

California Polytechnic State University, San Luis Obispo

# HAAS AUTOMATION UMC-750 5-AXIS MILL ASSEMBLY PROCESS IMPROVEMENT



A Senior Project submitted in Partial Fulfillment of the Requirements for the Degree of  
Bachelor of Science in Industrial Engineering  
Bachelor of Science in Manufacturing Engineering

by

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# Abstract

The improvement of the current assembly of the motor and casting components for the Haas UMC-750 5-Axis vertical CNC mill includes the evaluation, development and proposal of a new pair of material handling carts. To meet these deliverables, a student team began by assessing the assembly workstation, defining the problem to be solved, researching ergonomics in material handling equipment and drafting the final design of the improved cart models using SolidWorks.

The final design considered the initial improvement request from the client, as well as better ergonomic features to enhance the safety of the operators. It was estimated that the new design can provide Haas Automation with savings in material cost and production of the cart. At the same time, by improving the design, the new carts reduce risk of employee injury by decreasing the use of an overhead crane for assembling the motor components. The SolidWorks models and engineering drawings will be presented to Haas Automation in the hope of a future implementation.

# Introduction

The subject of this report is the design of material handling equipment, specifically for ease of transportation and assembly. The team will be working with Haas Automation to redesign carts used in the assembly process for their machines. Specifically, the Universal Machining Center (UMC) model 750 will be the focus of this report since this model is where the employees see the most room for improvement. The assembly of this machine involves several casting components that come together, assembled or stacked, using an overhead gantry crane. However, according to the employees working on the machine, the process has not been improved in a long time.

The existing procedure requires the employee(s) to do initial preparation on the UMC-750 spindle head casting while it sits on a cart. When it is ready to move on through the assembly process, it must be attached to the overhead crane, rotated and lifted to line it up with the spindle head motor assembly, which sits on a different cart. Once the frame is correctly aligned with the motor, it is lowered and secured. This method requires the employee to exert unnecessary energy and consumes excessive time, according to the employees working at the station. While the position of the motor on the cart is necessary for loading and transporting it, it doesn't match up with the position of the spindle head casting. The existing carts currently have the ability to rotate the parts from a vertical position to a horizontal one, but there are no ergonomic safeguards to keep the parts from flipping too fast and damaging parts or injuring employees. The study aims to do the following:

- Collect information about ergonomic practices that will lead to decreased physical strain on the employees
- Research and implement safe material handling practices to reduce the risk of employee injury
- Use computer assisted design (CAD) software to develop a new cart design

In order to accomplish the project deliverables, the team will research existing studies on ergonomics and lean principles, conduct time studies, gather measurements, and use SolidWorks to design a new cart that will be presented to Haas representatives. Once the new carts can be implemented into the existing process, the employees will be able to spend less time and energy on the assembly of the components, resulting in higher throughput when necessary, or simply the ability to allocate the saved time to work on other tasks.

# Background

Haas' UMC-750 is a 5-axis vertical machining center, as seen in **Figure 1**, known for its versatility and precision offered at a reasonable price. According to Haas Automation Europe Managing Director, Mr. Alain Reynvoet, "It is a high-performance CNC machine tool for a fraction of the usual cost associated with machines of such significant capability and high quality."



**Figure 1. Haas UMC 750 Axis Mill at a trade show**

In order to produce and sell these machines at an affordable cost, the assembly process must be streamlined to reduce wasted time, energy, and other valuable resources. Haas currently uses systems such as forklifts, flexible manufacturing systems, and many different types of carts to move materials around the facility. In the UMC-750 machine line, large industrial steel carts, gantry cranes, and plastic push carts are the main modes of transportation at the workstations throughout the assembly process.

By improving the carts that are used, the carts themselves will bear the brunt of the component's weight, minimizing the strain on the employee's body during the assembly reducing the risk of injury. The new

carts will also reduce the processing time by minimizing the use of the overhead crane, allowing the employee to spend more time on other tasks.

The current process utilizes different workstations for each step. The materials used at each station are delivered in kits, and stored at the station until they are needed. The castings, motors, and other components that come together to make the UMC-750 machines are transported around the facility using carts and forklifts. Once they get to a station they are lifted, rotated, and lowered by an overhead gantry crane in order to be properly assembled. The main focus of this study is the machine cast assembly station in which the motor is mounted onto the spindle head casting for the UMC-750. **Appendix A** shows the entire routing sheet, with this station highlighted, to give an idea of where it fits into the whole assembly process. At this station the drive assembly is delivered on a cart, shown in **Figure 2**, in an upright position. Meanwhile, rails are mounted on the spindle head casting and then calibrated for parallelism. This process takes place while the casting is laying horizontally on a cart, shown in **Figure 3**.



