PROCESS IMPROVEMENT AND LIFT DESIGN FOR THE INSTALLATION OF A METROLOGY MACHINE ASSEMBLY

A Senior Project submitted to

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ABSTRACT

The objective is to work with Onto Innovations, a leading provider of semiconductor metrology and manufacturing solutions, to develop a system that safely installs a 250lb optics plate into the Atlas III: one of their metrology machines. Based in Milpitas, CA, Onto Innovations utilizes a variety of operations to create different products and assembles each product on site. The 250lb optics plates are WIP that are transferred between fixtures and the Atlas III using a combination of lifts and human workers. The WIP have long lead times, high tolerances, and large costs associated with their manufacturing process.

Onto Innovations identified a specific transfer in the WIP where they would like this team to find a safer and more efficient solution for the product and workers. Onto Innovations currently have rough solutions mocked up, but no significant progress has been made due to a lack of manpower. The Director of Operations Engineering, Jon, would like the team to re-address the problem and design a new process, lifting tool, and/or fixture to safely conduct the operation. A preliminary budget of $5,000 has been set for the project, and Onto Innovations expects a final product by the end of December 2019 that will work reliably, safely, and efficiently.

The team conducted a preliminary analysis and developed three distinct solutions. The primary solution is designing and manufacturing a small, portable lift that will be temporarily installed inside the Atlas III. The secondary solution is to modify the current lift Onto Innovations uses by changing the leg design and weight distribution. The tertiary solution is to create an SOP for the current installation process, as this will entail no product design or product modification. Further development of the preliminary analysis concluded in the team moving forward with the primary solution.

Using a mechanical design approach and extensive ergonomic consideration, the team developed a lift that bolts up into the Atlas III frame and meets all Onto Innovations' requirements. The design process entailed several revisions to the lift, including the redesign of major assemblies. However, once a detailed prototype design had been developed, the team transitioned into manufacturing. Three weeks of machining and welding lead to the creation of the first prototype, which was then tested for fitment and maneuverability.

The team delivered the underhung lift to Onto Innovations, and after a run-through of the process and a test fit, the team realized the positive and negative attributes of the design. Some aspects, such as the trolley that rides underneath the i-beam, need some additional design considerations. However, Onto Innovations was satisfied with the initial prototype and look forward to building

upon the team's work to develop a product that will address the issues found in testing. In addition to the prototype, an SOP and full CAD model were delivered to Onto Innovations so that the design can be modified, remanufactured, and the process can be solidified.

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Introduction

Optical metrology leads the industry in measuring semiconductor components for applications in most electronic applications. Optical metrology requires a complex machine of significant cost and highly precise optical sensors to measure critical dimensions of semiconductors, often to the size of +- 0.003mm. Due to the complexity, metrology machinery manufacturing yields long lead times and tedious assembly processes. Onto Innovations, this project's sponsor, supplies semiconductor manufacturers around the world with various Optical Critical Dimension (OCD) Metrology systems.

Onto Innovations assembles all their products at their facility in Milpitas, CA. During one of the assembly processes, assemblers transfer a 250lb optical plate from a work fixture to the final assembly of one of their products, the Atlas III, during the machine assembly process. Onto Innovations have requested a new process and/or lift solution to safely install and uninstall the optical plate, during both the initial machine assembly process and in the field when the machine requires repair.

Background

To understand the scope of design and engineering work, the existing Onto Innovations process was evaluated. The frame of the Atlas III is manufactured and assembled at another company, which is then shipped to Onto Innovations. In parallel, the optical plate is assembled on a work fixture and placed on an assembly cart. Before installing the optical plate, workers remove the optical plate from the work fixture to a smaller rolling cart, as the work fixture interferes with the lift they use to install the optical plate. Once the plate is rolled to the machine, the operators place an aluminum ramp over the stabilizing pad of the machine to roll an Alum-a-lift with the optics plate up into the machine frame. Holding the optical plate, three operators position the optics plate in the frame and lower it into place. One operator is tasked with holding and using the lift, while the other two operators have the responsibility of guiding the plate into the frame.

Existing Lifts

Found from introductory research for potential solutions, five preliminary designs are shown in figure 1 on page 7.

Figure 1: Five potential solution directions

The first option depicts the current method of installing the optical plate into the Atlas III. As mentioned above, Onto Innovations currently uses three operators and the Alum-a-lift, one who controls the lift, and the other two for guiding the plate. The main issues with this solution are that the plate encounters interference issues with the feet of the lift and the legs of the Atlas III, the lift is awkward to operate, and it is not a suitable solution in the field.

The second option depicts a standard hydraulic engine hoist. It features a simple boom which moves the load up and down as well as long legs which serve as counterbalances to stabilize the load. This hoist is like the 4th option, and industrial take on the hydraulic engine hoist. It features low profile legs and a two-pronged mounting system. The main issues with both these designs, however, is their use of hydraulics and the potential risk of contaminating the clean room due to a leak during operation.

The third is an A-frame hoist setup, where the hoist rolls along an I-beam supported by two steel legs. It also features a manual chain hoist which transmits the load vertically. One issue with this design is its size and the difficulty of operating the chain hoist. This issue could be solved, however, with the implementation of an electric hoist, depicted in the #5. It can be operated remotely for ease of access and can be mounted on rollers to an I-beam to preserve horizontal movement.

Patents

Existing patents related to the process were also examined. An example of an applicable patent is that of a Portable Studio Hoist. It is designed to be attached to a standard pipe grid or other structure without the need for hard wired power supplies. This patent provides insight useful for field applications. While this patent is specifically centered around the studio environment; however, it has several aspects that would be applicable and beneficial to the project.

Another applicable Portable Drive Assembly for a Manual Chain Hoist. This is especially useful when determining the drivetrain for the final product. If a manual hoist is used, this patent will be a good reference of what design aspects to address when making the product. While it is not an elegant solution, it does provide some basic background information.

Lastly, the patent for a Portable Knockdown Trolley Hoist features a product very similar to Onto Innovations' process revision request: hoist placed on a trolley that can be set-up and torn-down easily and repeatedly. Review of these patents are a crucial step forwards in designing and producing a quality product.

Academic Resources

Another valuable resource for this project is Shigley's Mechanical Engineering Design, which is a textbook that provides equations to design many different systems. From bolt design to gear train systems, this textbook has characterized most fundamental loading conditions into variable equations. The bearing area stress equation can be used in the mechanical analysis of this project:

$$B(t) = F / (t\ d)$$

Where F is the applied force, t is the wall thickness, and d is the diameter of the bolt or pin. This equation verifies that the load condition - 250lb in the negative z direction - will work with the current fairing. The existing fairing could be utilized, but only with custom insert with padding.

Another important equation considered is the beam deflection calculation for a single point load at the free end and simply constrained at the other end. This equation notes the importance of beam length, as the variable is cubed.

$$delta = (P)(L^3) / 3(E)(I)$$

Finally, since the final product will be implemented into a working, manufacturing environment OSHA, ANSI, and ASME codes and standards must be incorporated into the final design. The most pertinent codes are as follows:

ANSI/ASME B30.9, "Safety Standard for Slings"

ANSI/ASME B30.20, "Safety Standard for Below-the-Hook Lifting Devices"

ANSI/ASME B30.16, "Overhead Hoists (Underhung)"

ANSI/ASME B30.16, "Testing and Maintenance"

OSHA 1926.554, "Overhead Hoists"

OSHA 1926.552, "Material hoists, personnel hoists, and elevators"

OSHA 1926.451, "Scaffolds"

OSHA 1920.179, "Overhead and Gantry Cranes"

Objectives

Problem Statement

Onto Innovations manufactures complex OCD Metrology Systems that involves heavy and fragile equipment. One process in the manufacturing operation involves risky conveyance of an optics plate – a component weighing 250 lbs. and is complex in physical structure. The plate must be maneuvered around the shop floor and is then tediously lifted into the frame of the assembly. The risky operation involves multiple workers lifting the plate between tools to accurately place it within the final system. Onto Innovations needs a process to increase the safety, efficiency, and service released products.

