Modeling and Simulation of an Agile Assembly Center in a Physical Internet inspired Manufacturing System

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Motivation – Durable Goods

- Complex and large durable goods
- Customized goods
- Large plan floor space requirements
- Complex and expensive transportation

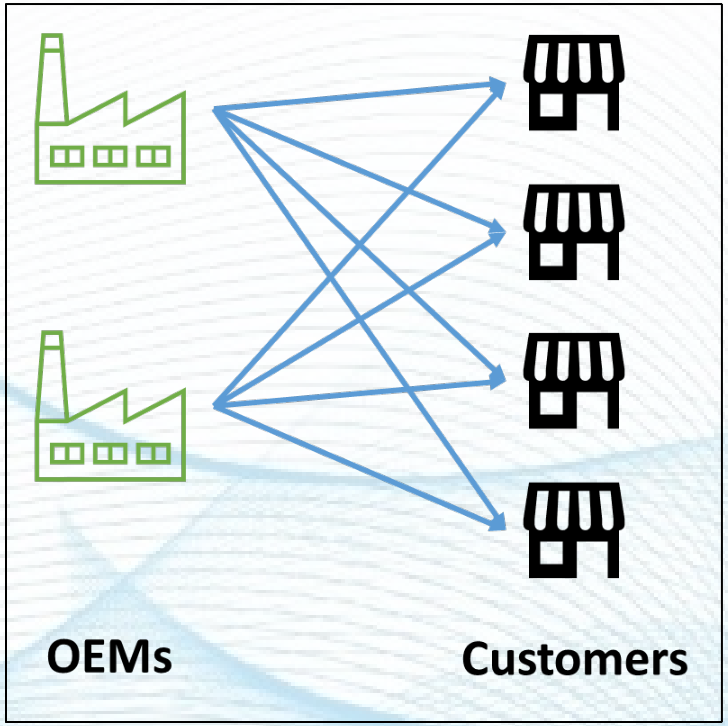
Source: https://theconstructor.org/construction/heavy-construction-equipment-types/26305/

Source: https://www.overweightpermits.com/what-is-an-escort-vehicle/

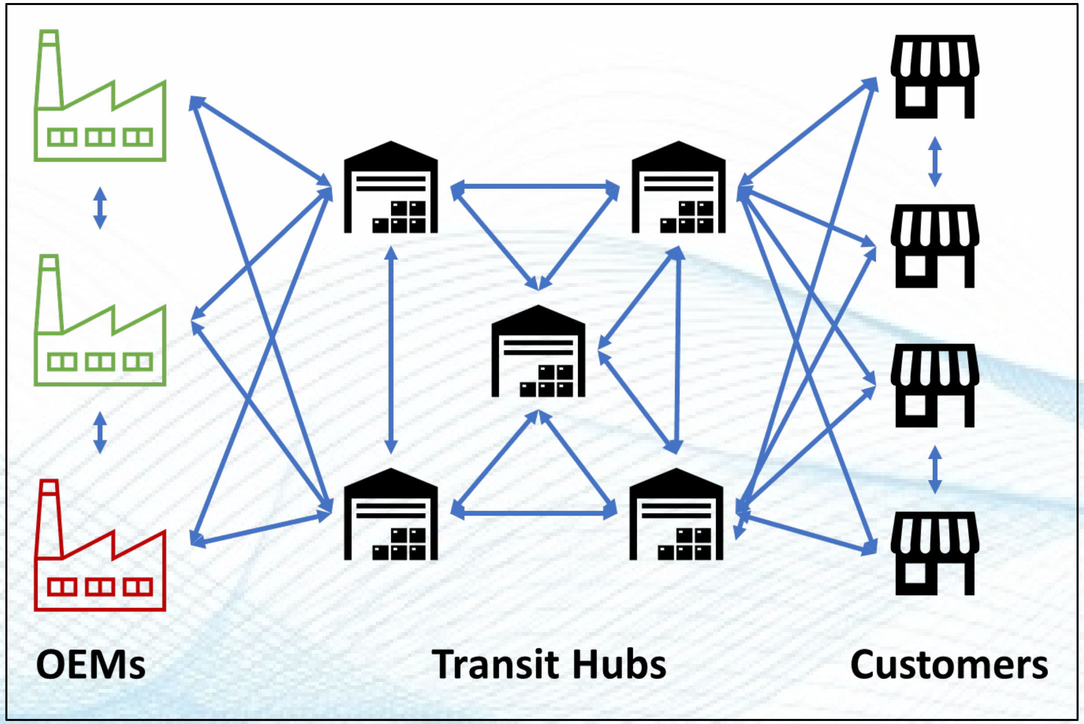
Source: https://www.freepik.com/free-photo/