**Figure 2. Drive  
Assembly  
Transportation Cart**



**Figure 3. Spindle Head Preparation  
Cart**

After the spindle head is prepared it is secured to an overhead crane, rotated, lifted, and aligned with the drive assembly, see **Figure 4**. It is then lowered and secured, see **Figure 5**, and the whole assembly is moved onto a pallet to await transportation to the next station. This process can take up to 15 minutes to complete, from attaching the crane through lowering it onto the pallet.



**Figure 4. Aligning the spindle head with drive assembly**



**Figure 5. Securing the casting**

After observing the process and taking employee suggestions into account, the main area for improvement appeared to be the transportation carts. By changing the design for these carts, the use of the overhead crane could be minimized, reducing the risk of employee injury and the physical stresses associated with it. In order to accomplish this, the schematics of each piece of equipment were studied along with the dimensions and specifications of the products they are associated with. From that, a viable new cart design was developed.



# Literature Review

This project generally covers a process redesign which focuses on how material is handled. There are many different types and styles of material handling that manufacturing companies can use in their processes. Companies also need to consider ergonomic factors that pertain to the particular manufacturing function and movements of the employees in the manufacturing process. There needs to be safety considerations for the protection of the employees and the products. In order to design the new carts with these considerations there needs to be knowledge in the use of solid modeling software. This literature review will look deeper into the styles, ergonomics, safety factors, and solid modeling principles that need to be considered and applied in the new design of the Haas Automation UMC-750 5-Axis casting assembly carts.

Three possible modules generally used when selecting material handling equipment are,“(1) a database to store equipment types with their specifications; (2) a knowledge-based expert system for assisting material handling equipment selection; and (3) an analytic hierarchy process (AHP) model to choose the most favorable equipment type” (Chan). This article also stresses that, “A key task in the material handling system design process is the selection and configuration of equipment for material transport and storage in a facility” (Chan). This is a good reference to understand the process of new styles of material handling. Before the modification of the current process can happen, it must be evaluated using an analysis of these three modules in order to determine whether or not it can be improved. In addition to the modules, “The most suitable process plan for fabricating the part is recommended based upon a multi-criteria analysis as a resolution for decision-making” (Nguyen). The current system seems to be designed for the type of loads that the castings apply to the carts. The designs are also limited to the type of rotation of one cart and the way the two carts need to mate with one another. Some basic principles of a multi-criteria analysis (MCA) will be applied in order to come up with viable solutions for the new design

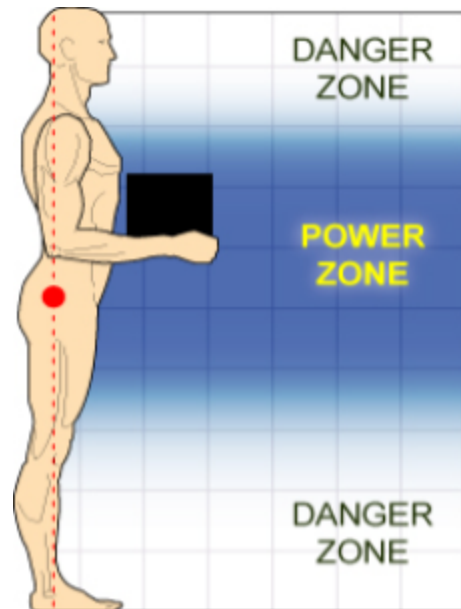
for the two carts. A few things such as using less steel, making the carts smaller, and increasing or keeping the same strength of the carts that can carry the same loads as the current carts. Having a structured decision analysis will allow for a clear and definitive way to make decisions, and come to conclusions.