Boundary Diagram

This project directly involves operations and tools directly surrounding the manufacturing process of the Atlas III. Thus, those items will be the focus of this project. Once a safe and reliable method has been designed, focus will divert towards full implementation on the production floor and economic considerations.

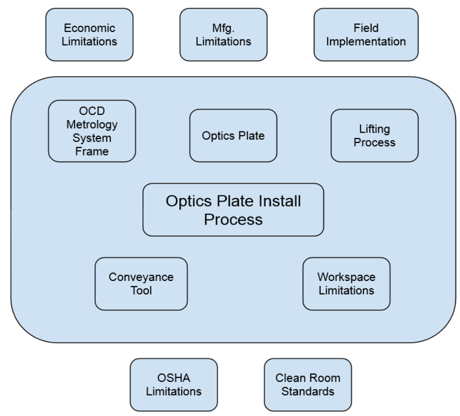

Figure 2: Boundary Diagram

Customer Wants & Needs

Needs	Wants
Component Safety	Sub $5,000 Project Cost
Refined Process and Tools for Install	Field Applications
Q4 Prototype Implementation	Design Ready for Implementation

Table 1: Customer Wants & Needs

Onto Innovations' main concern is with the optic plate's safety. Prototypes of any fixtures needed for the process are also expected in the beginning of Q4 for testing and implementation in Q1 2020. Beyond the basic needs, Onto Innovations would also like the project to incorporate economic considerations and the ability to implement in the field for any mid product life servicing.

QFD Process

The requirements Onto Innovations provided were analyzed in order to determine the metrics which would drive the product during the designing process. The five requirements determined by Onto Innovations were, in no particular order, to (1) refine the installation process, (2) design a fixture, (3) meet a budget constraint of $5,000, (4) have the final product be approved for use in a clean room, and (5) design a product that can be used in a field application. They were then ranked by requirement on a scale from 1-5, with five being the most important and one being the least, and related these requirements with quantifiable engineering requirements. The results of this correlation can be found in figure 3.

NanoMetrics		Weighting (1 to 5)	Engineering Requirements: Weight	Coatings	Material Strength	Material Stiffness	Installation time	# of Operators	Min. NIOSH Value	Number of Steps	Working Memory	# of Parts	Benchmarks: Alum-a-lift
Customer Requirements	Refine Process	4	3				9	9	9	9	3	1	3
	Fixture	4	9	1	9	9	3	9	1	9		3	1
	Sub 5K	3	9	3	3	3						9	1
	Clean Room	5		9									5
	Field Application	2	9	3			9	9	3	9	1	3	2
	Units		lb.	lb.	KSI	KSI	min.	#	Index	#	#	#	
	Targets		50	0.5	36	10,900	20	2	1	7	7	N/A	
	Benchmark #1												
	Benchmark #2												
	Importance Scoring		93	64	45	45	66	90	46	90	14	49	
	Importance Rating (%)		100	69	48	48	71	97	49	97	15	53	

9	Srong Correlation
3	Medium Correlation
1	Small Correlation
Blank	No Correlation

Figure 3: QFD Table

After creating the table, the 3 most critical engineering aspects to the design were weight, the number of operators needed to complete the task, and the number of complex steps an operator completes per task. This project's design will focus around these three requirements.

After completing the QFD table, the engineering requirements were further analyzed, creating an Engineering Specifications Table. In table 2, we listed all of the engineering requirements from the QFD table and associated tolerance, risk, and compliance of that requirement to engineering subsets.

Spec. #	Parameter Desciption	Requirements or Target (Units)	Tolerance	Risk	Compliance
1	Weight (individual)	50 lbs	Max.	H	A, T, A, S
2	Coating	.5 lbs	±.2	L	P,A
3	Material Strength	36 KSI	Min.	H	M, S
4	Material Stiffness	10,900 KSI	Min.	H	M, S
5	Installation Time	20 Minutes	±5	M	K, P
6	# of Operators	2	±2	H	C,P, S
7	Min. NIOSH Value	Index 1	Min.	M	K, S
8	Number of Steps	7 Steps	±2	M	C, P
9	Working Memory	7 Tasks	Max.	L	P,S
10	# of Parts	1	Min.	M	A, S

A	Assembly
T	Transportation
M	Materials
P	Production
K	Kinnematics
S	Safety

Table 2: Engineering Specifications

From this table, the high-risk parameters are part weight, material strength and stiffness, and the number of operators needed to complete the task. All these tasks deal either directly or indirectly with worker safety. For Onto Innovations, safety is the main concern when designing this product, making it a priority of the design. While not the main concern, the team will also focus on meeting the design goals of the 'moderate' specifications first, followed by the low risk parameters.

Design Process

This project will undergo 4 main phases before handoff of the final product. The first phase entails research of the process, metrology equipment manufacturing, and other solutions on the market. Detailed documentation of the current process will also be recorded during this phase. The second phase will entail the design phase. During this phase, a preliminary design review will take place to outline the research completed, design decisions investigated, and desired direction. Once the direction has been agreed upon with Onto Innovations, a final critical design review will take place reviewing the near-final design. Once any final changes are made, the project will enter the 3rd phase of prototype manufacturing. Once the prototype has been completed and tested off-site, the prototype will undergo testing from Onto Innovations on-site at their manufacturing facility. Any necessary changes can be made before the product is ready for Q1 2020.

Literature Review

Before designing a lift solution for Onto Innovations, it was important to conduct research on several aspects of the problem we are addressing. These aspects stem from process improvement, static and dynamic analysis, and journals on engine hoists. These resources create a comprehensive literature review, which include the relevant standards, patents, senior projects, articles, case studies, textbooks, and journal entries.

Patents and Standards

For standards, research was conducted on the United States Department of Labor's OSHA standards. The first of which were the OSHA standards that regulate Overhead and Gantry Cranes. This standard, *1910.179 - Overhead and Gantry Cranes*, consists of over 100 designs and safety criteria which are either required or recommended to be followed when both operating and designing an overhead or gantry crane. This provided some general background on what the industry expects out of companies which produce products similar to this project, and therefore describes the criteria that should be followed when designing the product.

The next standards researched were *1926.451 - General Requirements: Scaffolds, 1926.552 - Material Hoists, Personnel Hoists, and Elevators, and 1926.554 - Overhead Hoists.* Since one of the prototype ideas involves installing hoist in a structure in a shop environment, these standards together describe the requirements for each aspect of what that design might entail. Standard 192.451 describes the requirements that must be followed when attaching suspended structures in the proximity of workers. Meanwhile, standards 1926.552 and 1926.554 describe the pertinent requirements to designing, installing, operating, and maintaining an overhead hoist in a working environment.

In addition to OSHA standards, research was conducted on the ASME standards which related to this project. The ASME standard B30.10, which addresses the design and operation of hooks, discusses the selection criteria for choosing, operating, and maintaining hooks used in industrial environments. These standards will be important when determining what kind of hooks should be used to attach a hoist to the structure and/or what hook the hoist should use to lift the optical plate, should the design require either. Research was then conducted on the ASME standards HST-2-2014 and B-30.16. HST-2-2014 describes the design and operation standards for operating and hand-chain, manually-operated chain hoist while B30.16 specifies the standards in place for designing and operating underhung overhead hoists. Altogether, these OSHA and ASME standards are crucial to understanding the governmental and industry requirements that will directly influence this design.

