

Skyline Transport: A New Era in Overhead Material Handling for Semiconductor Fabrication

Jacob Reyes, Justin Kang, Yahany Francisco

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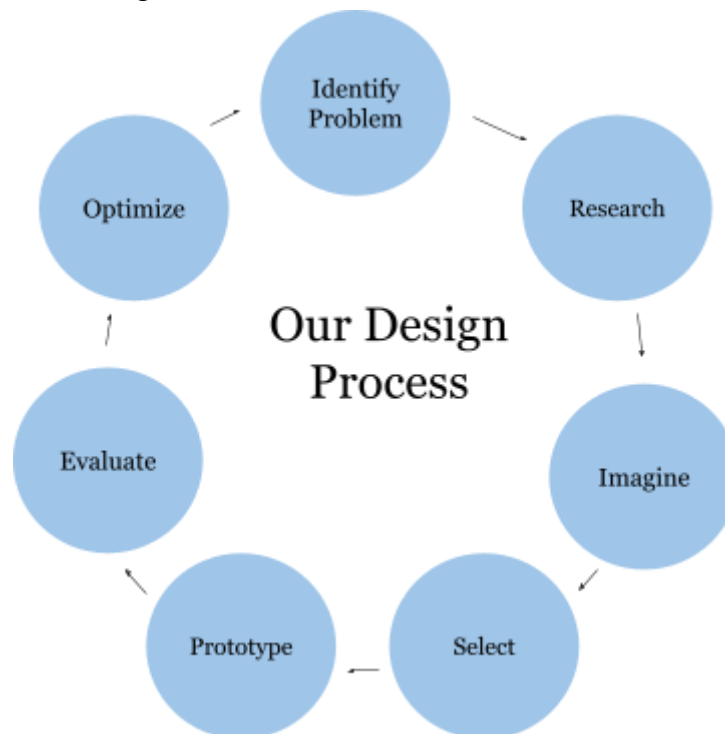


1. Abstract

This paper challenges the current state of material handling within semiconductor fabrication facilities. As a team, we propose an improved overhead hoist transport system that integrates an advanced gantry design and a cart. Our solution emphasizes efficiency, safety, and cleanliness—meeting ISO 14644 standards while minimizing vibrations, preventing static discharge, and ensuring ease of cleaning. Leveraging inspiration from automated systems in other industries, such as the innovative service technology of smart restaurant carts, our concept enhances both fab-wide automation and localized material transport

2. Design Process

Upon reviewing the challenge, our group subsequently followed the engineering design process throughout the whole process. In doing so, we were able to create and optimize your design to best fit the challenge.



2.1 Research Summary

In conducting our research for this project, we focused on understanding the strict environmental and design requirements of cleanrooms in semiconductor fabrication facilities to inform the development of our improved overhead hoist transport system. To maintain ISO 14644 compliance, we also explored how cleanroom layouts incorporate smooth, modular surfaces with minimal joints or crevices to prevent particle buildup and allow for easy cleaning. Additionally, our research emphasized the importance of minimizing vibrations and preventing static discharge, as both can severely disrupt sensitive fabrication processes. This

led us to investigate structural features like vibration-isolating mounts and anti-static materials. We also considered how equipment is transported in and out of cleanroom environments, which must be done in self-contained systems that maintain cleanliness and reduce the risk of contamination. Our research laid the foundation for designing a transport system that enhances efficiency and safety without compromising the cleanliness required in semiconductor fabs.

2.2 Brainstorm

After evaluating both the problem and research, our team began brainstorming with examples of transporting mechanisms. Doing so, we collected various mechanisms in our everyday life, including grocery stores, schools, and restaurants. An example that stood out to us was the Sushi Conveyor Belt, showcased in Figure 1. In addition to this, an example close to our hearts, the Korean Barbecue transportation robot showcasing our nutritious goods being transported from the kitchen to our dining table.

Ideas such as rotating or smart service carts used in restaurants inspired future designs where smart, mobile, self-contained carts travel through different systems.



Figure 1: Kura Revolving Sushi's conveyor belt



Figure 2 : Smart Robot used in KBBQ Restaurant

2.3 Concept Development

This led us to investigate structural features like vibration-isolating mounts and anti-static materials, which will influence both the gantry and cart components of our design.

Drawing inspiration from automated technologies in other industries—such as smart service carts in restaurants and conveyor belts—we began integrating similar principles of mobility and automation into our solution.