In order to choose a solution, the options must be evaluated to consider how their implementation and sustained use will affect manufacturing. The general ease of use must be carefully considered, which is where ergonomic studies come into play. Two different ergonomic and manufacturing implementation studies from *The effect of handle height and cart load on the initial hand forces in cart pushing and pulling* and *An ergonomic evaluation of three classes of material handling device (MHD)* will be utilized. These studies will allow the consideration of different aspects of ergonomics during the testing of the material handling system. Both of these studies have accounted for different forces that affect male and female subjects to minimize stress and unnecessary movement. Regulatory bodies, such as Occupational Safety & Health Administration (OSHA), National Institute for Occupational Safety and Health (NIOSH), and the Center for Disease Control (CDC) have determined what the

optimal lifting weight and positions are for employees (Galassi). While OSHA does not have set regulations on how much employees should carry and does not lay out or specify what the optimal work positions are, they do heavily reference NIOSH. NIOSH defines, “The power zone for lifting is close to the body, between mid-thigh and mid-chest height”

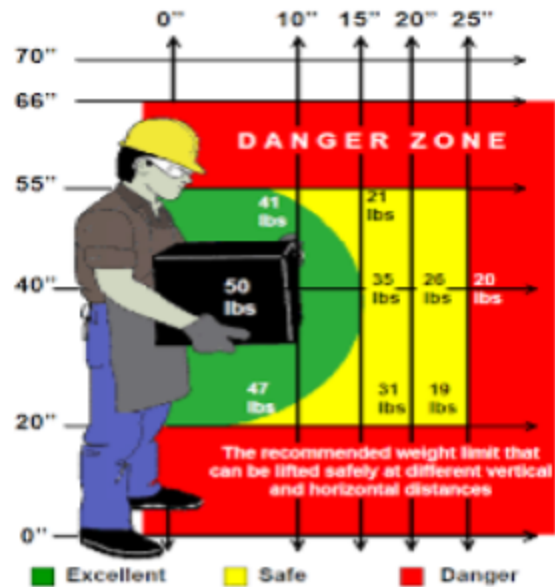
([www.osha.gov/SLTC/etools/electricalcontractors](http://www.osha.gov/SLTC/etools/electricalcontractors)), as seen in **Figure 6**. Both carts will need to be designed where employees will perform their assembly operations at or very close to the power zone. This will ensure that the work and lifting positions

are at the most effective height. In addition to the power zone, NIOSH formulated a lifting equation to



**Figure 6. Power Zone**

calculate, “a recommended weight limit for one person under different conditions” (Galassi). From this lifting equation it is determined that the recommended lifting weight is 51 pounds. It is noted that other state agencies have adapted this equation in order to develop tools to help determine safe lifting practices as seen in **Figure 7**. This project will take the recommendations and standards defined by the three regulatory bodies discussed, in order to design a new cart for the spindle drive assembly that will minimize the amount of weight that will be lifted when rotating the carriage on the cart to a horizontal position. When considering the power zone and optimal lifting weight, employee efforts will be maximized for comfort, safety, and efficiency.



**Figure 7. Safe work zones based on weight of loads and their location from the body**

The next step is to analyze and design a new way to process the materials within the assembly operation. “Technological, economic, and logistic parameters are taken into account simultaneously as well as manufacturing constraints being integrated into the product design” (Nguyen). The article *Product design-process selection-process planning integration based on modeling and simulation*, emphasizes the use of computer aided design (CAD) and computer aided modeling (CAM) systems for simulation as “Virtual manufacturing”. CAD/CAM systems will be used to model and simulate potential solutions that are designed specifically to accommodate the current process, and the materials that are used in it. Once there is a viable solution, the entire assembly process can be simulated in CAD/CAM software to prove that there is room to improve the process. Current state models and the new design models for both carts will be analyzed using CAD software such as SolidWorks. A thorough knowledge of structural members

and mates in SolidWorks is needed and will be applied in the design of the new carts. Once the CAD models are verified, the ability for the two carts to mate will all be done in SolidWorks.

The literature reviews presented in this section give insight in different requirements needed to design new carts for the Haas UMC-750 drive system casting assembly. Safety and ergonomics are the key factors in the project and in the new design of the carts. While the cart designs will decrease the cycle time for the assembly process, the two main goals are injury risk reduction and improved ergonomics. A decision analysis will be used in order to assure that the best designs are considered for the new carts. Based on the research, a safe, ergonomic, and effective cart will be designed and modeled.

# Design

The initial approach for the design of this project was to observe the current process at the Haas facility in Oxnard, CA. During the visit, the team toured the whole facility, observed the processes and workstations that directly related to the UMC-750 assembly, with the main focus being on the machine cast assembly station. While observing this station, the team noticed that the employees had to exert excess effort to mount the spindle head onto the drive assembly. Pictures and videos were taken to document the process, and were analyzed to improve the process and materials used. In addition, Haas Automation provided the engineering drawings for the current drive assembly cart in **Figure 8**, spindle head casting in **Figure 9**, the spindle drive casting in **Figure 10**, and ram casting in **Figure 11**. The solid model for the entire drive assembly was also provided.