Motivation – Hyperconnected Logistics Network

Conventional point-to-point delivery

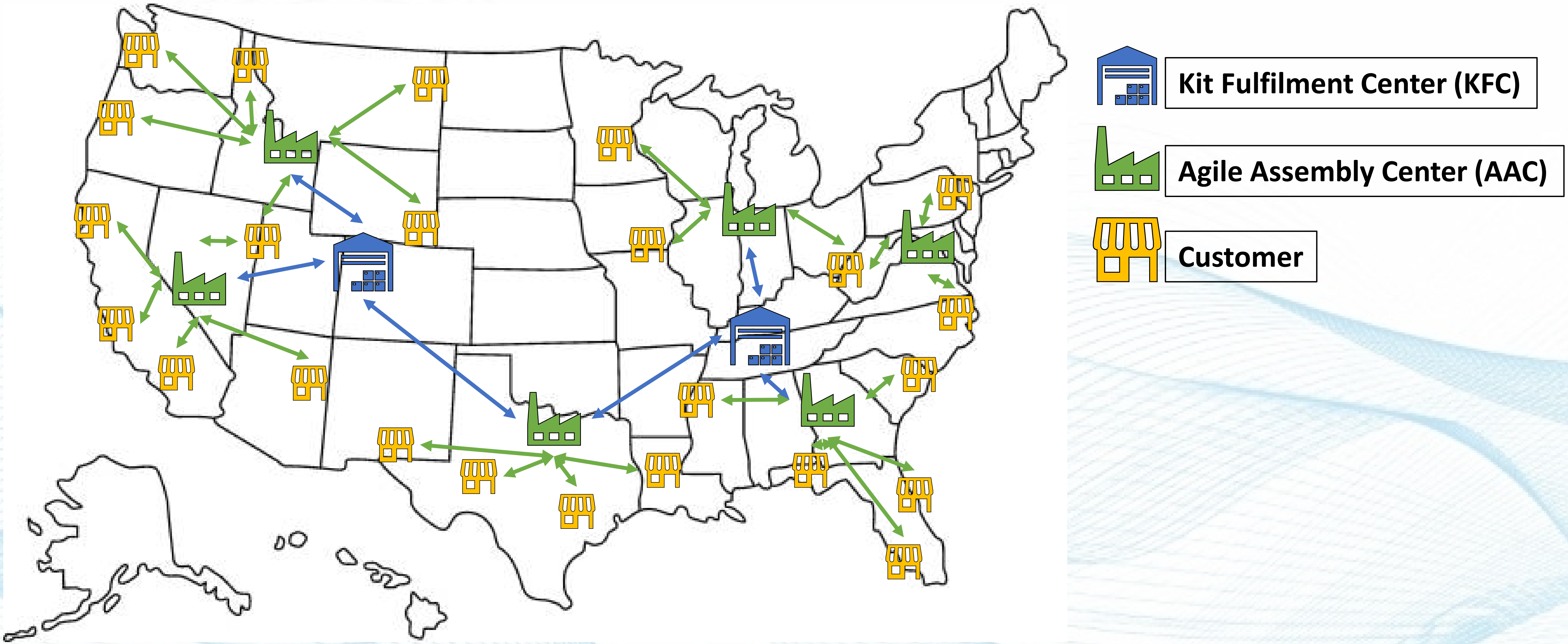


PI Enabled Hyperconnected Relay Logistics Network



In this context, Transit Hubs serve as intermediary facilities open to different OEMs (Original Equipment Manufacturers) for facilitating the transportation up to the final customer and reducing the drive time.

Context - Hyperconnected Logistics Network



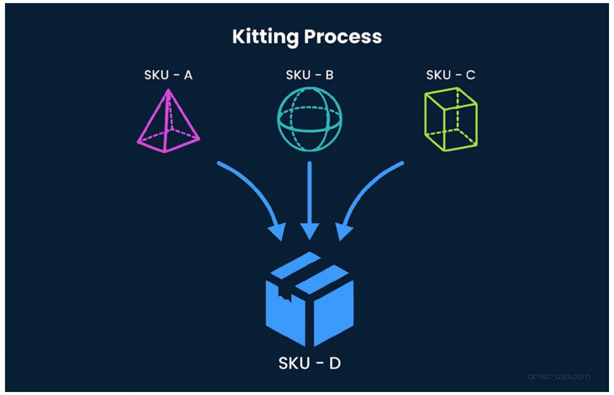
Context - PI Nodes

Kit Fulfilment Center (KFC):

- Facility in charge of preparing kits with components that will be used in the assembly process at the AAC
- The scheduling of kit production and the compactness of kit structure in the KFCs must be designed to minimize inventory space
- KFCs produce kits that are easy and safe to transport between KFCs and AACs; and easy and safe to handle, distribute and use in AACs

Agile Assembly Center (AAC):

- Manufacturing facility that can be open to multiple stakeholders and concurrently serve the needs of several clients for small-series production of complex and large durable products
- Are meant to be temporary and easy to set up in locations close to the clients, reducing the logistics costs of transporting full assembled final products.



Source: https://www.amsc-usa.com/blog/what-is-kitting-benefits-and-kitting-definition/

Source: https://stockarea.io/quick-guides/kitting

Source: https://en.wikipedia.org/wiki/Assembly_line

Context - Modular PI Inspired Containerization

AAC Design - Models

Product Model: Contains the detailed design of the product to manufacture with all technical specifications

Production Process Model: Based on the product model describes in detail the production process required for manufacturing a product, including resources, time, precedencies, etc…

Technology Model: Describes the level of technology/automation to be implemented in the facility

Organization Model: Describes the way in which the facility will operate, defining centers, stations, manufacturing discipline, etc…

Assembly Capacity Model: Corresponds to the optimization of the number of stations and centers required to meet a desired throughput

Layout Model: Represents the physical location of all areas in the plan floor, can be 2D and 3D