This helped inspire our team to brainstorm carts, a mobile device that can be both used to carry and move. This method ensures that the cart can be brought outside and inside semiconductor facilities.

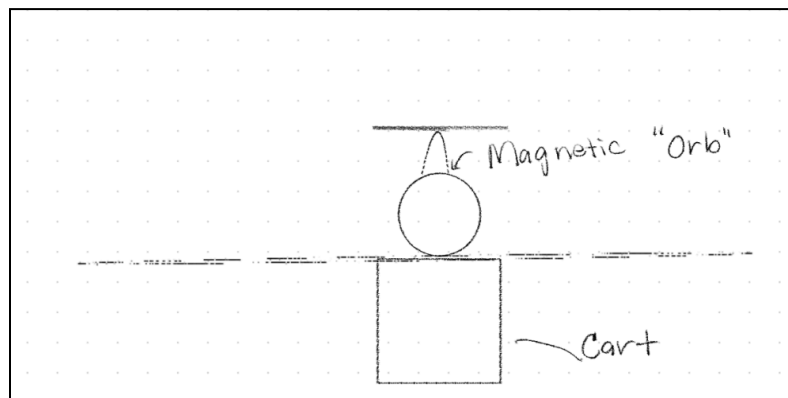


Figure 3: Magnetic Orb Holder

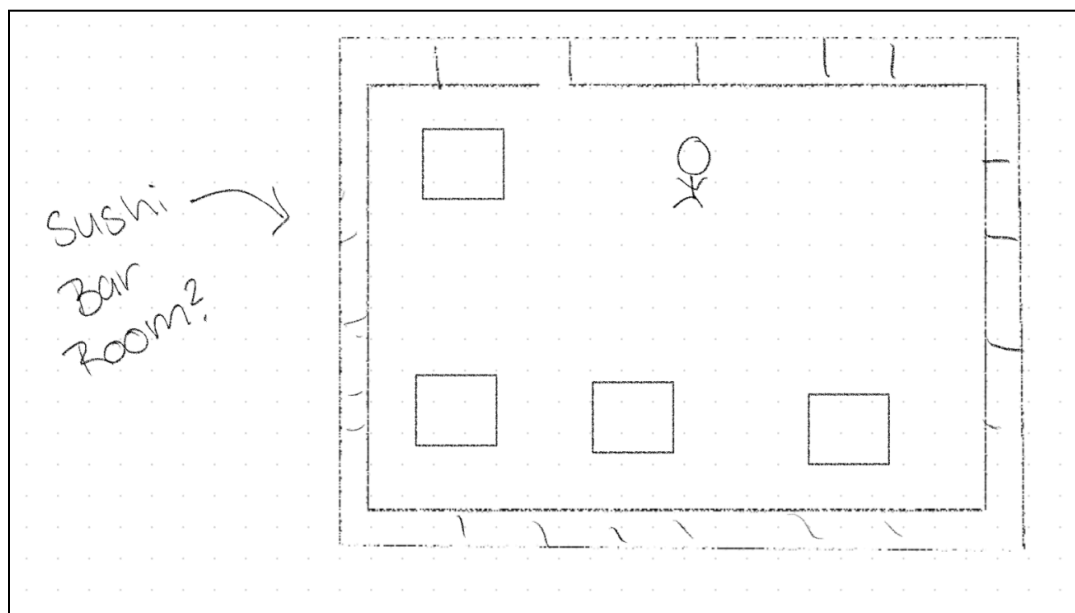


Figure 4: Conveyor Room



Figure 5: Mechanical Locking Attachment

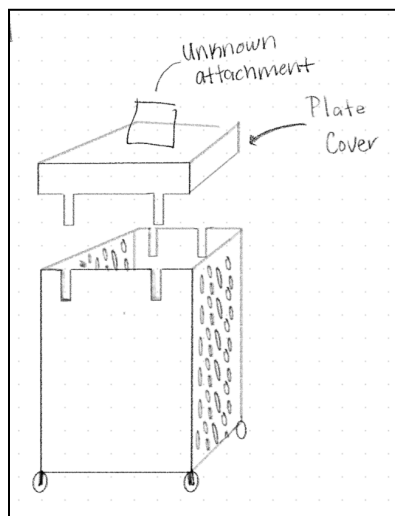


Figure 6: Outer Cart Design

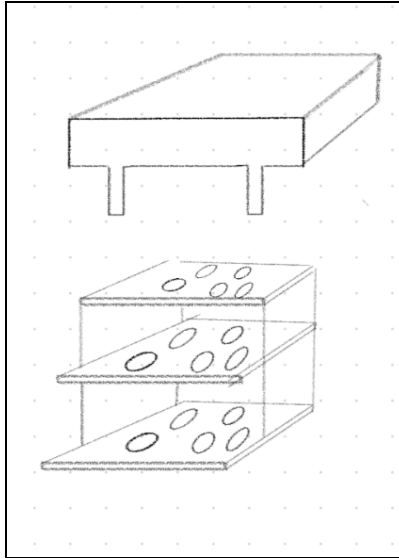


Figure 7: Inside View of Cart

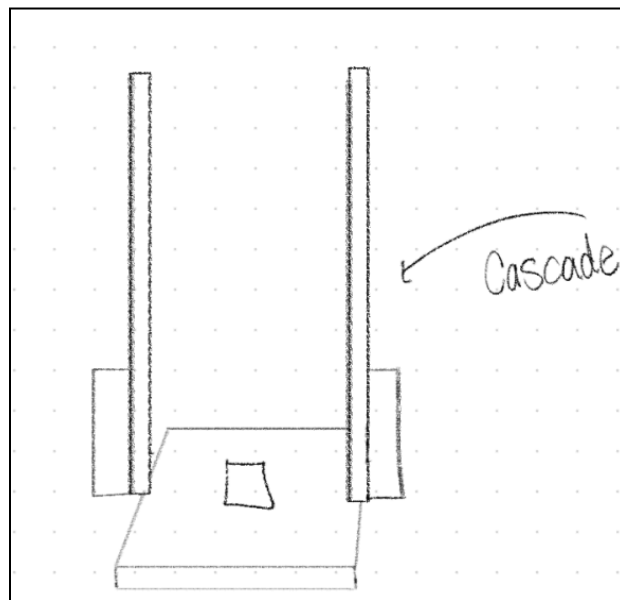


Figure 8: Inside Lift

2.4 Idea Selections

After brainstorming different transportation ideas and drawing out initial sketches, we then created decision matrices to logically choose our first iteration of designs. Doing so, we came to the decision of combining both the idea of a cart and what we began to call a ceiling conveyor, which is more accurately described as an overhead gantry mechanism system. The decision to combine the two ideas led to a more cohesive final product. From there, we then created a decision matrix for the attachment between the two systems of a cart and overhead gantry system.