One important aspect of this project is that it must be easily installed and removed before and after use. Therefore, when looking for patents, research was conducted on hoists and cranes which met this criterion. The first patent researched was the *PORTABLE DRIVE ASSEMBLY FOR A MANUAL CHAIN HOIST.* This patent depicts a design for a chain hoist that can be fully operated by a single person and a powered drill. It was apparent that the design intent of this patent simplicity, however the design component that was most critical to this project was the mechanism which routed the chains, providing mechanical advantage when lifting an object. While it isn't flashy, it is a quick and dirty means of creating a manually operated lift and could be important when designing this final product.

The second project researched was the *PORTABLE KNOCKDOWN TROLLEY HOIST.* While the size and scale of the patent doesn't apply to the project, it presents an interesting design for a telescoping hook which would extend past the linear travel of the I-Beam. This would be important if issues arose where either weight or size constraints become an issue, forcing a design change to a lift that has a travel range larger than its actual footprint.

The *Stabilizer for a Gantry Crane Lift Frame* patent does not discuss the actual design of a gantry crane, yet it provides valuable insight towards the subject of stabilizing the lift assembly. A gantry system typically has a frame that extends from the ground to above the loading location. However, one of the solutions will be supported inside the Atlas III frame. This frame is going to need to take not only the vertical point load, but the dynamic load of the optics plate being rolled into the machine. In addition, it is important to account for the oscillation motion of the optics plate, which will occur if the operator bums into the plate or begins rolling it into the machine. The loads are going to be more complex than initially thought, and the stabilization solution to mitigate those loads is heavy. This research has shown a potential flaw in two of the initial design alternatives. However, it may be able to make the frame mounting gantry work if the system is fastened completely with hardware.

One of the design solutions is to modify the current Alum-a-lift that Onto Innovations uses for assembly. A method of modification would include shortening the legs that are on the machine and designing an outrigger system that would be engaged once the lift is linked to the 250lb optics plate. The *Vertical Outrigger Leg* patent discusses an outrigger design for a mobile crane that can lift several tons. The lift is smaller, but these design principles can still employed in order to create a fold down support that braces the optics plate during installation. However, the outrigger would need to be able to move with the current lift, not extend down like the foot of a backhoe, as the boom on the Alum-a-lift is stationary. The current Alum-a-lift would need to go through extensive testing before it was cleared for a legitimate installation. However, this type of outrigger may be a good redundancy tactic for if a change in the leg design is needed.

Northrup Grumman developed a sensor system to implement in their crane design, which is defined in their patent *Crane Safety System*. The system is essentially a group of sensors located in the boom, supports, and other structural members on the crane. Using an onboard computer and DAQ system, the crane determines when a movement may lead to crane overturn and system failure. While not dealing with several tons of material for this project, it's incredible to view this type of technology as a safety system, as it prevents the operator from making a mistake that would cost his or her life. While the sensors will not be used, this patent verified the notion that putting the lift legs or gantry through significant testing before filed it for use is critical.

The final patent researched was the *PORTABLE STUDIO HOIST*. This patent depicts the design for a hoist and track system that is intended for the studio environment. Like before, the scale and scope of this patent doesn't directly relate to the project, however it has several aspects which could have an important application in this project. The most notable of these is the control setup for moving the hoist using a controller. The system was wireless and could allow the operator to move the crane while maintaining a safe distance and not deal with the hassle or safety risk of a chord dangling from the hoist. Each of these patents provides several design insights which could provide useful when designing this project, allowing to make a quality product without having to "reinvent the wheel."

Finally, when analyzing previous senior projects, the *SAE Small Vehicle Lifts* project conducted by Mechanical Engineering students at Cal Poly in 2017 was reviewed. The scope of their project was to design and manufacture three lifts to lift up two types of Formula vehicles and a Baja car. While their final design doesn't apply to this project (No hydraulics can be used in clean rooms) there were several aspects that do apply. The first of which is the criteria in which they measured the results of their design. The process that they used for completing this analysis will be very beneficial to follow as it can provide an accurate and efficient means of determining how much this product improves upon the original process. Secondly, they completed a full risk analysis which was used to determine what hazards are present and what designs are currently or should be implemented to keep them from happening. Lastly, one of the most important aspects of their senior project were the calculations and design which they provided in their appendix. These calculations, especially, can help jump start the design process and help validate that the design made will be safe and withstand the load case presented in this project.

Mechanical Design

This senior project requires an understanding of loading conditions, as two of the design alternatives are to design a quick pin lift that interfaces with the Atlas III frame. *Shigley's Mechanical Engineering Design* is one of the most trusted mechanical design textbooks, as it provides comprehensive walkthroughs of how to design for 3D structures. Since one of the lift designs is a static system with a dynamic boom – the gantry attached to the i-beam – the design should be made around the max loading conditions. These conditions occur when the lift is raising and lowering the optics plate, as this is a vertically dynamic 250 lb point load at two specific points on the i-beam.

In parallel with Shigley's, *Beer & Johnston Mechanics of Materials* has a few sections on beam loading. This will provide understanding on the i-beam dimensions required to support a cantilevered 250lb single point load that is displaced 17" from the Atlas III frame. This component of this design is the most alarming aspect of the project, but the six frame connection points should be enough for the load case provided. As the textbook title states, this textbook provides an understanding of material properties useful for different loading applications. Since weight is an important factor of the design, it is important to analyze whether low carbon steel structure will be feasible for the main lift structure. It is important to not compromise operator safety or Atlas III components by designing a solution that cannot be easily installed and meet the 20-minute window.

All design alternatives will require a fundamental understanding of loads, so the *Vector Mechanics for Engineers* textbook will help set up those fundamental models. Each design will need a FBD that fully defines the force flow through the lift once the 250lb optics plate has been attached. The interest of the Alum-a-lift redesign is understanding how the legs can be redesigned so that they do not interfere with the stabilizing plate under the Atlas III. It is mission critical that the solution does not make the operator's install process more difficult or less safe for installing the optics plate. It is also important to make sure that the lift is okay moving at a constant speed with the 250lb optics plate attached. In addition, if redesigning the legs, they must be able to take more than these loads, as Onto Innovations recently released an Atlas III+ that may have a heavier optics plate.

While problem solving for an ideal beam size using beam deflection equations in textbooks, the *Topology Optimization* research study has conducted FEA on moving point loads across beams. There are few resources that have tried to determine ideal beam styles for gantry cranes, as most of the designs are oversized with large factors of safety. Upon setting up the boundary conditions of two simply constrained ends of the beam and a point load traveling along the beam, the software change from square tube extruded material to i-beam extruded material, with the objective of minimizing the beam deflection: delta. The study concluded that square tube extruded stock would provide the greatest resistance to bending. While an interest in using extruded square tube exists, it is important to first make sure that the roller assembly can properly interface with this type of beam, as this system is simply constrained at one end and in the center. This includes dealing with a cantilever system and a mid-support that will not allow the use of a top mounted roller, however it will be difficult creating a roller system that can interface with the square beam given these conditions.

While busy researching design textbooks, analysis methods, and design ideas, the book *Proceedings of China Modern Logistics Engineering* focuses on the process of crane design. It is easy to lose sight of the operator who uses the machine daily, and sometimes trusting a topology model or FEA model more than a primitive approach to design. Chapter 20 states that it is important to step away from the computer and design a solution that best meets the entire process of the installation, not just the specific tasks and load conditions. In context of this project, this means designing a gantry that is lightweight, new Alum-a-lift that are not intrusive in the tight work envelope, and a machine that does not impede the operator's quality of work. By creating a lift with the operator in mind, Onto Innovations' success of implementing the lift as a legitimate solution will be greatly increased.