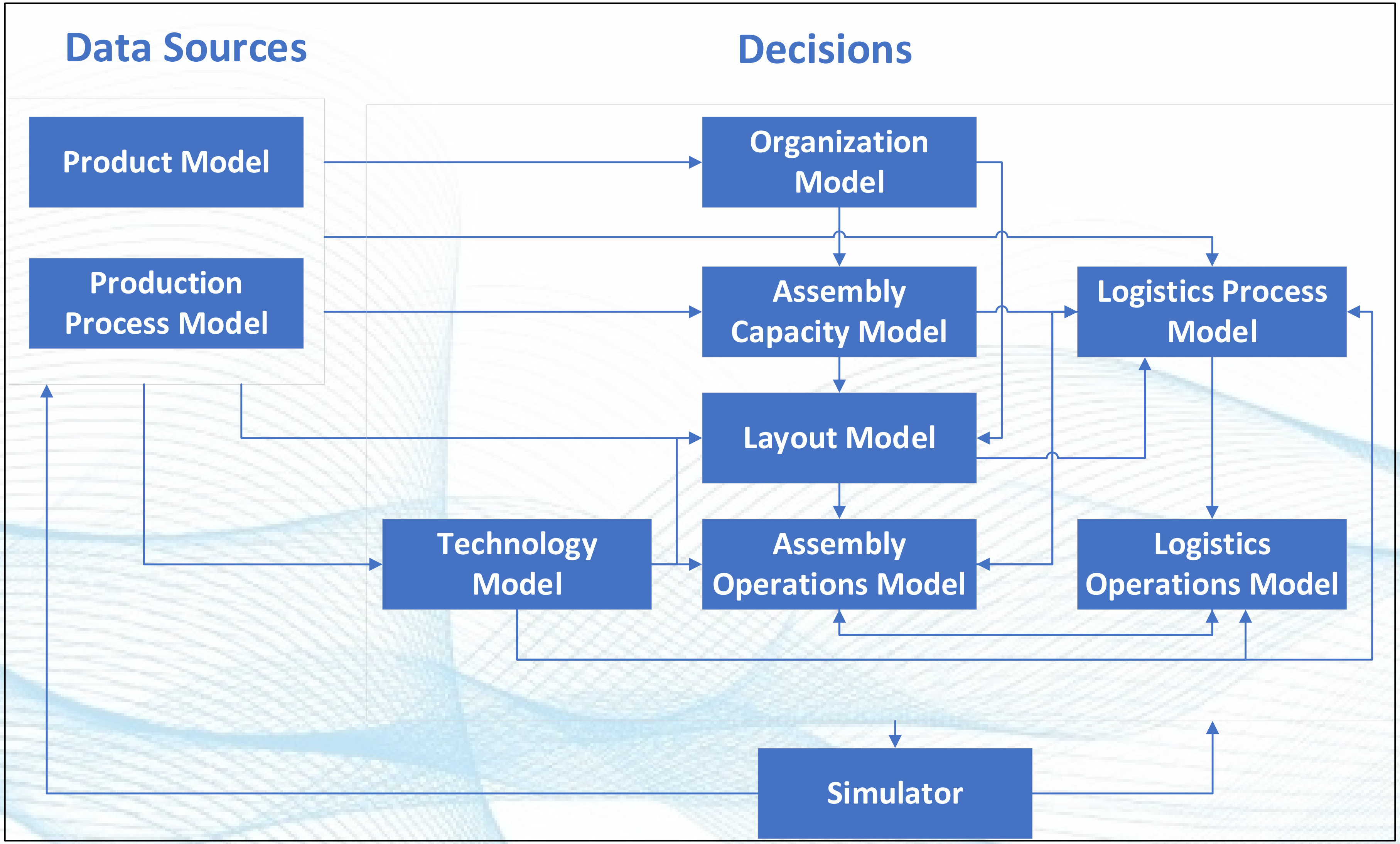
Assembly Operations Model: Optimizes the assembly labor required for operating the facility based on the assembly capacity model

Logistics Process Model: Defines the logistics tasks for moving kits and materials through the facility

Logistics Operations Model: Optimizes the logistics labor and equipment required for operating the facility based on the logistics process model

Simulator: Capable of representing different instances of aacs, assesses the performance of the facility