Overall Product								
	Ease Usability	Efficiency	Cost	Design Change Feasibility	Maneuverability	Cleanliness	Safety	Final Weight
Weight	1.70	1.90	1.00	1.60	1.87	1.80	1.99	
Choice-1- Conveyor	9	7	9	2	0	6	8	67.02
Choice-2-Ceiling Conveyor	7	7	4	3	6	6	8	71.37
Choice-3-Cart 1 Magnetic Rail	1	1	1	1	1	1	1	11.86
Choice-4- Cart 2	1	1	1	1	1	1	1	11.86

Figure 9: System Matrix

Attachment Mechanisms								
	Ease Usability	Efficiency	Cost	Design Change Feasibility	Maneuverability	Cleanliness	Safety	Final Weight
Weight	1.70	1.90	1.00	1.60	1.87	1.80	1.99	
Choice-1- Magnetic Charged	9	7	3	2	8	6	8	76.48
Choice-2-Air Suction	7	4	4	3	4	5	8	60.7
Choice-3-Mechanical Lock	9	9	7	6	4	3	9	79.79

Figure 10: Attachment Matrix

3. System Design & Prototype Overview

3.1 Tray Design

Pull-out Trays:

As our initial tray holder designer, we created an aluminum three layer holder to hold the semiconductor materials. From doing so, our main concerns for this was the method of attachment to the gantry system and the overall mass, worrying it would be too heavy to hold.