It's important to look at both effective crane designs and cranes that have failed. In this case, the *Failure Analysis of a Mobile Crane* discusses the failure of an overhead crane at the turret bolts. As it turns out, many cranes in ports are beginning to fail due to the corrosive environment that they are exposed to. This crane failed due to bolt shear, as the bolts had cycled an aggressive life in a highly corrosive environment and began to destruct. For these purposes, this project does not need to worry about corrosion, as the lift will be operating in a climate controlled clean room. However, it is important to analyze all factors that may affect the lift design. Had coatings not been considered in the initial discussions with Jon, the design could have rusted from any contact with the oils on the operator's skin. While everyone in the clean room is required to wear a full jacket and gloves, you can never underestimate the power of oxidation and its negative effects on a clean environment. Therefore, it is important to perform an extensive failure case analysis and mitigate any outstanding issues.

In addition to the failure of the gantry bolts, it is important to address the failure mode of the wheels, examined in the case study *Journal of Failure Analysis and Prevention*. The steel wheels travel along the horizontal axis of the crane and failure occurs in two main ways. The first is due to misalignment of the rails on which the wheels travel, leading to excess wear and increase stress along the wheel over time. However, the main reason the wheels fail is due to improper heat treatment during the manufacturing process. This will be an important aspect to address if designing a gantry system requiring steel wheels.

Finally, while a robust crane or lift design is the goal of this project, it is important to look at the smallest details, including the correct specifications for a hook or carabiner. *Stress Analysis of Crane Hook* is a design report that analyzes the design and implementation of the hook on a crane taking several tons of loading. I found this article important, as a chain is only as strong as its weakest link. The level of detail that goes into the design will need to include every part of the installation process, and no step can go without the proper design considerations. It is important to specify exactly what type of hook is needed to be purchased, what grade bolts and what types of coatings are needed, and many more factors. No portion of the design can go unaccounted for.

Process Improvement

Metrology manufacturing equipment involves numerous aspects with respect to process development and process control to ensure reliability and a minimal impact on total production of a product. A proper approach to development of a revised component install process for Onto Innovations' Atlas III must be taken to ensure the machine does not see any added complexities added to the manufacturing process, or maintenance process while in customer's hands. A complete understanding of optical metrology will also ensure the newly developed process does not inhibit the manufacturing process or the product's performance during its life. And given the scope of work for this team, the project's focus is largely around the manufacturing of the product. Workplace considerations will also enhance the process and its feasibility of industry implementation.

It's important to understand the current design that Onto Innovations is using. When researching the *Alum-a-lift* website, the exact lift designed for this installation process was found with all the correct specifications. In addition, Alum-a-lift has written a comprehensive breakdown of their structure, their design process, and their requirements for creating a lift for an ISO 7 clean room. Most of the lifts used in the semiconductor industry have electric powered lead screws to move the boom vertically. The Alum-a-lift leg design is also fairly simple, as there are four point loads at each of the wheels. By understanding where the mass and CG of the Alum-a-lift, the leg redesign strategy so that the lift operates safety and accommodates the new design requirements becomes more feasible.

Development of any new process in today's industries needs an analytical approach and complete understanding of the problem. New Product Development (NPD) encapsulates the inception of the new process to the end of its lifecycle. The NPD process can be applied to a light consumer product refresh only to boost sales, or to a new process seen in a manufacturing facility to increase efficiency and safety. Four general steps make up the NPD process: 1) Fuzzy Front End (FFE), 2) Design, 3) Implementation, and 4) Fuzzy Back End (FBE) ("Product Development Process 101", 2019).

Step	Description
1. FFE	FFE involves fully understanding the problem, the goal, and systematically creating the solution to the initial problem.

2.	Design	Design sees the realization of the requirements of the product and ensuring feasibility.
3.	Implementation	Implementation confirms the developed product meets initial requirements and begins to lay the groundwork in the process of getting the product to the customer.
4.	FBE	FBE launches the product to its customers in a structured way.

Table 3: NPD Process General Steps

The NPD process creates the basis for a successful development process and implementation of the product to the customer. The most important step of the process is step 1, FFE. Achieving a full grasp on the issue, goal, and direction to solve the problem will prevent any scrapped work during the project timeline. Furthermore, the IDEO Process applies to a manufacturing environment with its human focused design process. The IDEO Process observes existing workers and the Form, Fit, and Function (FFF) of the existing design. If there is no need for a part in the FFF, then the part is removed from the process. The model also has benefits for quick implementation of new products and/or processes ("Product Development Process 101", 2019).

Process innovation also will allow for the process development to succeed. Four types of Manufacturing Process Innovation exist, listed below:

- Type I: Structural, Local
- Type II: Infrastructural, Local
- Type III: Structural, Radical
- Type IV: Infrastructural, Radical

A complete description of each type can be found in Appendix 1. Type I directly applies best to process revision on a small, local region. Type I usually sees a large capital investment but does not require ongoing maintenance and input from workers. A Type II approach may bring fewer costs, but typically involves an ongoing change to the workflow (Yamamoto, 2013). In the revision of a process and implementation into the field with customers, a Type I approach will be more effective and concrete.

A realistic timeline in the development process is crucial to ensure success. The customer need-date usually sets the scope of the project. Full understanding of the timeline allows for the right direction to be selected in the early stages of the product. In the event of an aggressive timeline, the product may be sacrificed in terms of capability to ensure an on-time delivery ("Product Development Process 101", 2019).

Mathematical models are increasingly being applied to design and manufacturing environments to aid in efficiency and accuracy. Simulations can drive multiple design processes and tests to gather a strong understanding of all aspects. In today's engineering arena, use of simulation tools are valuable to save time and bring out the best product possible for the project. Simulation requires a similar understanding to the NPD process to ensure a model is developed to provide the most relevant information possible. Models in manufacturing environments are gaining in complexity, and use of large-scale computers have brought simulations into more environments (Oden, 2003). For small process development and revisions, simulation can be utilized to save time and improve a company's goal. Incorporating simulation models in the FFE and Design stages of the development process will aid to introduce an effective solution quickly.

It is important to understand the environment in which the lift is operating. Reading *What are Cleanroom Classifications?* helped garner a greater appreciation for working in a Class 10,000 or ISO 7 clean room. Clean room requirements lead to more hesitancy to employ any type of hydraulic system on the lift, and hydraulics are prone to leaking. There is concern with the use of chains, as chains have a lot of surface area and will be able to capture a lot of dust particles. Finally, it helped raise the question of how to properly clean and maintain tools in an ISO 7 clean room so that oil transfer is minimized, particle collection, and overall contamination. Semiconductors are sensitive to environmental factors, and the clean room helps ensure that the machine assembly process does not allow for foreign bodies in the Atlas III before it ships to the consumer.

Optical Metrology (OM) benefits the metrology industry by providing measurements of products that would be either inefficient or impossible to probe. A large factor of OM relies on light interference. The optics within OM Machines are a driving factor in producing accurate results when measuring parts. Any mishandling of the plates during the installation process can lead to a failure in the part (Grous, 2013).

Metrology is a utilized function in most semiconductor manufacturing processes. The overall wafer cycle time is dependent upon all aspects from start of wafer manufacturing to finish. Slowing the overall wafer cycle time directly affects the bottom line and can slow profits (Jayez, 2017). Introducing a revised process must not add additional time to any wafer manufacturing process, and in the best case, minimize any down time.

Manufacturing environments can pose safety risks to products and workers involved in the process. In 2005, roughly 4.6% of American workers were injured in some way at work. In the manufacturing field, a typical injury due to a fall can cost a company north of $40,000 when considering direct and indirect costs (Gagne, 2011). Some industries are at more risk than others, but the event of an accident can displace a company's progress significantly.

