or scanning of the storage units, based on the continuous arrangement of the manufacturing cells; and

a computerized control system in operable communication with each of the storage/retrieval vehicles, the computerized control system configured to orchestrate movement of the storage/retrieval vehicles on a two-dimensional gridded track structure interconnecting each of the manufacturing cells and the ASRS structure, the computerized control system further configured to trigger said storage/retrieval vehicles to deliver the storage units just-in-time, grouped based on corresponding work orders, and in specific sequences to the manufacturing cells, instead of linearly with conveyors, thereby facilitating just-

in-time manufacturing of subassemblies at any stage of a manufacturing process, and thereby allowing any number of manufacturing processes to be completed multiple times in any order.

2. The manufacturing system of claim 1, wherein each of the manufacturing cells is configured to receive the workpieces a plurality of times for performance of a plurality of process steps of the manufacturing process.

3. The manufacturing system of claim 1 or 2, wherein the workpieces are received at a first one of the manufacturing cells for performance of a plurality of process steps of the manufacturing process and subsequently stored in the storage locations of the ASRS structure and retrieved from the storage locations of the ASRS structure for the transfer of the workpieces to a second one of the manufacturing cells.

4. The manufacturing system of claim 1, further comprising a track structure attached to the ASRS structure and extending beyond the two-dimensional footprint of the ASRS structure to define an extension thereof, wherein the track structure is configured to define travel paths on which the robotic storage/retrieval vehicles are navigable and along which the manufacturing cells are distributed.

5. The manufacturing system of claim 1, wherein the tool pieces are stored within and retrieved from the ASRS structure in the storage units and delivered to the manufacturing cells by the fleet of robotic storage/retrieval vehicles.

6.The manufacturing system of claim 1, wherein the storage units are configured to be carried by the robotic storage/retrieval vehicles for transfer of the storage units to and from the storage locations and to and from the manufacturing cells, and wherein the storage units comprise:

workpiece storage units, each configured to hold the workpieces; and

tool piece storage units, each configured to hold the tool pieces.

7. The manufacturing system of claim 6, wherein the workpiece storage units comprise inventory storage units and kit storage units, wherein each of the inventory storage units is configured to contain a collection of inventory workpieces, and wherein each of the kit storage units is configured to contain a kit of mixed workpieces picked from the inventory storage units according to a manufacturing process to be performed on the mixed workpieces delivered to one of the manufacturing cells.

8. The manufacturing system of claim 7, further comprising at least one kitting workstation configured to accept delivery of the inventory storage units from the ASRS structure by the robotic storage/retrieval vehicles for allowing picking of the inventory workpieces from the inventory storage units at the at least one kitting workstation.

9. The manufacturing system of claim 8, wherein the at least one kitting workstation is configured to receive a drop-off of the workpiece storage units and a travel of the workpiece storage units therethrough, by the fleet of robotic storage/retrieval vehicles.

10. The manufacturing system of claim 6, wherein each of the manufacturing cells comprises at least one workpiece holding area configured to hold the workpieces awaiting processing at corresponding manufacturing cells, wherein the at least one workpiece holding area is configured to accept placement of one of the workpiece storage units thereon.

11. The manufacturing system of claim 1, wherein each of the workpiece supports is configured to hold the workpieces in predetermined positions during manufacture of goods, and wherein the workpiece supports are stored in the ASRS structure, and wherein the workpiece supports are retrievable from the ASRS structure and deliverable to the manufacturing cells by the fleet of robotic storage/retrieval vehicles.

12. The manufacturing system of claim 11, wherein each of the workpiece supports is of a common footprint of a standardized shape and size as each of the storage units configured to fit within the storage locations of the ASRS structure, and wherein each of the workpiece supports comprises a base of a standardized shape and size configured to fit within the storage locations of the ASRS structure.

13. The manufacturing system of claim 12, wherein each of the workpiece supports and each of the storage units are configured to have a matching layout of interface features by which the robotic storage/retrieval vehicles interact with the workpiece supports and the storage units to allow loading and unloading of the workpiece supports and the storage units to and from the robotic storage/retrieval vehicles.