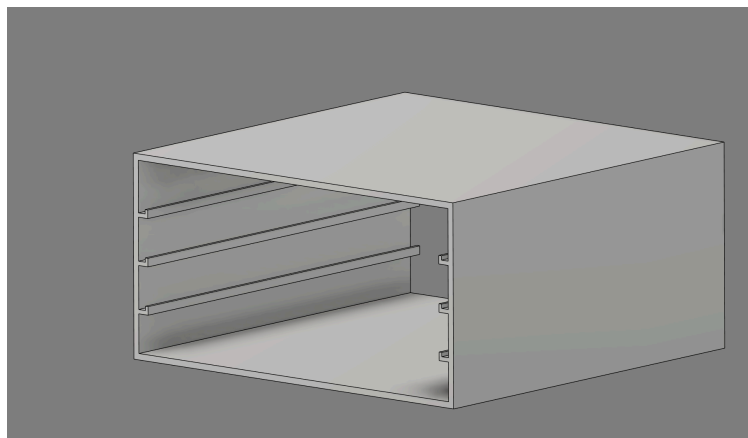


Figure 11: Trayholder Draft V1

3.2 Overhead Gantry System

Reconfigurable Tracks:

After coming up with the overhead gantry system, we began with the initial CAD models. In these models, the frame of the gantry (T-Slotted Rails) is constructed with 6560 T6 aluminum with modular segments. Doing so, the design accommodates different facility layouts and is scalable for future expansion, shown Figure 12.

Cleanroom Compatibility:

To address all surfaces are polished and sealed to reduce particle accumulation, with slot covers or sealed extrusions used to meet ISO 14644 standards. Hardware and fasteners are also covered to prevent potential points of debris accumulation.

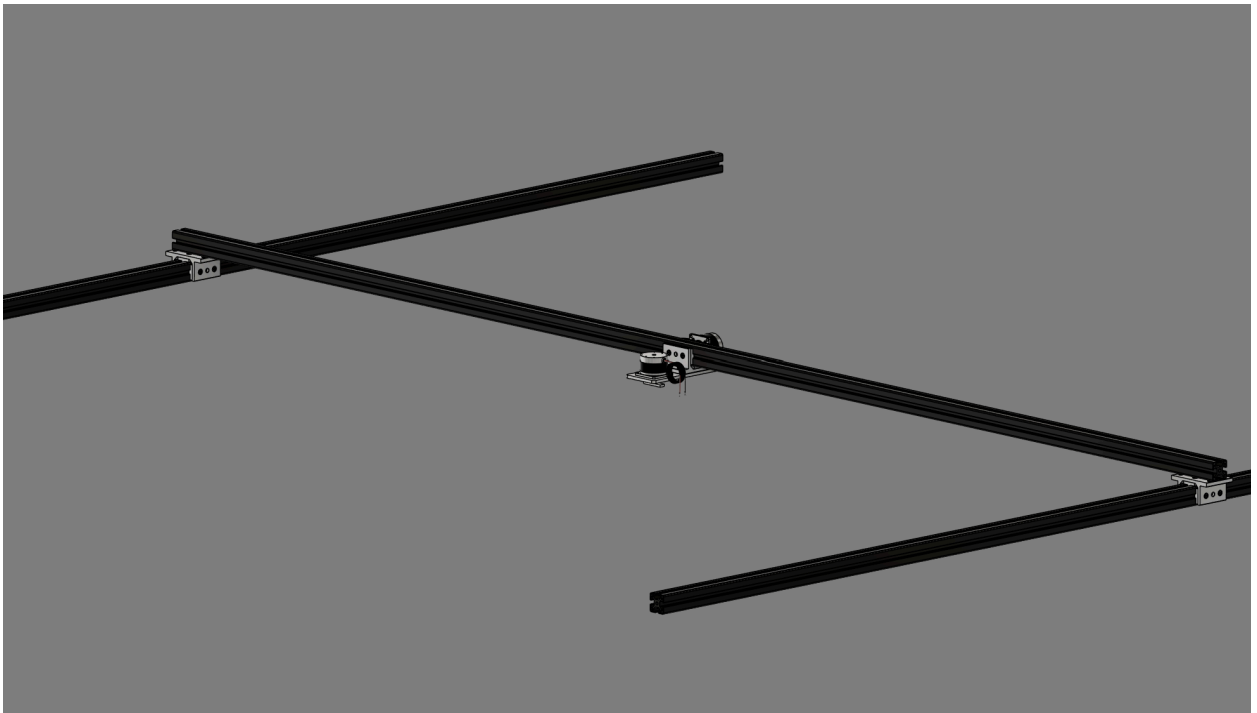


Figure 12: Overview of the Overhead Gantry System

3.2 Locking Mechanism

After creating the gantry system, our team began modeling attachments for the two systems. Thus, we moved towards a mechanical Lock system featured from our brainstorm and decision matrix. As shown in Figure 12 The black extruded rail serves as the main structural guide overhead. In this Mechanism, we utilize another stepper motor to go into the tray holder to create a turn and hold the tray in place when the holder is being lifted to its destination.