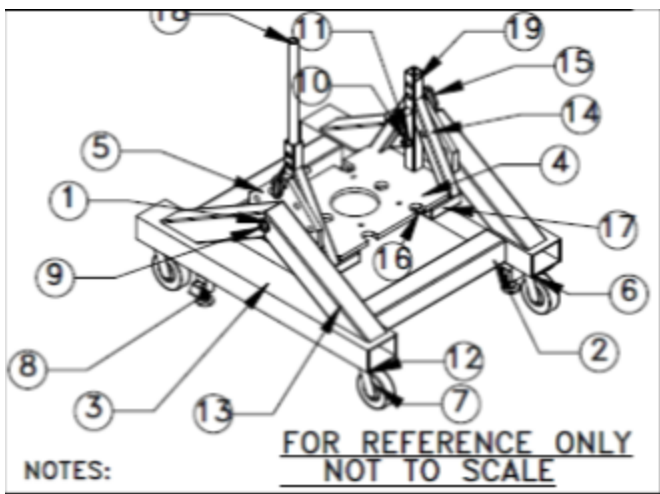


Figure 8. Current drive assembly cart drawing isometric view

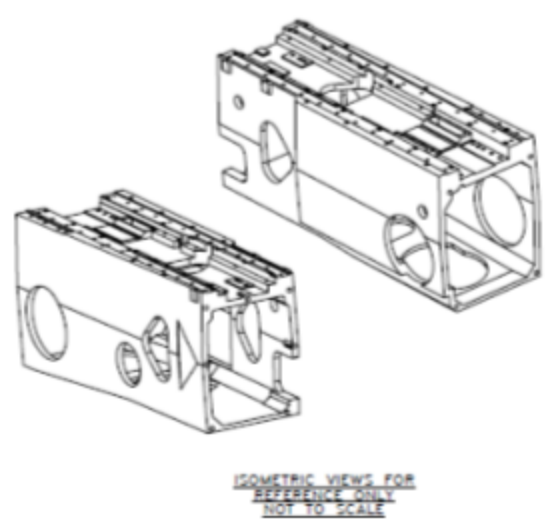
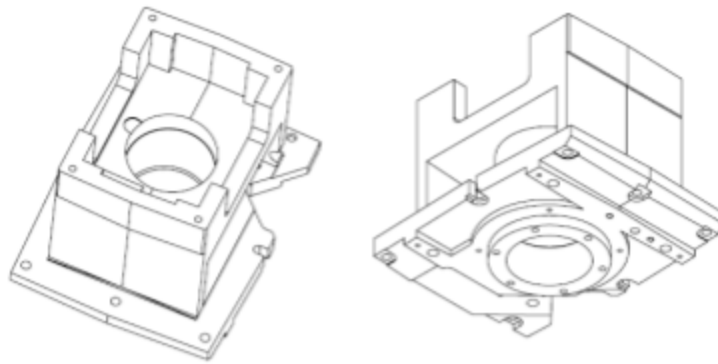
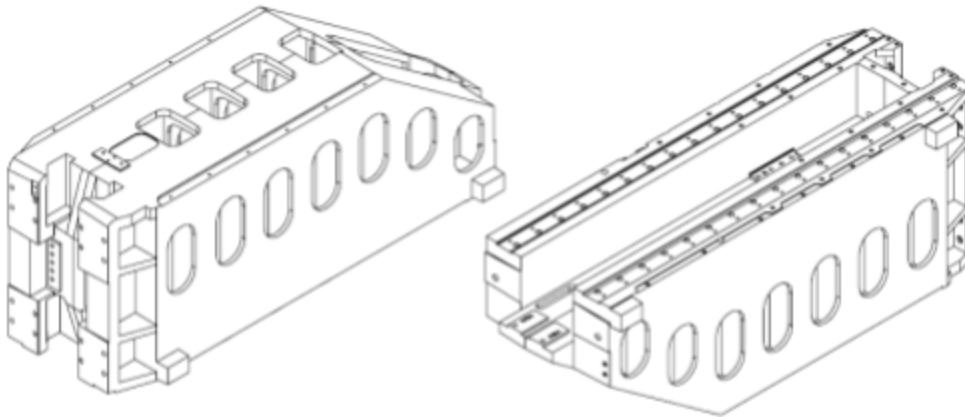