14. The manufacturing system of claim 1, wherein each of the manufacturing cells comprises at least one workpiece holding area configured to hold the workpieces

awaiting processing therein.

15. The manufacturing system of claim 14, wherein each of the manufacturing cells comprises two workpiece holding areas, and wherein each of the two workpiece holding areas is configured to hold a respective set of workpieces required therein.

16. The manufacturing system of claim 14, wherein the manufacturing cells are positioned at a two-dimensional gridded track structure, and wherein the two-dimensional gridded track structure comprises sets of intersecting rails on which the robotic storage/retrieval vehicles are navigable in two dimensions, and wherein a width of the at least one workpiece holding area in each of the two dimensions is generally equal to a whole number multiple of a distance measured between two adjacent parallel rails of the two-dimensional gridded track structure.

17. The manufacturing system of claim 16, wherein the width of the at least one workpiece holding area in each of the two dimensions does not exceed a distance measured between the two adjacent parallel rails of the two-dimensional gridded track structure.

18. The manufacturing system of claim 14, wherein each of the manufacturing cells comprises at least one robotic picker operable to pick the workpieces from the at least one workpiece holding area, and wherein each of the manufacturing cells further comprises a working area to which picked workpieces are transferred from the at least one workpiece holding area by the at least one robotic picker.

19. The manufacturing system of claim 1 or 16, wherein at least a subset of the manufacturing cells is positioned at the two-dimensional gridded track structure, and wherein each of the manufacturing cells in the subset comprises at least one tool holding area configured to hold the tool pieces required therein, and wherein a width of the at least one tool holding area in each of the two dimensions is equal to a distance measured between the two adjacent parallel rails of the two-dimensional gridded track structure.

20. The manufacturing system of claim 19, wherein the width of the at least one tool holding area in each of the two dimensions does not exceed a distance measured between the two adjacent parallel rails of the two-dimensional gridded track structure.

21. The manufacturing system of claim 19, wherein each of the manufacturing cells in

the subset comprises at least one robotic worker mounted atop a mounting base installed on or within the two-dimensional gridded track structure, and wherein a width of the mounting base in each of the two dimensions is generally equal to a whole number multiple of a distance measured between the two adjacent parallel rails of the two-dimensional gridded track structure.

22. The manufacturing system of claim 21, wherein the width of the mounting base in each of the two dimensions does not exceed a distance measured between the two adjacent parallel rails of the two-dimensional gridded track structure.

23. The manufacturing system of claim 16, wherein the two-dimensional gridded track structure comprises square spots, and wherein each of the square spots is delimited by a first pair of parallel rails of the two-dimensional gridded track structure lying in a first direction and a second pair of parallel rails of the two-dimensional gridded track structure lying in a second direction perpendicular to the first direction, and wherein each of the manufacturing cells occupies a cell space of an area equal to a predetermined number of the square spots.

24. The manufacturing system of claim 1 or 23, wherein the cell space is a square space whose area is divisible into nine square subspaces, and wherein each of the nine square subspaces is equal in area to one of the square spots of the two-dimensional gridded track structure, and wherein four corner subspaces of the nine square subspaces are configured as holding areas for holding supplies needed by the manufacturing cells, and wherein a first pair of mid-perimeter subspaces positioned between the four corner subspaces at a first pair of opposing perimeter sides of the cell space is occupied by robotic workers, and wherein a central subspace positioned between the robotic workers is configured as a working area to which the workpieces are transferred and processed by the robotic workers.

25. The manufacturing system of claim 1 or 24, wherein the working area is neighbored by a second pair of mid-perimeter subspaces positioned between the four corner subspaces at a second pair of opposing perimeter sides of the cell space, and wherein at least one of the second pair of mid-perimeter subspaces is an unoccupied open area by which the robotic storage/retrieval vehicles are configured to enter and exit the working area.

26. The manufacturing system of claim 25, wherein both of the mid-perimeter

subspaces in the second pair are unoccupied open areas, whereby the robotic storage/retrieval vehicles travel fully through corresponding manufacturing cells.