3.3 Cart



Figure 13: Cart Draft V1



Figure 14: Cart Draft V2

Initially, we planned to make the storage unit as a fixed part of a larger push cart, but then we moved towards making the cart its own separate component to our system. This allowed for the gantry system to avoid carrying unnecessary loads and making transportation of critical components more practical. The cart itself featured skeletonized aluminum tube stock truss design to optimize strength and minimize weight. Four swivel wheels were added to allow for smooth maneuverability and reduced vibrations when transporting.

4. Iterations

4.1 Tray Holder Iteration

During our iteration process, we created pre-compartmentalized sections cut out for users to utilize. We realized that giving the user the ability to modulate the storage unit to their own needs could improve the efficiency and utilization of our design. We also cut out a waffle texture into the containing sheets to allow for more versatility in what and how elements could be stored. To address our initial concerns in our brainstorming process, we added an attachment to the top of the holder to allow for a locking mechanism, as well as made intentional holes to the sides of the holder to allow for a lighter mass without compromising the strength of the overall holder.

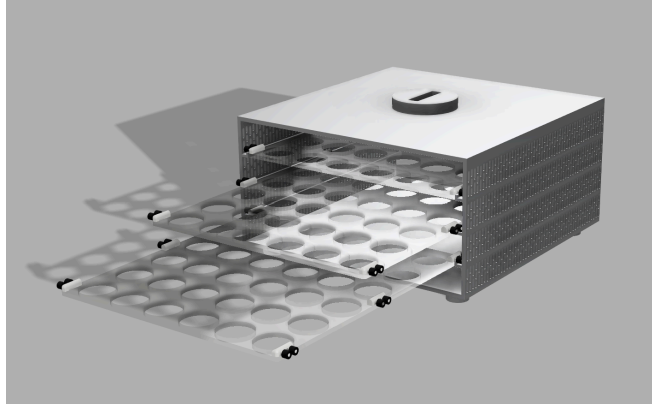


Figure 15: Pull-Out Tray Final Design

Gantry Head Assembly:

The stepper motor drives a rotary mechanism that can insert into a T-slot mount on the storage unit, anchoring itself once rotated (Figure 16). This allows for the gantry head to grab and release the storage unit from and onto the transportation cart.

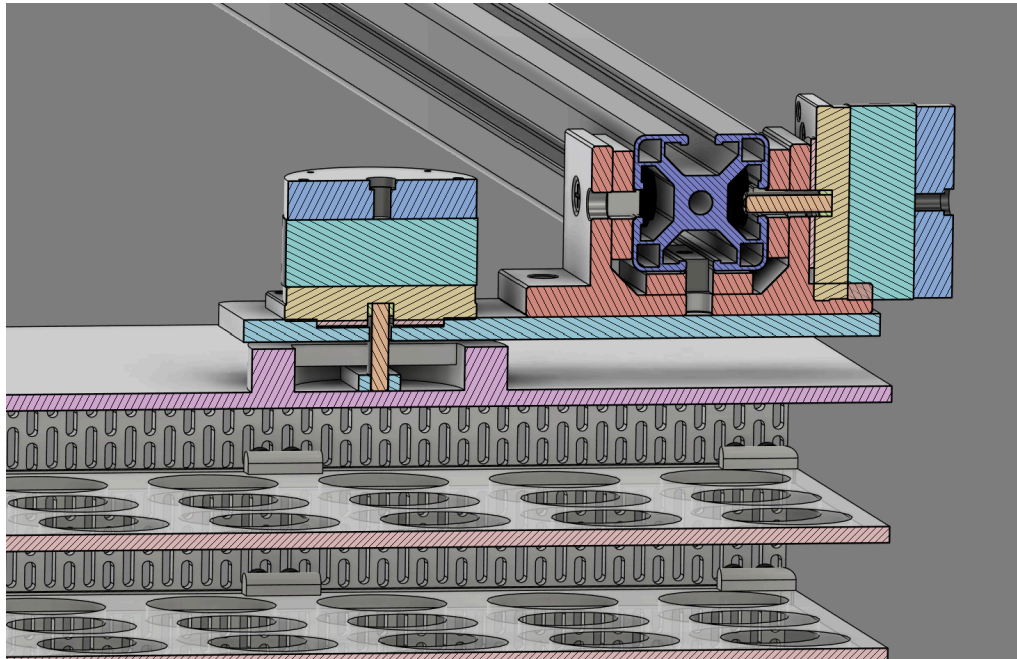


Figure 16: Stepper motor attached to Gantry head Cross Section

4.2 Integrated Load Platform

As our final integrated loaded platform, we attached both the tray holder and our gantry mechanisms. Thus, featuring a multi-axis hoist mechanism for vertical and lateral load handling. This allows for seamless attachment of the storage unit to the Overhead Gantry.