Figure 9. Ram casting drawing isometric view



ALTERNATE VIEWS FOR  
REFERENCE ONLY  
NOT TO SCALE

Figure 10. Spindle drive drawing isometric view



FOR REFERENCE ONLY  
NOT TO SCALE

Figure 11. Ram casting drawing isometric view

While observing the assembly of the spindle head, the team took note of the difficult work positions the employees had to endure in order to properly join the two parts. These included uncomfortable bending of the back and knees, squatting to install bolts, and reaching around heavy metal castings in order to secure them to the crane. These body positions can be seen in **Appendix B**. The

pictures taken were then analyzed to address the uncomfortable ergonomics of the procedure and the design of the existing carts were evaluated for ease of use in the assembly of the parts.

After observing the work stations in order to get a general idea of the current carts and process, basic measurements of the components and the spindle head casting cart were taken with a tape measure. This was necessary because Haas Automation had no drawing specifying the measurements of the casting cart. As a result, the group had a chance to see the amount of space used for both carts, with relation to the assembly area, and the height of the work surfaces, in relation to the employees. A current state model for the spindle drive assembly cart was made in order to get a good visual understanding of the cart and how it looks and works in SolidWorks seen in **Figure**

**12.** By altering the existing designs using measurements taken at the worksite and CAD software, new improved cart designs were developed. These new designs, shown in **Figure 13** and **Figure 14**, are much more ergonomically friendly and were designed with the safety of both the employees and parts in mind.

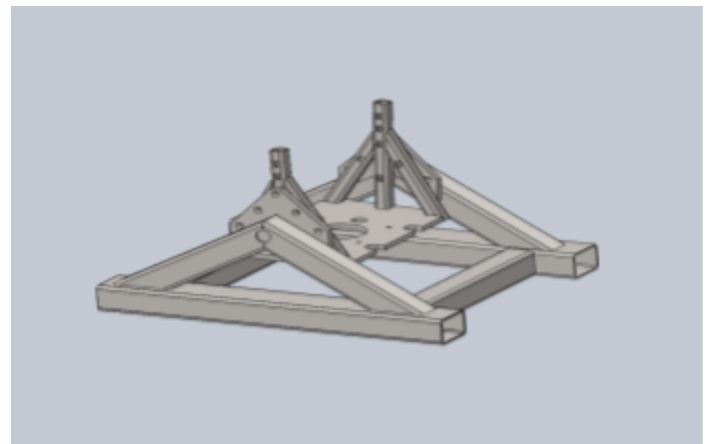


Figure 12. Current state solid model of the spindle drive assembly cart.