27. The manufacturing system of claim 1, wherein the plurality of manufacturing cells are configured in a multi-level structure, the multi-level structure comprising a plurality of levels of the manufacturing cells.

28. The manufacturing system of claim 16 or 27, wherein:

each of the plurality of levels includes the two-dimensional gridded track structure, wherein the two-dimensional gridded track structure comprises the sets of intersecting rails on which the robotic storage/retrieval vehicles are navigable in the two dimensions; and

the multi-level structure comprises upright frame members interconnecting the intersecting rails of the plurality of levels.

29. The manufacturing system of claim 1 or 28, wherein the upright frame members are configured for traversal of the robotic storage/retrieval vehicles thereon in an ascending direction and a descending direction to transition between the plurality of levels.

30. The manufacturing system of claim 1 or 29, wherein the two-dimensional gridded track structure at one of the plurality of levels of the multi-level structure is attached to a corresponding one of the storage levels in the ASRS structure at which the robotic storage/retrieval vehicles transition between the ASRS structure and the multi-level structure.

31. The manufacturing system of claim 1 or 16, wherein the manufacturing cells include fully automated manufacturing cells and human-attended manufacturing cells configured with respect to the two-dimensional gridded track structure comprising the sets of intersecting rails on which the robotic storage/retrieval vehicles are navigable in the two dimensions, wherein the fully automated manufacturing cells are positioned at distributed locations throughout a main internal area of the two-dimensional gridded track structure, and the human-attended manufacturing cells are positioned at an outer perimeter area of the two-dimensional gridded track structure.

32. The manufacturing system of claim 1 or 7 or 8, wherein the computerized control

system comprises:

a network interface coupled to a communication network;

at least one processor coupled to the network interface; and

a non-transitory, computer-readable storage medium communicatively coupled to the at least one processor, wherein the non-transitory, computer-readable storage medium is configured to store computer program instructions, which when executed by the at least one processor, cause the at least one processor to activate the robotic storage/retrieval vehicles to:

(a) navigate within the ASRS structure and through the manufacturing cells;

(b) retrieve the workpieces contained in the storage units stored at the storage locations of the ASRS structure;

(c) deliver the workpieces contained in the storage units to the at least one kitting workstation for kitting into the kit storage units;

(d) pick up the kit storage units from the at least one kitting workstation;

(e) return and store the kit storage units to the storage locations of the ASRS structure;

(f) retrieve at least one of the kit storage units and the workpieces contained in the storage units, the tool pieces contained in the storage units, and the workpiece supports from the ASRS structure;

(g) deliver the kit storage units and the workpieces contained in the storage units, the tool pieces contained in the storage units, and the workpiece supports to the manufacturing cells for manufacture of goods; and

(h) induct the goods into the ASRS structure on a final workpiece support.

33. A manufacturing system, the manufacturing system comprising:

a storage arrangement, the storage arrangement comprising:

an automated storage and retrieval system (ASRS) structure comprising a three-dimensional array of storage locations distributed throughout a two-dimensional footprint of the ASRS structure at a plurality of storage

levels within the ASRS structure, wherein the ASRS structure further comprises at least one track-equipped level comprising a two-dimensional gridded track layout;

a supply of workpieces, tool pieces, and workpiece supports stored within the storage locations of the ASRS structure for use in manufacturing goods; and

a fleet of robotic storage/retrieval vehicles navigable within the ASRS structure in at least two dimensions on the two-dimensional gridded track layout, each of said robotic storage/retrieval vehicles configured to carry storage units of compatible size and shape for storage in the storage locations of the ASRS structure, the storage units configured to hold at least the workpieces and tool pieces;

a plurality of manufacturing cells positioned outside the ASRS structure, wherein each of the manufacturing cells comprises a plurality of modular components, the manufacturing cells configured in a continuous arrangement outside the ASRS structure, wherein the storage units are configured to be transferred to and from the storage locations of the ASRS structure and between the manufacturing cells, free of identification or scanning of the storage units, based on the continuous arrangement of the manufacturing cells;