Ergonomic considerations can modify a process to reduce worker injury, and the process can also be developed to eliminate any possibility of accidents causing harm to workers or components. Promotion of good ergonomic practices also tend to improve worker productivity and confidence. Simple ergonomic practices can be implemented such as the eight below in Table 4 (Middlesworth, 2019):

Practice	Benefit
Maintain Neutral Posture	Reduces stress on the body
Work in Power/Comfort Zone	Arms can operate with the least amount of effort
Allow for Movement and Stretching	Allow the body to move in its environment
Reduce Excessive Force	Prevents musculoskeletal fatigue and strain
Reduce Excessive Motions	Prevents musculoskeletal fatigue and strain
Minimize Contact Stress	Promotes blood flow
Minimize Vibrations	Minimizes health issues
Provide Adequate Lighting	Minimizes eye fatigue and worker error

Table 4: 8 Fundamental Ergonomic Principles

Conclusion

Each of these sources were important to review in order to garner a holistic understanding of the problem and the solutions present, both from the relevant to the obscure. Only through doing this process can the best solutions and designs be made and well-implemented.

Engineering Design Process

Regardless of the solution chosen, all options need to meet a set of requirements instituted by Onto Innovations. Safety for the operator and optics plate is paramount; therefore, a factor of safety (FOS) of 5 is required for lifting solutions. While the design needs to be lightweight, the high FOS ensures that no component failure will cause the optics plate to fall. Another top priority is that the solution can be used in their Class 10,000 clean room. This requirement barred any solution that could have metal on metal contact. The use of winches, hoists, pulley systems, and cam devices are prohibited from the solution design. While minor metal or metal contact is inevitable and necessary, using a system that has continuous frictional contact, such as a ratchet system, will not be acceptable. Finally, having a portable solution is important for servicing operations in the field. This requirement helped drive a solution that could be easily disassembled and put into a truck or onto a plane. The portable constraint drove the team towards a lightweight solution, however, a heavier design that requires multiple people to load/unload from transit would be acceptable. More importantly, making sure the design did not have many parts with obtrusive geometry will allow it to be shipped.

The team determined a few different solutions, each having a distinct set of positive and negative attributes. However, all should be able to complete the basic objectives established for adequacy. In particular, the three solutions are: designing and manufacturing an underhung gantry system, redesigning the Alum-a-lift for the Atlas III, or simply improving the routing for the current process that's in place. Each will be described in more detail below, with the preferred solution listed first.

The underhung gantry system is a solution that the senior project contact at Onto Innovations has been promoting since the first meeting. This option has grown into an ideal solution because it best meets the design criteria. The lift design is lightweight for installation, collapsible for transport to offsite locations, and simple to use for one to two operators. The lift also allows for some lateral movement within the machine, which is useful for the operator installing the lift into the Atlas III. The frame of the Altas III has a few M12 x 1.25 threaded holes that are tapped into the .250" 1020 steel frame by the frame manufacturer. These holes were crucial for frame design, as the installation of large diameter, high grade bolts will be loaded in conditions close to direct shear. With only a 250lb weight bearing on a bolt able to take thousands of pounds of direct shear loading, the team did not have a concern with bolt or frame fatigue. From the bolts, there is an i-beam structure that pins into the mounts.

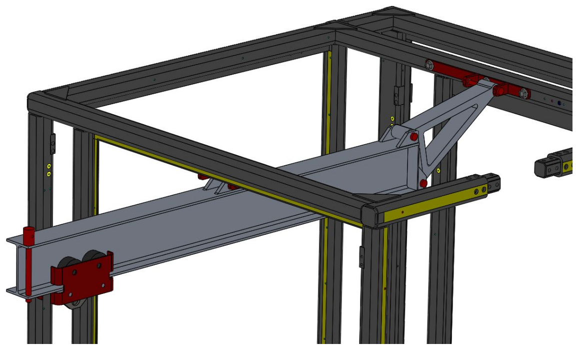

Figure 4: A first prototype underhung gantry system

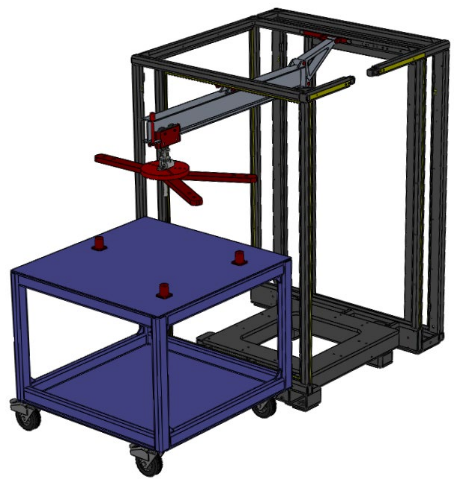

Figure 5: The Atlas III frame with the underhung gantry installed

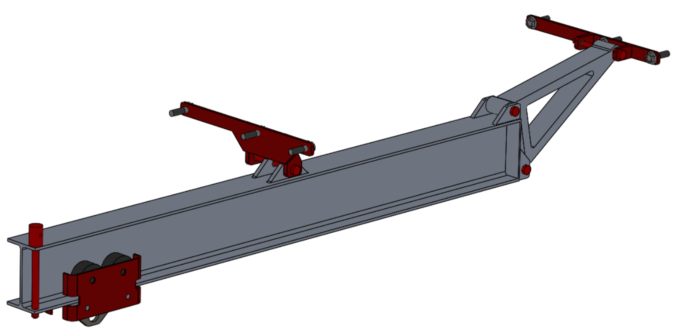

Figure 6: The underhung gantry without the Atlas III frame

A large concern stems from the i-beam as a cantilever member that is constrained simply at one end. Therefore, the team created a beam deflection calculator that allowed them to use Excel solver to find the ideal size of a beam:

I Beam Cross Section			Solving Delta			Weight		
h	3.374	in	P	250	lb	Density	0.0975	lb/in^3
a	0.313	in	L	25	in	Area	3.560	in^2
b	4.000	in	E	1E+07	psi	Length	63	in
H	4.000	in	I	3.347	in^4	Volume	224.284	in^3
Target Iy	3.347	in^4	delta	0.039	in	Weight	21.868	lb

Figure 7: Beam Deflection and Weight Calculations

This calculator accounts for the weight of the i-beam as well, because the team needs to make sure that operators do not get fatigued during the installation process. Using the NIOSH equation, the team determined that each operator would be able to lift approximately 20lb. According to the calculations above, this means the operator will need help installing the i-beam into the bolted in steel mounts. However, the connection is designed with pins that slide into clearance holes and slots, which means the operators will have to use little effort to constrain the i-beam into the mounts. The goal is to make sure that the installation process is simple yet effective for lifting the optics plate.

A thorough process flow is required to ensure the operators are aware of proper installation procedure. Without the proper documentation and training, the operators may make a critical error where a piece falls during installation. This is one of the few negative attributes to the project - complexity and likelihood of dropping a part. With proper training, redundancy in safety features, and the correct tools, the team can mitigate these issues. Another concern is the life expectancy of the machine. The team needs to make sure that the lift does not deteriorate quickly with use. However, since the operation is low rate, the team feels as though they will not deal with a short component life cycle.