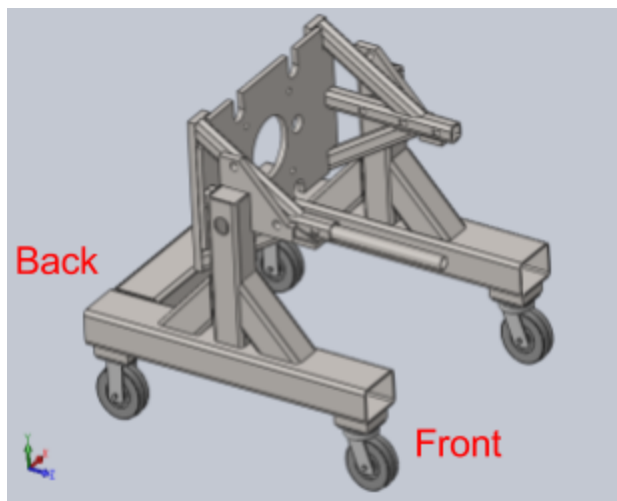


Figure 13. New spindle drive assembly cart rotated 90°

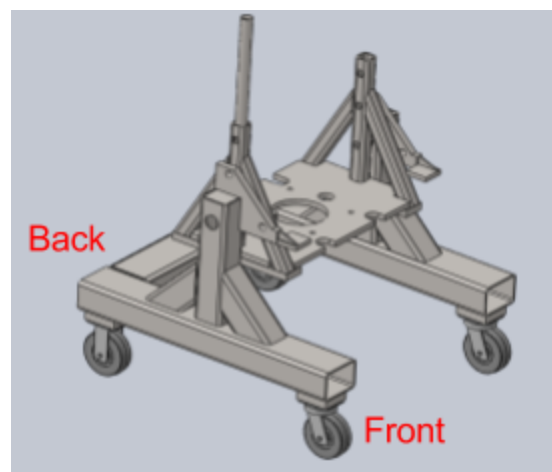
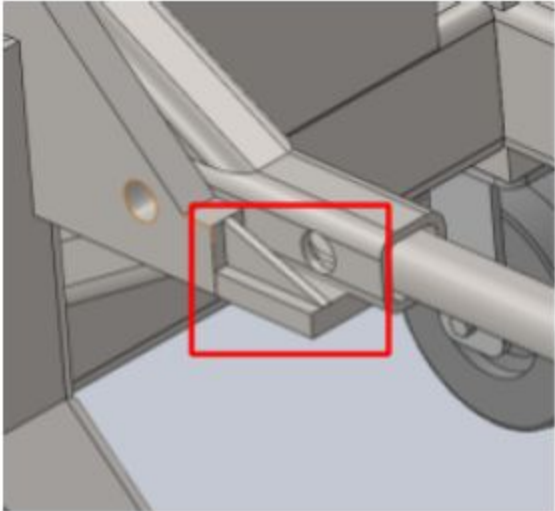
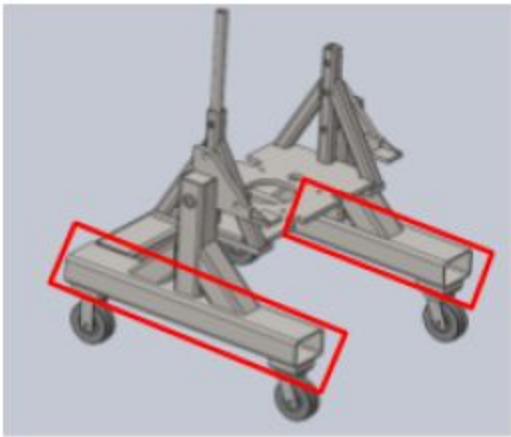


Figure 14. Spindle drive assembly cart in the upright position

The new drive assembly cart has the ability to rotate the assembly from the upright position that is necessary for loading and transporting it into the horizontal position, which will make mounting it much easier. There are hard stops at the bottom of the arm's movement that will prevent the assembly from flipping further than is necessary, as well as pinholes for insertion of the same pins used currently to hold the arm in place during transportation and assembly. The hard stops are welded to the rotating pin plate with only a small amount of area, and will take a huge brunt of load from the spindle drive assembly. Gussets were added in order to add structural integrity and help distribute the load better as seen in **Figure 15**. The two members at the bottom of the spindle head assembly cart had to be 4" x 6" box tube steel members, seen in **Figure 16**, to allow for the carts to be transported to the assembly station by a forklift.



**Figure 15. Hard stop with a gusset to prevent over rotating**



**Figure 16. Box tube steel big enough for transport by forklift**

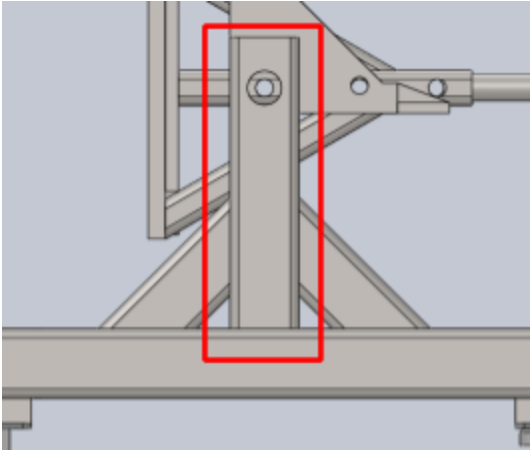
To obtain the desired mating of the components, both carts must be at the same height during the assembly. Thus, the height of the spindle drive assembly's rotating axis was increased by increasing



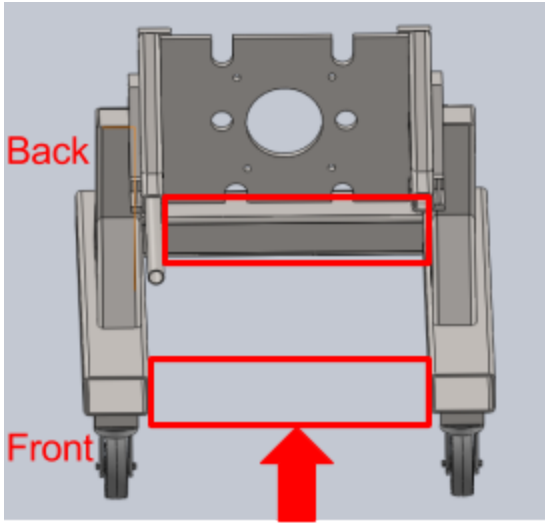
the height of the vertical steel tube, as shown in **Figure 17**.