AAC Design - Framework



Simulator vs. Simulation Model

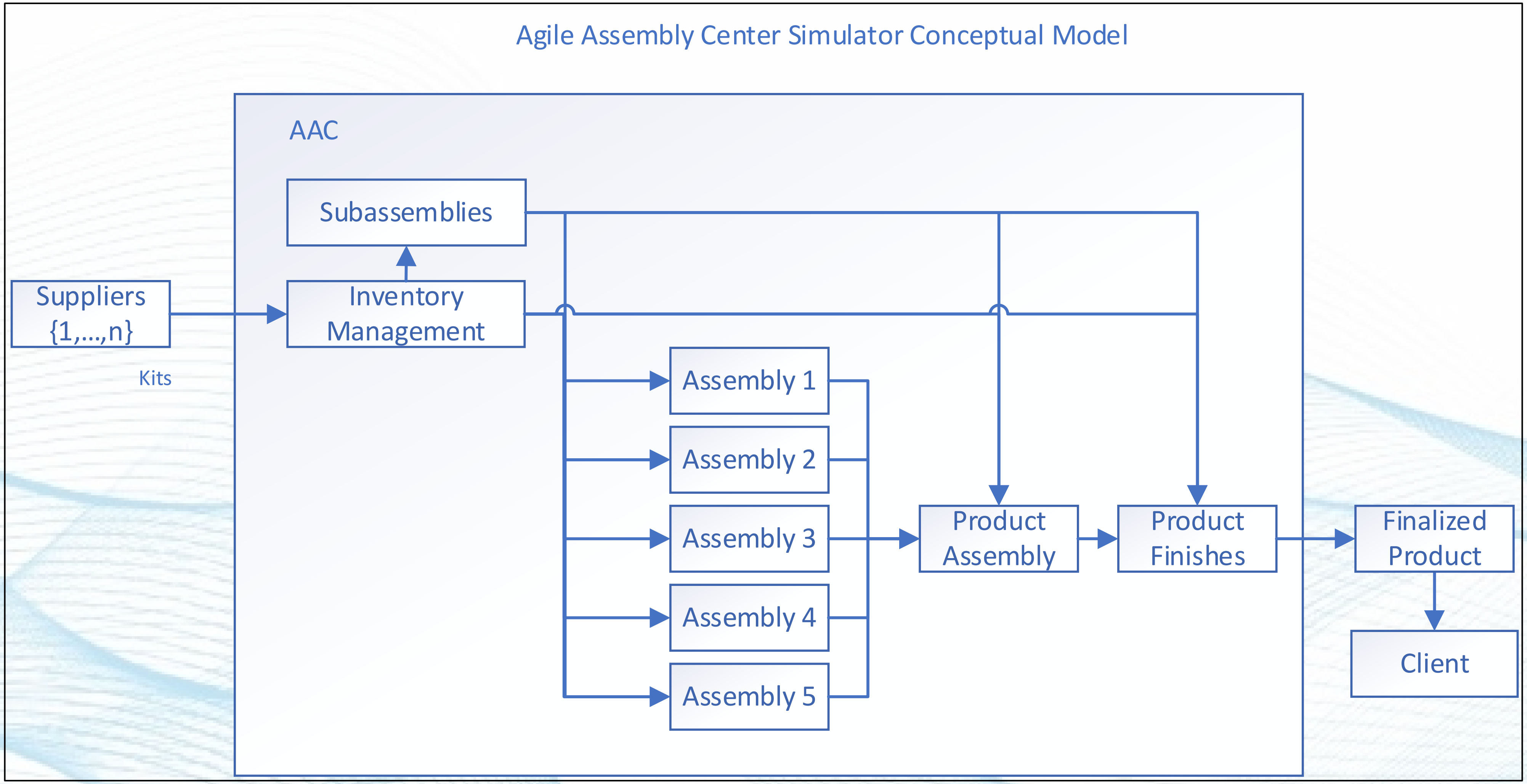
Differences

- In this context, a simulation model is a virtual representation of an instance of a system (one system)
- A simulator is a tool capable of representing various instances of a type of system, without the need for creating new models, by adjusting input information

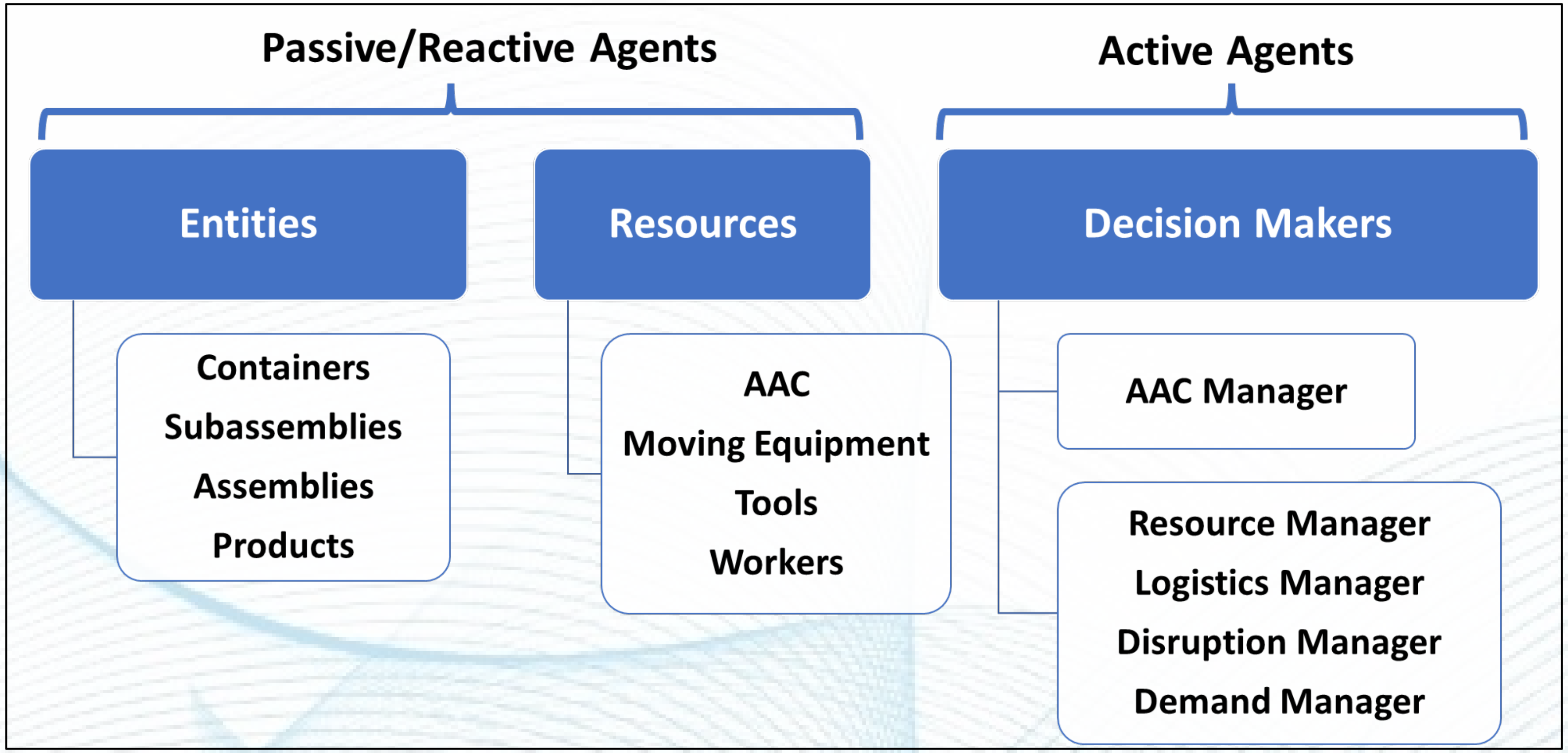
Challenges

- Automatically generate different plant layouts
- Read and implement any type of production process
- Read and implement any type of logistics process
- Be able to produce new/different types of products
- Validate large sets of input data