a track structure connected to the ASRS structure and laying out travel paths traversable by the robotic storage/retrieval vehicles from the ASRS structure, wherein at least a subset of the manufacturing cells is positioned along the track structure; and

a computerized control system in operable communication with each of the storage/retrieval vehicles, the computerized control system configured to orchestrate movement of the storage/retrieval vehicles on a two-dimensional gridded track structure interconnecting each of the manufacturing cells and the ASRS structure, the computerized control system further configured to trigger said storage/retrieval vehicles to deliver the storage units just-in-time, grouped based on corresponding work orders, and in specific sequences to the manufacturing cells, instead of linearly with conveyors, thereby facilitating just-

in-time manufacturing of subassemblies at any stage of a manufacturing process, and thereby allowing any number of manufacturing processes to be completed multiple times in any order.

34. The manufacturing system of claim 33, wherein the track structure is a gridded track structure comprising sets of intersecting rails on which the robotic storage/retrieval vehicles are navigable in the at least two dimensions.

35. The manufacturing system of claim 34, wherein each of the modular components comprises a footprint whose width, in at least one of the two dimensions, is equal to a whole number multiple of a distance measured between two adjacent parallel rails of the gridded track structure.

36. The manufacturing system of claim 34, wherein the width of the footprint, in each of the two dimensions, does not exceed a distance measured between the two adjacent parallel rails of the gridded track structure.

37. The manufacturing system of claim 33, wherein the tool pieces are stored within the ASRS structure in the storage units, and wherein the tool pieces are retrievable from the ASRS structure and deliverable to the manufacturing cells by the fleet of robotic storage/retrieval vehicles.

38. The manufacturing system of claim 33, wherein each of the modular components comprises holding station modules configured to hold supplies required by each of the manufacturing cells.

39. The manufacturing system of claim 33 or 38, wherein the storage units are configured to be carried by the robotic storage/retrieval vehicles for the transfer of the storage units to and from the storage locations and to and from the manufacturing cells, and wherein the holding station modules are configured to receive the storage units.

40. The manufacturing system of claim 33, wherein the storage units comprise:

workpiece storage units, each of the workpiece storage units configured to hold the workpieces; and

tool piece storage units, each of the tool piece storage units configured to store the tool pieces.

41. The manufacturing system of claim 33, wherein the track structure is an extension

of the two-dimensional gridded track layout of the track-equipped level of the ASRS structure.

42. A method for executing a workflow in a manufacturing system, the method comprising:

(a) in an automated storage and retrieval system (ASRS) structure of the manufacturing system, storing workpieces, tool pieces and workpiece supports in respective storage locations of the ASRS structure, wherein the workpieces are stored in workpiece storage units at the storage locations, and the tool pieces are stored in tool piece storage units at the storage locations;

(b) using a fleet of robotic storage/retrieval vehicles navigable within the ASRS structure, extracting the workpiece storage units and selected workpiece supports from the ASRS structure according to requirements of manufacturing processes to be performed at manufacturing cells positioned outside the ASRS structure and in a neighboring relation to the ASRS structure, and separately delivering the workpiece storage units and the selected workpiece supports to the manufacturing cells, free of identification or scanning of the storage units, based on the continuous arrangement of the manufacturing cells outside the ASRS structure;

(c) at each of the manufacturing cells, positioning the selected workpiece supports in working positions accessible by workers of the manufacturing cells; and

(d) at each of the manufacturing cells, with the selected workpiece supports maintained in the working position:

(i) transferring the workpieces from the workpiece storage units onto the selected workpiece supports; and

(ii) performing process steps of the manufacturing processes on the workpieces held on the selected workpiece supports;

(e) orchestrating, by a computerized control system, movement of the storage/retrieval vehicles on a two-dimensional gridded track structure interconnecting each of the manufacturing cells and the ASRS structure, and

triggering the storage/retrieval vehicles to deliver the storage units just-in-time, grouped based on corresponding work orders, and in specific sequences to the manufacturing cells, instead of linearly with conveyors, thereby facilitating just-in-time manufacturing of subassemblies at any stage of a manufacturing process and allowing any number of manufacturing processes to be completed multiple times in any order.