This change led to the elimination of the lower horizontal steel tube that the previous cart had in the front, because it was blocking the path of the spindle head casting cart. After making both changes, it was apparent that the overall dimensions of the lower frame could be reduced, which would increase the space around the workstation. Raising the height of the rotating axis allowed for the rotating handle to be located in a more ergonomic place. The back steel beam

was kept and pushed further towards the back of the cart. These two changes can be seen in **Figure 18**.



**Figure 17. Middle tube support on the spindle drive assembly cart**



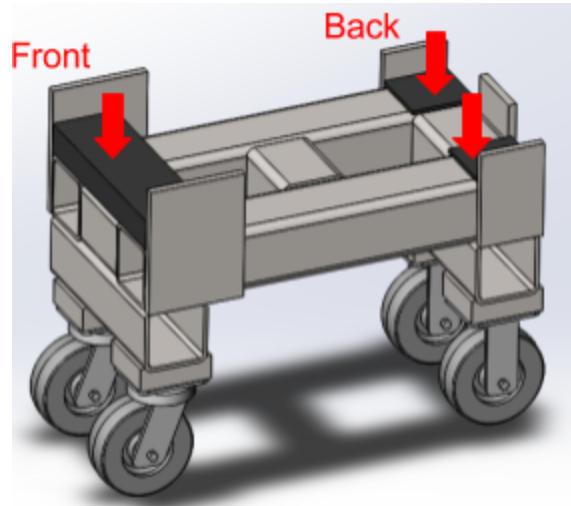
**Fig 18. Front box tube steel beam removed and the back box tube steel beam moved toward the back of the cart.**

For the spindle head casting cart

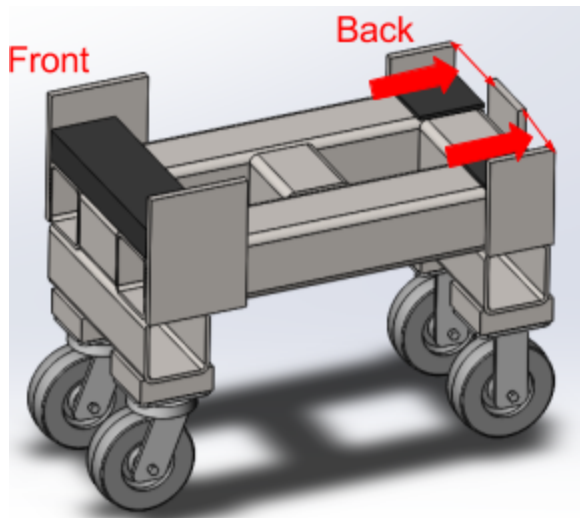
SolidWorks model, our team decided to make three important changes. First it was decided to narrow the cart to fit the dimensions of the spindle head casting better. The old cart was too short and wide to secure the casting. In the current state model of the spindle head casting cart, the spindle head casting was raised a small amount with aluminum blocks in order to have it at a comfortable position for the operators to work.

In the proposed design, these blocks were replaced

with rubber pads that will be permanent components of the cart seen in **Figure 19**. These pads will not only raise the spindle head to the desired height, but will also prevent any undesired slippage. The rubber pads are also designed to give three points of contact to offer a solid level plane to work with. This will



**Figure 19. Rubber pads on the spindle head casting cart**



**Figure 20. Clearance to allow for ease of access to threaded holes on the spindle head casting**

allow for the employees to accurately check Geometric Dimensioning and Tolerancing (GD&T) on the spindle head casting. Supports on the sides and back of the cart were added to ensure that the casting will not slip or fall off the cart. The back support was designed with enough clearance to allow for easy access to threaded holes on the spindle head casting seen in **Figure 20**. This clearance will allow employees to screw in eyebolts in order to secure the castings to the gantry crane and move them to the pallets once all assembly is finished.

# Methods

The new designs were modeled using SolidWorks to test for proper functionality. In addition, ergonomics of the new designs were studied in order to confirm best safety practices when assembling both casting components. As mentioned before, the current spindle assembly carts have the ability to rotate 90°. However, doing this results in an uncomfortable bend in the employee's back. Measuring the angle that the body makes with the horizontal, in **Figure 21**, and comparing it to the angle resulting from raising the cart XX inches, depicted in **Figure 22**, proves that this bend can be dramatically decreased. Decreasing the angle of the bend minimizes stress on the employee's body, resulting in a more ergonomically friendly method of assembly that reduces the risk of employee injury.