Agile Assembly Center Conceptual Model



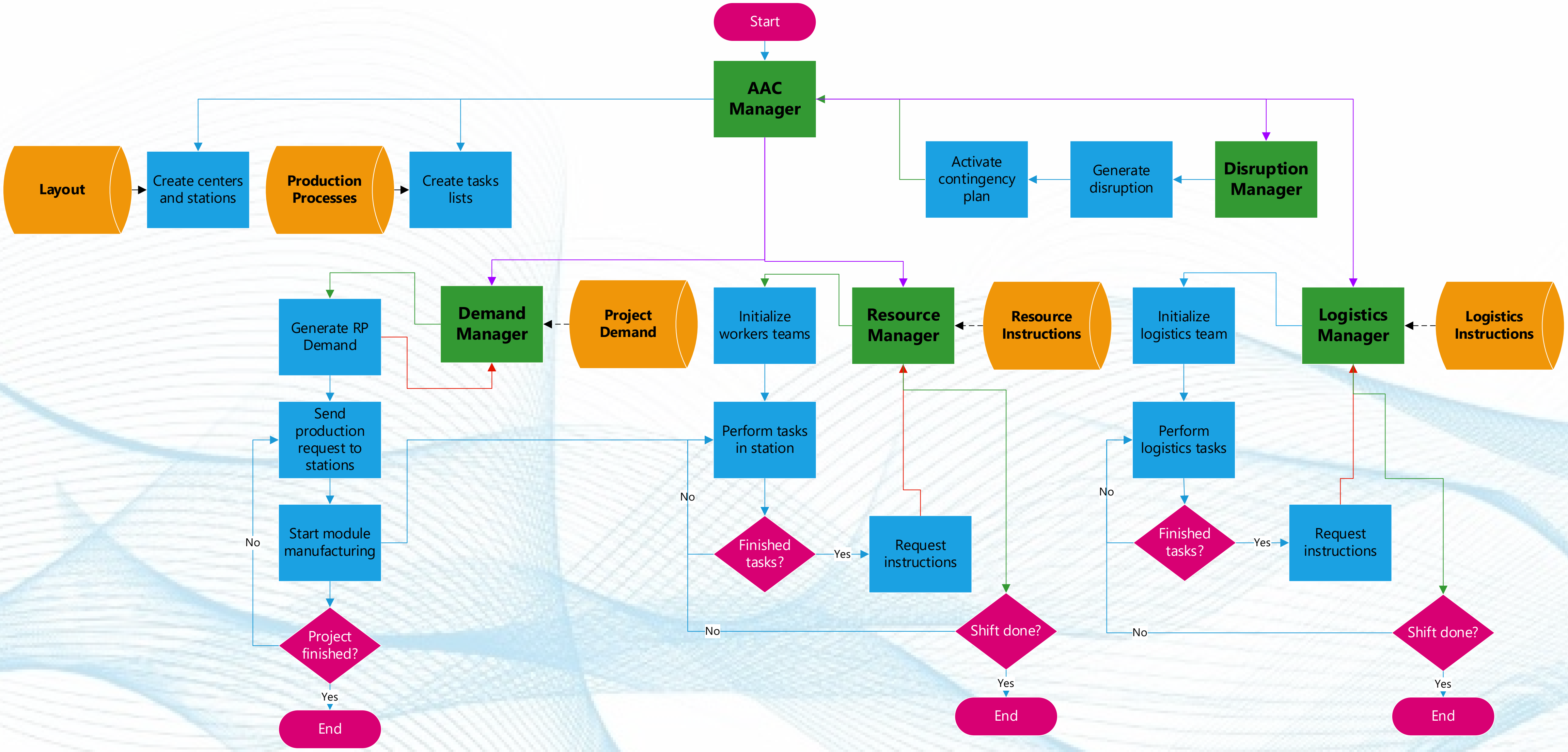
Simulation Agent Structure



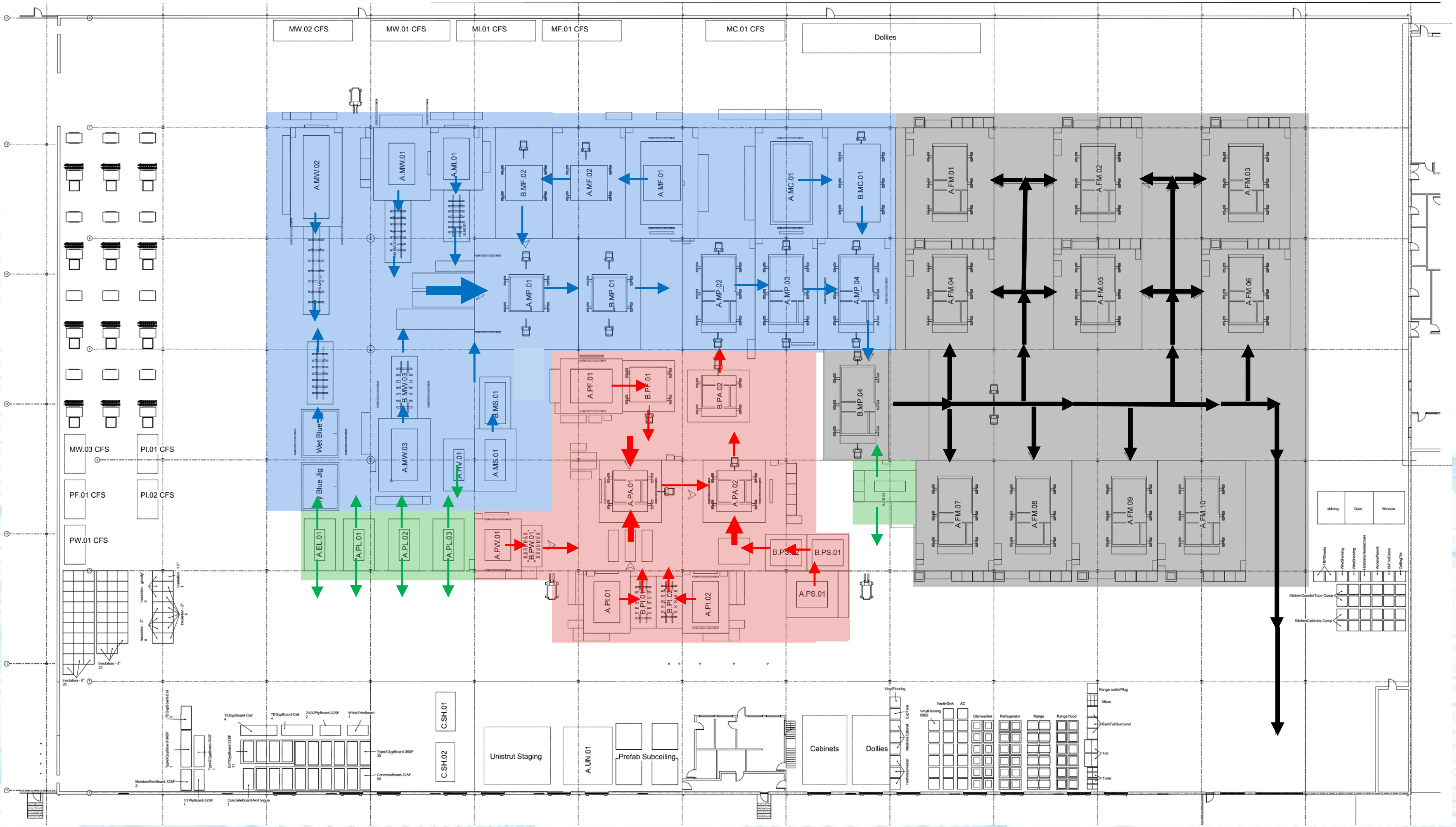
Active Agents

AAC Manager: Initializes the scenario settings and coordinates other active agents
Resource Manager: Initializes assembly processes, gives instructions to assembly workers
Logistics Manager: Initializes logistics processes, gives instructions to logistics workers
Disruption Manager: Generates disruptions and coordinates with other agents the implementation of solutions
Demand Manager: Creates demand scenarios contemplating potential disruptions on the client side