43. The method of claim 42, wherein the step of using the fleet of robotic storage/retrieval vehicles navigable within the ASRS structure, includes a step of using the robotic storage/retrieval vehicles to perform extraction and delivery of both the workpiece storage units and the selected workpiece supports from the ASRS structure to the manufacturing cells.

44. The method of claim 42, wherein:

the step of storing the workpieces, the tool pieces and the workpiece supports in the respective storage locations of the ASRS structure further includes, storing tool piece storage units in the ASRS structure, wherein the tool piece storage units are configured to hold the tool pieces for use in the manufacturing process; and

prior to performing the process steps of the manufacturing processes on the workpieces held on the selected workpiece supports, using one of the robotic storage/retrieval vehicles to extract a subset of the tool piece storage units from the ASRS structure and deliver the subset of the tool piece storage units to the manufacturing cells.

45. The method of claim 42 or 44, wherein the step of performing the process steps of the manufacturing processes on the workpieces held on the selected workpiece supports further includes, prior to performing the process steps of the manufacturing processes, attaching a select one of the tool pieces from the subset of the tool piece storage units to robotic workers of the manufacturing cells according to the requirements of the manufacturing processes to be performed on the workpieces by the robotic workers.

46. The method of claim 42, wherein the step of extracting the workpiece storage unit further includes delivering at least two workpiece storage units to two respective holding areas of a manufacturing cell, and transferring two workpieces

respectively from the two workpiece storage units parked at two respective holding areas, onto a selected workpiece support.

47.The method of claim 42, further comprising:

removing from the manufacturing cells, unneeded or empty workpiece storage units from which selected workpieces are already removed and from which no further workpieces are required for the manufacturing processes at the manufacturing cells; and

using one of the robotic storage/retrieval vehicles to deliver to the manufacturing cells additional workpiece storage units containing additional workpieces.

48. The method of claim 46 or 47, wherein the additional workpieces are for use in a different manufacturing process to be performed at the manufacturing cell, and wherein the method further comprises:

removing from the manufacturing cell the selected workpiece support and the workpieces mounted thereon;

using one of the robotic storage/retrieval vehicles to deliver another workpiece support to the manufacturing cell for use in the different manufacturing process;

supporting the another workpiece support in a working position;

transferring the additional workpieces from an additional workpiece storage unit delivered to the manufacturing cell, onto the another workpiece support; and

performing process steps of the different manufacturing process on the additional workpieces.

49. The method of claim 48, further comprising removing the unneeded or empty workpiece storage units using a robotic storage/retrieval vehicle different from the robotic storage/retrieval vehicle that delivered the additional workpiece storage unit to the manufacturing cell.

50. The method of claim 42, further comprising after completion of a finished good by processing of the workpieces at the manufacturing cells, inducting the finished good into the ASRS structure on one of the robotic storage/retrieval vehicles.

51. The method of claim 42, further comprising inducting the finished good into the

ASRS structure on a final workpiece support on which final process steps were carried out to complete the finished good.

52. The method of claim 42, further comprising filling each of the workpiece storage units with a kit of different workpieces according to the requirements of the manufacturing processes.

53. The method of claim 42 or 52, wherein the filling of each of the workpiece storage units is performed at a kitting workstation connected to the ASRS structure, and wherein at the kitting workstation:

the fleet of robotic storage/retrieval vehicles is configured to deliver inventory storage units retrieved from respective storage locations in the ASRS structure, wherein the inventory storage units are configured to contain inventory workpieces;

the different workpieces of the kit are picked from the inventory workpieces stored in the inventory storage units, and compiled into the workpiece storage units; and

each of the workpiece storage units is carried away from the kitting workstation by the robotic storage/retrieval vehicles and deposited into a respective one of the storage locations in the ASRS structure for subsequent retrieval from the ASRS structure.