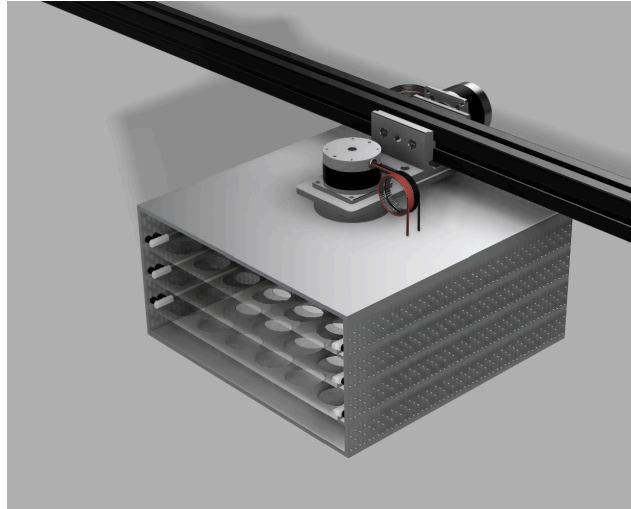


Figure 17: Overview of the Storage unit Design

4.3 Cart

After iterating our initial tray holder and gantry attachments, we then moved onto reiterating our initial cart design. We originally planned to incorporate a feature within the head gantry assembly to lower and hoist the storage unit. We realized this would add a lot of weight to the gantry system which could cause more points of failure and unnecessary risks. Figure 18 shows a vital iterated feature including a motorized elevator system that raises the storage unit to the gantry, as opposed to having the gantry be lowered to the storage unit. Thus, leading to our final cart design, shown in Figure 19.

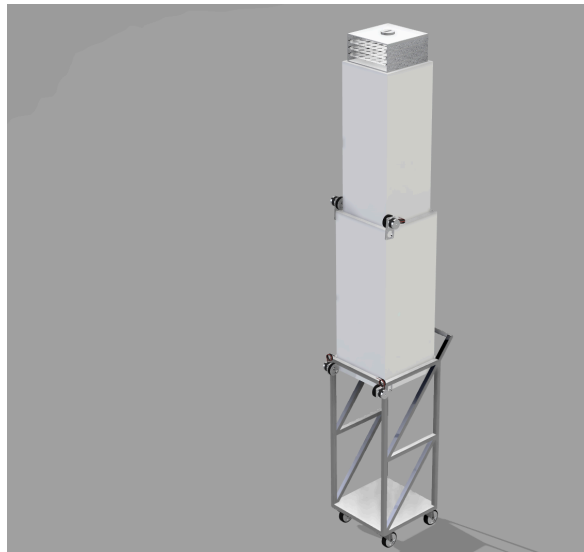


Figure 18: Showcasing Elevator System



Figure 19: Overview of the Push Cart Design

5. Reflection & Future Work

5.1 Bill of Materials

After finalizing our designs, Figure 20 reflects the total costs of all the materials utilized to create all of the designs.

Item	Link	Quantity	Single Cost	Total Cost
T-Slot Rail	https://www.mcmaster.com/6575N25-6575N187/	3	\$81.56	\$244.68
T-Slot Slider	https://www.mcmaster.com/5537T643/	3	\$86.45	\$259.35
T-Slot Roller	https://www.mcmaster.com/5537T353/	30	\$12.07	\$362.10
Stepper Motor	https://www.mcmaster.com/6627T321/	8	\$115.52	\$924.16
Acrylic Sheet	https://www.mcmaster.com/8560K213/	1	\$33.40	\$33.40
Aluminum Rectangular Tube	https://www.mcmaster.com/6546K53-6546K151/	3	\$57.40	\$172.20
Aluminum Sheet	https://www.mcmaster.com/9057K509/	1	\$313.96	\$313.96
			Total	\$2,309.85

Figure 20: Bill of Materials

5.2 Lessons Learned

Modularity & Integration:

The ability to reconfigure our gantry and cart systems proved essential. Modularity not only allows for adaptation to varying facility layouts but also supports future upgrades and scalability. Our work confirms that seamless integration of automated components—such as motorized drives and locking mechanisms—is critical for achieving reliable performance in cleanroom environments.