Simulator Logic Structure

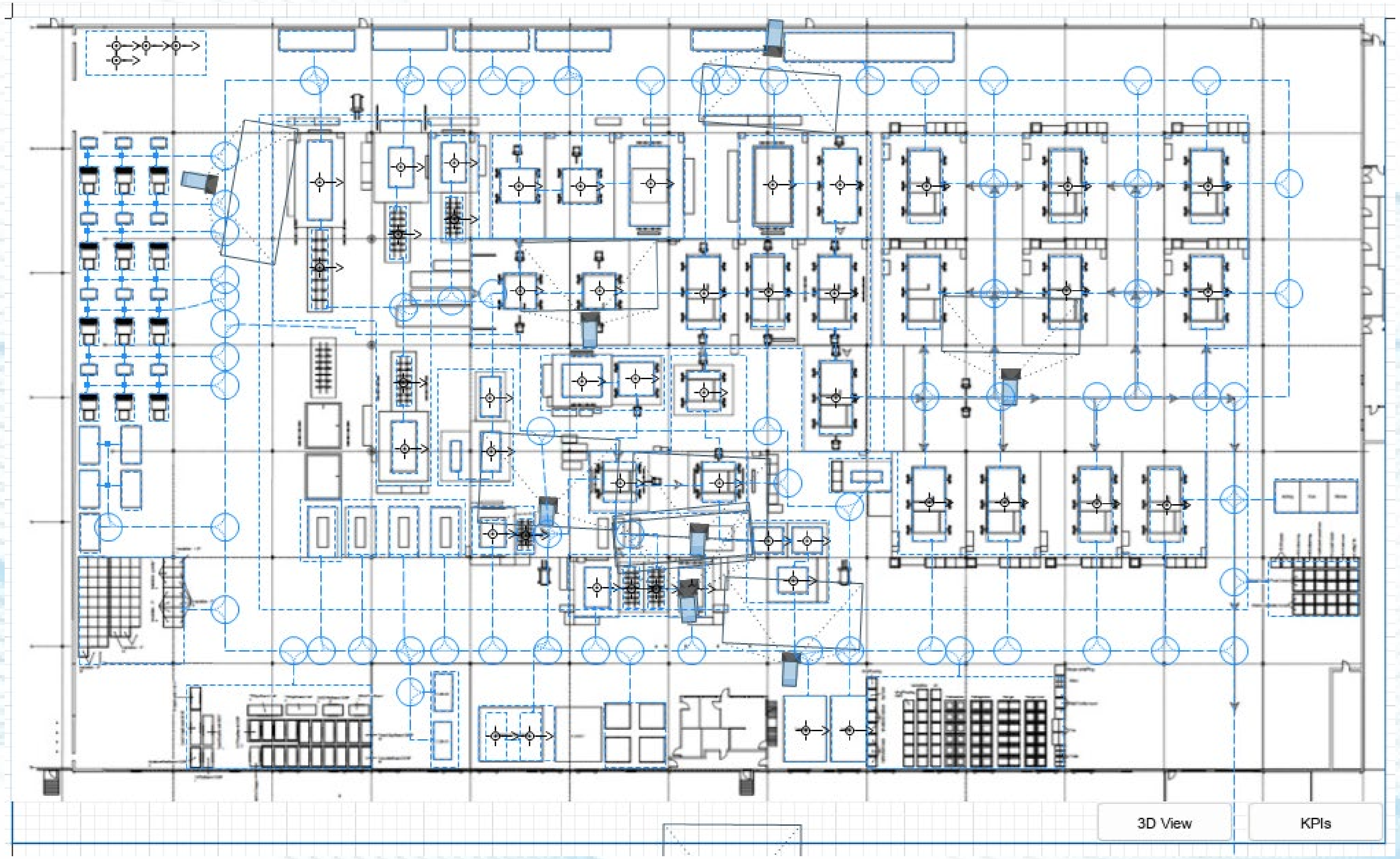


Plant Layout and Flow



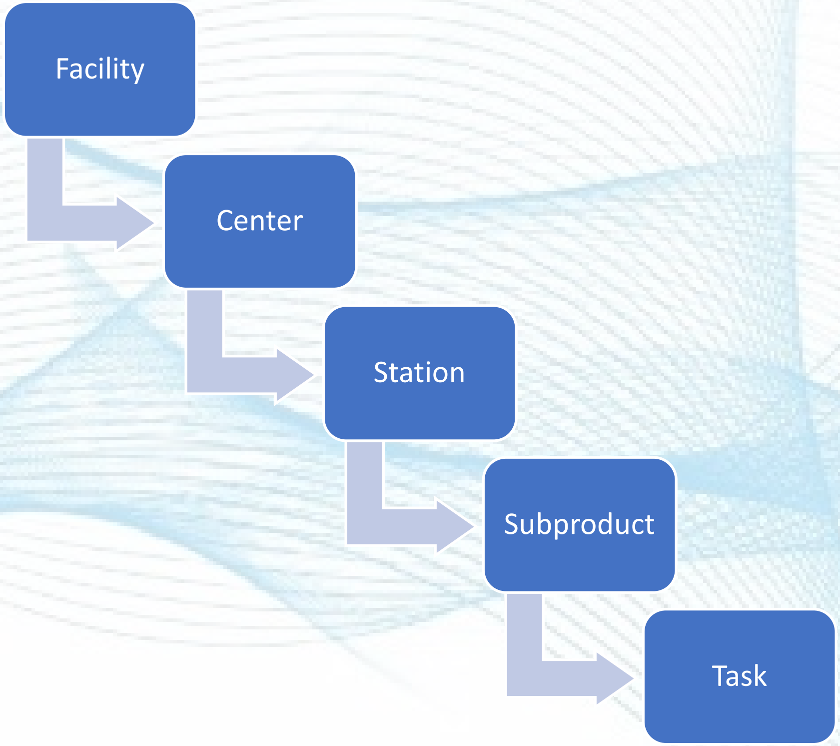
Layout Automation

ID	AssemblyCenter	AssemblyCenterID	Xcoordinate	Ycoordinate	Zcoordinate	Width	Length	StationName
0	MF	0	220	260	0	50	25	MF1
1	MF	0	150	260	0	50	25	MF2
2	MF	0	80	260	0	50	25	BMF2
3	MI	1	10	260	0	50	25	MI1
4	MI	1	0	240	0	50	25	BMI1
5	MW	2	40	220	0	50	25	MW1



Nested object structure

ID	Product Typ	Subproduct	SubproductTyp	CenterID	InitialStation	StartTaktTime	Route (Stations)	FinalStation	Required Subproducts
0	0	CSFL - C1	A1	0	A.FL.01	0	13	15	-1
1	0	CSIW - O1	A2	2	A.MI.01	3	7	15	-1
2	0	CSIW - P1	A2	2	A.MI.01	4	7	15	-1
3	0	CSIW - Q1	A2	4	A.MI.01	4	13	15	-1
4	0	CSIW R1	A2	4	A.MI.01	4	13	15	-1
5	0	CSMW - E1	A3	2	A.MW.01	0	7	15	-1
6	0	CSMW - F1	A3	2	A.MW.02	0	7	15	-1
7	0	CSMW - G1	A3	2	A.MW.03	1	7	15	-1
8	0	CSCE - H1	A4	4	A.MC.01	3	13	15	-1
9	0	VolMod1	A5	5	A.MP.01	8	15	15	[0,1,2,3,4,5,6,7,8]
10	0	DryMod	A6	5	A.MP.01	9	15,44	54	9