Another solution will be to implement modifications on Onto Innovations' current Alum-a-lift. The company purchased the lift for this installation process, but as the Atlas III saw revisional changes, the lift did not:

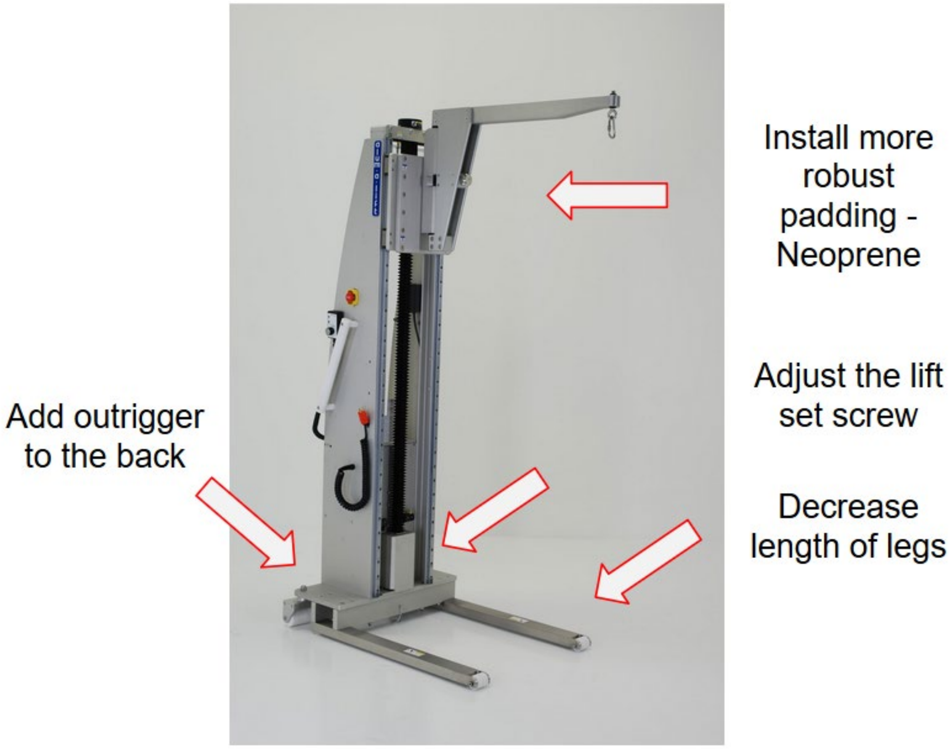

Figure 8: Current Alum-a-lift modification recommendations

As mentioned in the figure above, decreasing the length of the legs will allow the Alum-a-lift to fit under the blue fixture plate. In doing so, the CG and lift weight distribution will shift. In reading about lift design, the team determined that an outrigger, also known as a ballast weight, would be able to account for the change in leg length. the team will need to corner weight the scale and calculate the weight distribution in order to make sure the outrigger would be enough to keep the lift from tipping. From the research, it is not uncommon for lift to experience a failure case due to an unexpected load case. In this situation, an operator bumping into the lift would knock it off balance.

The team needs to adjust the set screw on the lift, as the current setting makes the lift bottom out before it can reach the optics plate on the fixture plate. This adjustment can be made in a matter of seconds, but it is important to note that the team will need to play with the adjustability features in order to make the design work. Finally, the team will need to install a more permanent type of padding on the lift. The current lift has bubble wrap around this section to keep the optics plate from being damaged. The preferred method is to use adhesive and secure a thick sheet of Neoprene for impact absorption. The team understands that thick Neoprene sheet will do a sufficient job for protection, but it is worth further exploration to understand if there’s a better material, such as an adhesive foam, that should be used instead. The goal of impact protection material is to decrease the time of the impact and distribute the load onto the deformable material, so foams seem to be a good choice. Testing will allow the team to find the best impact solution.

The third alternative is to implement a SOP for the installation of the optics plate. This alternative uses the current equipment that Onto Innovations owns, so the cost is low. The current process that Onto Innovations uses seems inefficient and is unsafe for the optics plate, but it does work. In a medium or high rate facility, this process would clearly be identified as a bottleneck. If this low rate facility, the time constraint is not severe, so a more practical solution is more of a luxury item for Onto Innovations. By creating an SOP, there would be no variability in methods from the operators, as each employee would be aware of the best installation method. The awkward facet of creating a current SOP is that the installation process is not ideal, which means these recommendations would be somewhat contradictory to what is known as safe for installation. It is important to reach exhaustive ends or budget cuts from Onto Innovations in order to employ this type of solution; however, it is a nice fail-safe option in the event of a severe project change.

After extensive review of the three solutions, the team moved forward with the underhung gantry system. As with all prototype designs, the team expected the initial prototype to have faults. However, implementing a design solution as opposed to modifying an existing method best met the requirements from Onto Innovations. No other solution proved to be as mobile, and the design can later be modified can re-manufactured if needed.

Factor	Weight	Underhung	Alum-a-lift	SOP
Stabilization	5	1	0	-1
Operator Control	3	1	0	-1
Clean Room	3	-1	1	1
Price	1	0	0	1
Mobility	5	1	-1	-1
		10	-2	-9

Table 5: Decision Matrix Justifying Underhung Solution

To verify that the underhung solution would work, the team developed and carried out a mechanical design process, ergonomic testing, in-depth packaging studies to ensure the prototype would be feasible. Starting at the preliminary level, hand sketches and calculations were conducted on the i-beam, mounts, and trolley. A major emphasis was placed on making sure the lift would spatially be able to package inside the Atlas III frame, as some mechanisms such as electric hoists provided to be too tall to fit inside the machine. A scale model was developed to run through the installation process with simulated weights. The findings of the test assisted with the process development, but the recommendation ultimately changed after some revisions to the material selection from the I-beam -- allowing for two operators to be utilized. Once a concrete design concept was created, the team would meet with engineers at Onto

Innovations to address the pros and cons of each design. Those engineers would provide constructive feedback, and the team would address any issues brought up during the meeting.

The design process carried on for a few months in the preliminary phase. Some of the main concerns with the prototype designs included spatial constraints and cleanroom compliance. However, the team was able to solidify a design idea: using a mechanical lever system underneath the trolley assembly on the i-beam to raise and lower the optics plate. This provided to fit inside the Atlas III and did not have any major sources for partial generation.

Engineering Skills in Design

Mechanical Design

One the preliminary design idea had footing; the team transitioned into detail design. This level of design work includes finalizing geometry, selecting materials, and performing finite element analysis (FEA) on all parts to ensure that the hand calculations provided accurate outputs. Since the geometry of the design was such an integral part of the requirements, there was no significant push to heavily modify geometry post preliminary design review. However, some of the most important changes were adding slots in the mounts so that the lift could accommodate variations in frame manufacturing. As with assemblies of this size, the Atlas III frame could see 1/16th inch variation in net frame dimensions. Having a mount on the i-beam that can accommodate for this variation allows the lift to have universal fitment.

Material analysis had been conducted for the i-beam in the preliminary design, but other systems needed to be developed. Working in a cleanroom, it is important that bare metal is not exposed. Rust, a red-oxide layer, is a chemical reaction that occurs between the metallic molecules and the atmosphere in ferrous materials. Rust could cause significant issues in a cleanroom environment if an electronic assembly encounters it. Therefore, ferrous materials must be coated with powder coat. In addition, aluminum will form an oxide layer, separate from rust, over the course of time. Aluminum in cleanrooms but also be coated, but with an anodized layer. Few materials on the project do not need to be coated, which include stainless steel and plastic components. While creating the project completely out of stainless steel seems enticing, the cost and weight of this material outweighed the benefits of cleanroom compliance. The team's biggest components where aluminum and steel coated assemblies.

Tied in with FEA, the material selection, wall thicknesses, and some geometry were determined by the results of load simulation trials. The team conducted FEA on all loaded parts to ensure that the material had enough padding around bolts, the plate was thick enough, and the members in bending such as the i-beam saw limited deflection. The FEA did help solidify whether aluminum or steel would apply best to a certain part. The i-beam, being a large component, needed to be made from aluminum, as the steel counterpart would weigh almost twice as much. FEA also helped the team understand load paths, as some of the initial mounts would risk tear-out on the frame due to the moment induced from the load onto the bolts. The loads drove our design towards parts that best meet requirements, but at the expensive of easy manufacturability. For instance, while the frame mounts to the i-beam minimize the moment on the frame by putting the frame bolts in direct shear, the mounts needed several CNC operations and setups. Once the FEA was finalized, the team made final improvements to the CAD design, and transitioned into creating drawing so the manufacturing process could begin.