Vibration & Contamination Control:

Vibration control and anti-static measures are paramount in semiconductor fabrication. Early prototypes underscored the need for robust vibration-damping mounts and tight seals on all interfaces. Even minor vibrations or particulate build-up can jeopardize wafer handling, prompting us to invest significant effort in refining our damping and locking solutions.

User Interface & Operational Safety:

Incorporating user-friendly interfaces (both physical and digital) enhances operational safety, ensuring that the system can be intuitively controlled by operators with minimal training.

5.3 Future Work

Refine Autonomous Routing:

Develop and integrate advanced algorithms for real-time path optimization. Additionally leverage predictive maintenance techniques to anticipate system wear and mitigate potential failures before they occur.

Extended Prototyping:

Scale up our prototype to full-system tests in an operational cleanroom environment. Furthermore, conduct long-duration trials to assess system reliability and the effectiveness of vibration and contamination controls under real-world conditions.

Further Material Innovations:

Investigate new coatings and composite materials that further reduce particulate generation. Thus, evaluate emerging anti-static treatments and manufacturing techniques to enhance durability while maintaining ease of cleaning.

5.4 Static Weight Stress testing

Static Weight Stress Testing:

Our stress tests demonstrate that the tray assembly can support between 5–50 lbs with a Factor of Safety (FoS) of approximately 4. This outcome validates both the robustness of the design and its potential for scalability in practical semiconductor applications. Nonetheless, these tests also highlight areas where further reinforcement or design refinement may be needed—particularly in regions with high localized stress.

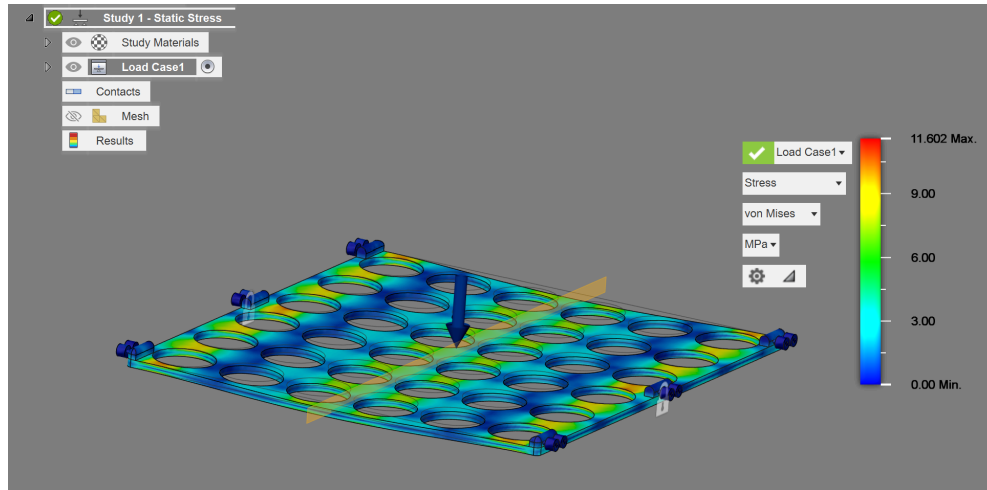


Figure 21: Stress testing stimulation on Trays

Feedback from Iterative Prototyping:

The iterative feedback loop from CAD simulations and physical prototypes has emphasized the importance of:

- Fine-tuning the active damping systems to further reduce vibration transmission.
- Enhancing alignment features in the locking mechanisms to ensure repeatable, precision engagement.
- Optimizing material choices and surface finishes to meet stringent ISO 14644 standards and minimize particulate generation.

6. Conclusion

The proposed Clean Gantry Transport System offers a significant advancement over traditional overhead hoist systems by integrating modular gantry design, a smart motorized cart with advanced locking and vibration mitigation, and an advanced motorized elevator. This comprehensive approach enhances efficiency, safety, and cleanliness—key to meeting the rigorous demands of semiconductor fabrication facilities. Our iterative design process and prototype testing pave the way for further integration and eventual deployment in high-precision cleanroom environments globally.

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