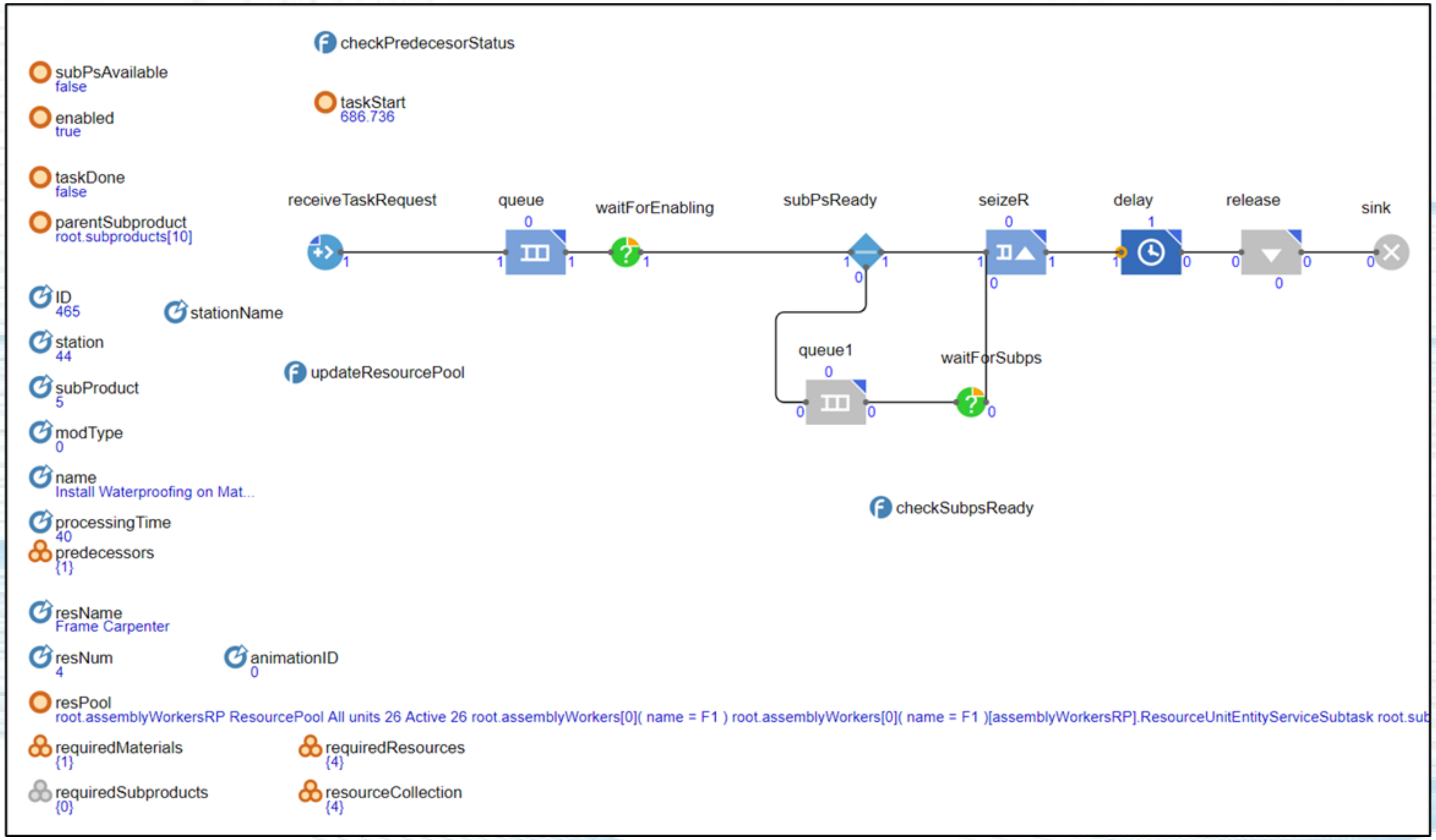


This nested structure allows to generate any instance with the topology of an AAC. A facility can have any given number of centers, and any centers any given number of stations.

Every object to be manufactured is considered as a subproduct, which will be processed at a given station. Each station needs to perform a given set of tasks, and the nesting of this tasks is what allows the process to be scalable. Notice the logic doesn't change, but different inputs will yield different system's configuration

Generic task processing automation

Task ID	Task Name	Predecessors	Resource Type	Number of workers	Duration	start	end	Resource	Day
1	Move to buffer area	0	Assembly Worker	4	5	8	13	[23, 24, 33, 34]	1
2	Place panel on table	1	Assembly Worker	4	5	13	18	[23, 24, 31, 32]	1
3	Install interior Assemblies	2	Assembly Worker	2	0	18	18	[23, 24]	1
4	Install exterior Assemblies	2	Assembly Worker	2	2	18	20	[23, 24]	1
5	Install protective Material	4	Assembly Worker	4	11.25	20	31.25	[23, 24, 31, 32]	1
6	Install Electrical Assemblies	5	Electrician	2	0	48.33333	48.33333	[51, 52]	1
7	Inspect Installations	4,5,6	Inspector	1	1.5	45	46.5	[60]	1



3D Visualization

Test Scenario

Product types: 2
Total products: 2
Time to build: 5 days
Facility size: 172,800 sq ft (720x240)
Plant throughput: 8/day
Stations used: 8
Takt time: 1 hour
Expected working time: 6 h/day
Robust working time: 8 h/day
Time per shift: 8h
Shift-s per day: 1

Day	Assembly Workers (Persons-days)	Logistics Workers (Persons-days)	Total
1	13	6	**19**
2	14	5	**19**
3	16	3	**19**
4	17	3	**20**
5	6	0	**6**
Daily Max	**17**	**6**	**17**
Total Workers (Persons-days)	**66**	**17**	**83**

Note: The facility was designed for producing 8 products a day, with a takt time of 1 hour. The test scenario was implemented as a pilot for producing 2 products in the same facility over a period of 5 days.

Model Validation – Deterministic Scenario

KPI	Planned	Simulated
Labor Utilization	17.57%	17.57%
Assembly 1 Worker/Minutes	182.08	182.08
Assembly 2 Worker/Minutes	340.33	340.33
Assembly 3 Worker/Minutes	145.33	145.33
Assembly 4 Worker/Minutes	58.67	58.67
Assembly 5 Worker/Minutes	68.67	68.67
Assembly 6 Worker/Minutes	84.5	84.5
Assembly 7 Worker/Minutes	194	194
Assembly 8 Worker/Minutes	214.33	214.33
Assembly 9 Worker/Minutes	155.33	155.33
Volumetric Product Worker/Minutes	2,002.4	2,002.4
Finished Product Worker/Minutes	350	350

***The validation process also included visual validation of movement and processes, and individual task follow-up. This deterministic scenario verification is useful for validating both the correctness of the data and the logic implementation in the model.**

Conclusion

- The main contribution of this paper consists in presenting the design, architecture, and implementation of a discrete-event agent-based high-fidelity simulator of a complete agile assembly center in the context of hyperconnected supply chain networks.
- The model built is parametrizable, flexible and reusable, modeled at a fine granularity level, including agents' behavior while emphasizing in the decision-making process, how this affects the systems' performance, and assesses the capability of leveraging PI concepts to deal with the assembly of customized big-sized products.
- This work is the cornerstone for implementing a digital twin of an AAC that will help make operative, tactical, and strategic decisions towards improving the performance of PI inspired assembly facilities.
- This paper offers insights into the future of durable big-sized product assembly and the role that the PI could play in shaping this future.

Future Work

- Extending the AAC manufacturing model to account for stochasticity and disruptions
- Connection of a discrete-event agent-based simulation to live data bases for realizing the digital twin
- Connection of data bases into a real physical system sensors/information towards realizing the digital twin
- Exploring the use of Virtual Reality in the decision making process using physical internet (Physics of decisions type of interfaces)
- Implementation of a digital twin into a real manufacturing/logistics system

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Thank you

Questions & Comments:

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