Manufacturing

With our design finalized we transitioned into the manufacturing phase of our project. During this phase we would ensure that the principles of Design for Manufacturability and Assembly (DFM & DFA) were applied to our final design, formal part drawings were drafted, a manufacturing timeline was developed, and the prototype parts were manufactured and assembled.

Beginning with DFM and DFA, we analyzed the parts we designed for geometries that were either impossible or too difficult to make or assemble using conventional methods of manufacturing. For this project, the conventional methods of manufacturing we considered are listed in Table 6. Designing around these processes allowed us the ability to narrow the scope of our design and focus on the geometries that could easily and quickly be manufactured, as they would have to be manufactured in-house at Cal Poly in order to meet our project deadlines.

Beyond changing gerometies to get better tool clearance or reach, we also addressed designing clearances for assembled components. Since the project would have to be used in a clean room environment, all exposed carbon steel would have to be powder coated and any aluminum would have to be anodized. While anodization only slightly affects the part geometries, powder coating can leave a coating anywhere between .01-.02" greating affecting the clearance and fit of assembled components. Therefore, it was imperative that we account for these coatings when designing geometries where one or more parts are assembled together.

Conventional Manufacturing Methods	
Vertical Milling	Lathe Turning
MIG Welding	Waterjet
Cold Saw	Drilling

Table 6: Typical manufacturing methods

Once DFM and DFA was complete, formal design drawings were made with the proper dimensions and Geometric Dimensioning and Tolerancing (GD&T). It was important to include the GD&T of our part drawings as a means of better defining the dimensions and critical features both for our own manufacturing as well as for future suppliers. In addition to the drawings, we developed a manufacturing timeline which would outline when parts needed to be manufactured in order for the project to be finished on time (see figure 9). This was useful for distributing workload amongst team members, coordinating schedules with outside suppliers, and prioritizing the order for manufacturing parts.

Component	Sub-Assembly	Quantity	Operations	Wk. 4	Wk. 5	Wk. 6	Wk. 7	Wk. 8	Wk. 9	Wk. 10	Wk. 11	Finals
				Oct. 13-19	Oct. 20-26	Oct. 27-Nov. 2	Nov. 3-9	Nov. 10-16	Nov. 17-23	Nov. 24-30	Dec. 1-7	Dec. 8-14
I-Beam	-	1	CNC	In Transit	In Transit	In Transit	In Progress	Completed	Outsourced	Thanksgiving Break	Assembly and Testing	
Lever	-	1	Var.	In Transit	Preperation	In Progress	In Progress	Completed				
-	Handle	1	Welding	In Transit	Preperation	Completed						
-	Extention	2	Welding	In Transit	Preperation	In Progress	Completed					
-	Connection	1	Welding/ Drill	In Transit	Preperation	In Progress	Completed					
Trolley	-	1	Var.	In Transit	Preperation	In Progress	In Progress	Completed	Outsourced			
-	Wheel Mounts	2	Waterjet/Mill	In Transit	Preperation	In Progress	Completed					
-	Base Plate	1	Waterjet/Mill	In Transit	Preperation	Completed	In Progress					
-	Tabs	2	Waterjet/Mill	In Transit	Preperation	In Progress	In Progress	Completed				
-	Pivot Point	1	Welding/Drill	In Transit	Preperation	In Progress	In Progress	Completed	Outsourced			
-	Spacers	4	Lathe	In Transit	Preperation	In Progress	Completed					
-	Fixture Plate	1	TBD	In Transit	Preperation	In Progress	Completed					
-	Gusset	1	Waterjet	In Transit	Preperation	In Progress	Completed					
-	Part Stop	1	Waterjet	In Transit	Preperation	Completed						
Mounts	-	2	CNC (4th)	In Transit	Preperation	In Progress	In Progress	Completed				
-	Fixture Plate	1	CNC	In Transit	Preperation	In Progress	Completed					
	Total	21										

(orange)	In Transit
(grey)	Preperation
(yellow)	In Progress
(green)	Completed
(blue)	Outsourced

Figure 9: Manufacturing Timeline

For this project, a majority of the manufacturing operations for this project were done in the Mustang 60 Machine Shop. Most of the parts had complex part geometries with tight tolerances, so we chose to do a majority of our manufacturing on a CNC mill. This allowed us the ability to manufacture parts much quicker and with higher precision than that of a manual mill, which was necessary due to the high number of parts that needed to be manufactured. In addition, we chose to use a Haas VF3 as it has a work envelope which allowed for several work holdings to be positioned on a single table, reducing the setup time between operations. In addition to the VF3, several parts with less complex geometries were manufactured using manual machinery in order to avoid bottlenecks during the manufacturing process. For the components which required welding, we utilized a MIG welding process as well as several jigs to ensure the correct part geometries were met.

Once the components were manufactured, all parts were deburred to remove sharp edges. We conducted test fits on all components that interfaced with one another as well as measured critical dimensions to ensure that the parts were manufactured in-spec. Once completed, the manufactured parts were sent out to receive powder coating or anodizing to make them clean room compliant. When the parts were received from outside vendors, a final check was conducted to make sure the coatings met both our's and Onto's specifications before conducting full-process testing.

Testing and Implementation

Following receipt of components, the team assembled the prototype to ensure proper fit and finish. A few issues and oversights were realized following final assembly. Most notably, the powder coat finish on some pieces did not consider various features of the design such as bolt holes and holes for pins or bearings. The coating process did leave some bare steel surfaces exposed which would not be acceptable in a clean room environment due to outgassing and particle generation from the steel. Following communication with Onto, we elected to proceed with controlled testing on the production line despite these coatings issues. *Note: due to intellectual property present during the testing, limited photos are available to share within this report.*

Upon arrival to Onto for in-house testing, a design issue was immediately discovered once the team attempted to mount the frame mounts to the frame. Both the mounts and frame were threaded, causing the bolt to be overconstrained and prevent a proper jointed connection. The team was able to drill out the threads on the frame mounts and continued on with the testing. All of the components were successfully installed into the machine and were ready to attempt to install the optics.

Once the optics were attached to the trolley, the trolley tilted and rested on two of the four wheels as seen in figure 10. This was due to an oversight with the analysis on the moment created by the load on the trolley. This oversight highlights a critical issue with the trolley design and proves that the trolley could not be implemented into production as-is.

Figure 10: Trolley Moment

While the oversight was present, the team was still able to walk through the installation process and successfully place the optics within the machine. This was possible by placing a placing a protective strip along the i-beam to prevent any particle generation via metal on metal contact. A summary of the test findings can be found in table 7.

Measured Metric	Expected	Achieved	Reasoning
Concept Validation	Validated	Validated	Concept direction shows promise and after further revisions could be implemented into production
Prototype Readiness	Ready for repeated use	Ready for limited testing in controlled environment	Issues during manufacturing (coatings) and with some early analysis (moment about trolley mis-analyzed)
Expected Install Time	< 20 mins (optics + tooling)	~ 6 minutes for tooling install	Prototype issues prevented from a full installation, but total <20 mins achievable
Expected Operator Input	30 lbs. to operate lever system	21 lbs. to operate lever system	Initial analysis and design did not account weight of lever, dummy optics for install

Table 7: Testing conclusions

Moving forward, Onto is in a position to proceed with refinement of the design. The design can stabilize the optics, and also provide a faster overall installation time to aid in a goal of reducing overall cycle time. The only vital changes needed are to the coating process and to the trolley design. Further refinements can be made to clean up and speed up the existing process. These changes are better suited to be completed by engineering at Onto, as they have direct access to the facilities needed to further develop this concept.

Economic Analysis of Design and Broad Impact

Economic Analysis

The economics of the projects present an interesting challenge to justify the tooling. Specialty tooling to improve operations typically requires a sizable investment and benefits that are harder to quantify. Given this, a large majority of the financial figures used are estimates and may not encapsulate the whole financial picture. The three options were compared using an ROI calculation over a single year, shown in table 8. This approach estimated both direct and indirect costs for a total of 5 units produced for production and servicing worldwide. The underhung gantry direction yielded the highest positive ROI around 8% after 1 year and 52% after 5 years. The alum-a-lift revision yielded lower numbers - 5% and 41% respectively.

Solution Cost	SOP	Underhung Solution	Alum-a-lift Revision
R&D	$3,500.00	$5,500.00	$3,000.00
Build Cost	$500.00	$47,500.00	$32,500.00
Labor Costs	$959.04	$1,440.00	$950.40
Indirect Cost	$0.00	$20,000.00	$40,000.00
Total Investment	$4,959.04	$74,440.00	$76,450.40
Cost/Operation	$137.75	$2,067.78	$2,123.62

Savings	SOP	Underhung Solution	Alum-a-lift Revision
Mfg Time Wages	$240.00	$240.00	$480.00
Field Update	$0.00	$80,000.00	$80,000.00
Totals	$240.00	$80,240.00	$80,480.00

ROI Calculation	SOP	Underhung Solution	Alum-a-lift Revision
Cost	$4,959.04	$74,440.00	$76,450.40
Year Savings	$240.00	$80,240.00	$80,480.00
ROI	-95.16%	7.79%	5.27%

Table 8: Initial 1 year ROI

	Underhung		Alum-a-lift	
	Savings	Expenses	Savings	Expenses
0	$80,240.00	-$74,440.00	$80,480.00	-$76,450.40
1	$80,240.00	-$21,400.00	$80,480.00	-$40,950.40
2	$80,240.00	-$21,400.00	$80,480.00	-$40,950.40
3	$80,240.00	-$66,400.00	$80,480.00	-$40,950.40
4	$80,240.00	-$21,400.00	$80,480.00	-$40,950.40
5	$80,240.00	-$21,400.00	$80,480.00	-$40,950.40
Total	$481,440.00	-$226,440.00	$482,880.00	-$281,202.40
ROI		52.97%		41.77%

Table 9: 5 year ROI for two feasible design directions

This analysis is somewhat limited and does not provide the entire picture. Costs and savings were estimated due to the uncertain direction of the project. This project sided more on the R&D side of the equation than actual implementation making it difficult to achieve a comprehensive analysis. However, the underpinnings of this analysis are sound as the underhung gantry system would expect to see a reduction in costs over existing processes and allow for easy servicing opportunities providing new opportunities for cost reductions.

Broad Impact

Designing a lift that revolves around the safety of the optics plate does not align with one of the most important aspects of the process: the operators. The requirements that drove the lift design were to make sure the plate was safe, which led the team to the creation of a lift that is heavier than necessary, somewhat awkward to install, and dependent on the strength and capability of the operator. This introduces a flaw that is seen as detrimental on a broader scale: making sure designers and engineers always keep the operator in mind. If engineers are to design around the product only, the safety of the operator could be at severe risk. This has been seen in the early stages of the industrial revolution, where machines with exposed belts and flywheels would lead to the loss of fingers and limbs. As our world works towards continuous improvement in manufacturing, there needs to be a greater emphasis on continuous safe improvement. In retrospect, the team should have paid closer attention to the safety of the operator, and maybe move towards a semi-automated solution. While the initial costs are high and the development more complex, no cost is high enough that the risk of an operator’s safety is put into question.

Conclusions and Recommendations

The project provided a design experience for a specialty operation in a unique manufacturing environment. Challenges were presented not only by the issue at hand, but also by the method of solving the problem. Unfortunately, the project team was offsite and 3 hours away from the production line, heavily relying on CAD to work through the design. Initial problem identification was not fully developed, ultimately hurting the group and causing issues with the design process not going as intended. The actual experience due to the distance issues, lack of the production line, and incomplete problem identification early highlight the issues stopping progress. All future projects should ensure it has a clear problem identified from day 1 and accounts for all possibilities of newfound knowledge.

The process and lift design here lean more towards R&D than a ready to implement prototype, largely due to some of the issues mentioned previously. While Onto Innovations has a prototype, significant revisions need to be made to the design to ensure implementation to production is worthwhile. Changes are centered around the lift tooling design but the process should remain relatively intact.

The project provided significant insight into the design process from not only an industrial engineering perspective, but also a mechanical engineering and out of office perspective. The learning was significant for the team, and hopefully provided useful knowledge to Onto Innovations. However, the group would recommend all parties explicitly outline and review expectations to ensure the topic of the project aligns with the field of study and the deliverables are achievable.

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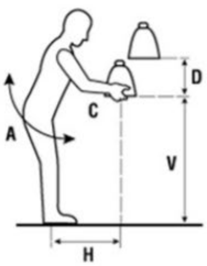
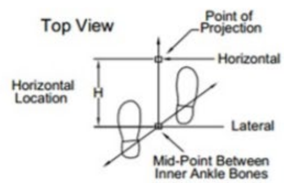
Appendices

Appendix A - NIOSH Lifting Calcs





		METRIC	U.S. CUSTOMARY
Load Constant	LC	23 kg	51 lb
Horizontal Multiplier	HM	(25/H)	(10/H)
Vertical Multiplier	VM	1-(.003 |V-75|)	1-(.0075 |V-30|)
Distance Multiplier	DM	.82 + (4.5/D)	.82 + (1.8/D)
Asymmetric Multiplier	AM	1-(.0032A)	1-(.0032A)
Frequency Multiplier	FM	From Table 5	From Table 5
Coupling Multiplier	CM	From Table 7	From Table 7

NIOSH = LC * HM * VM * DM * AM * FM * CM = RWL

Lifting Index = Load/RWL

Variable	Origin	Destination	O	D
H	12.00	24.00	0.83	0.42
V	48.00	72.00	0.87	0.69
D	24.00	24.00	0.90	0.90
A	0.00	0.00	1.00	1.00
F	0.95	0.95	0.95	0.95
C	0.95	0.95	0.95	0.95
LC	51.00	51.00	0.58	0.23
RWL			29.69	11.76
LI		20.00	0.67	1.70
		30.00	1.01	2.55
		40.00	1.35	3.40
		50.00	1.68	4.25
		60.00	2.02	5.10

Table 5
Frequency Multiplier Table (FM)

Frequency Lifts/min (F) ‡	Work Duration					
	≤1 Hour		>1 but ≤2 Hours		>2 but ≤8 Hours	
	V < 30†	V ≥ 30	V < 30	V ≥ 30	V < 30	V ≥ 30
≤0.2	1.00	1.00	.95	.95	.85	.85
0.5	.97	.97	.92	.92	.81	.81
1	.94	.94	.88	.88	.75	.75
2	.91	.91	.84	.84	.65	.65
3	.88	.88	.79	.79	.55	.55
4	.84	.84	.72	.72	.45	.45
5	.80	.80	.60	.60	.35	.35
6	.75	.75	.50	.50	.27	.27
7	.70	.70	.42	.42	.22	.22
8	.60	.60	.35	.35	.18	.18
9	.52	.52	.30	.30	.00	.15
10	.45	.45	.26	.26	.00	.13
11	.41	.41	.00	.23	.00	.00
12	.37	.37	.00	.21	.00	.00
13	.00	.34	.00	.00	.00	.00
14	.00	.31	.00	.00	.00	.00
15	.00	.28	.00	.00	.00	.00
>15	.00	.00	.00	.00	.00	.00

†Values of V are in inches. ‡For lifting less frequently than once per 5 minutes, set F = .2 lifts/minute.

Table 7
Coupling Multiplier

Coupling Type	Coupling Multiplier	
	V< 30 inches (75 cm)	V ≥ 30 inches (75 cm)
Good	1.00	1.00
Fair	0.95	1.00
Poor	0.90	0.90