Figure 21. Current Cart Bending Position



Figure 22. Proposed Cart Bending Position

# Results and Discussion

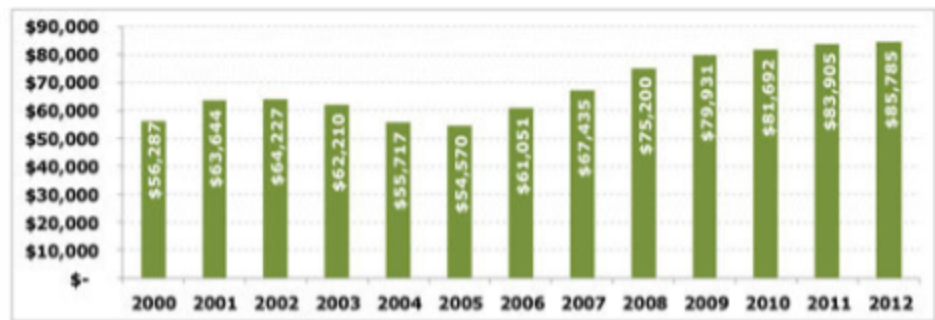
In order to justify the spending on the new carts, an economic analysis was performed. By implementing the new designs, one area that Haas could potentially see savings in is the worker's compensation program. Since employee safety could be increased with the implementation of this process, the risk of potential employee injuries resulting in worker's compensation claims can be significantly reduced. Although there haven't been any injuries using the current carts, there is still a great risk of injury by having a 500+ pound steel casting being moved around at head level. With the new carts, all of the movement will be when the parts are securely mounted on the carts, and will take place right around waist level, allowing for maximum comfort for the employees. After looking at historical data of worker's compensation claims, in California specifically, it is clear that the average price of claim payouts have been constantly rising since

the year 2000, seen in

**Figure 23.** Based on current predictions, this trend is projected to continue, resulting in a greater increase every year.

According to

Woodruff-Sawyer, an insurance brokerage and consultant firm, "The projected ultimate cost per indemnity (lost-time claim) is at a historic high according to the WCIRB's report. The estimated average cost of an indemnity claim is projected to reach \$85,785 [in 2012]" (Cartwright).



**Figure 23. Average Worker's Comp Payouts by Year**

An economic analysis was performed on the proposed carts, comparing the current carts and the newly designed carts as seen in **Figure 24**. The analysis took into account the cost of obtaining the materials used to manufacturing the new carts, and the time saved by using the new designs. The material costs were calculated by looking at the weight of the steel used for the carts and the estimated price of steel.

		Weight (lbs.)	% weight reduction	Cost per pound
Spindle drive assembly cart	Current Process	700		\$875.00
	New design	300		\$375.00
	Difference in processes	400		\$500.00
			57.14%	
Spindle head casting cart	Current Process	300		\$375.00
	New design	200		\$250.00
	Difference in processes	100		\$125.00
			33.33%	
Steel (\$ per pound)		\$1.25	Total Cost savings	\$625.00

**Figure 24. Economic analysis of cost savings (Not actual weights)**

Since the material costs used for manufacturing the new carts is less than the potential required claim payout, by going with the new design, as long as they prevent at least one injury, they will save money in the end. Also, by utilizing cart designs that are so similar to the existing ones, training costs for the employees would be negligible, and the number of employees necessary would remain the same, which results in a negligible difference in the current and the proposed cost of labor.

The proposed design for the new spindle drive assembly cart can be seen in **Figure 25**, where the improvements are numbered, 1 through 5. The first improvement (1) is the hard stop placed at the bottom of the 90° pivot. This prevents the part from flipping too far, avoiding potential damage to the drive assembly and injury to the employee. The second improvement (2) is the new pivot axis, located at the center of mass of the spindle drive assembly, which reduces the force necessary to rotate the part. The next improvement (3) is an open base that allows the spindle head cart to fit in between the base of this cart in order for the parts to mate without the use of the overhead crane. The fourth improvement (4) refers to the overall dimensions of the cart being reduced, minimizing material costs and improving storage space at the work station. Finally, (5) is the raised pivot point which reduces the need for the employee to bend over, reducing the stress on their bodies.

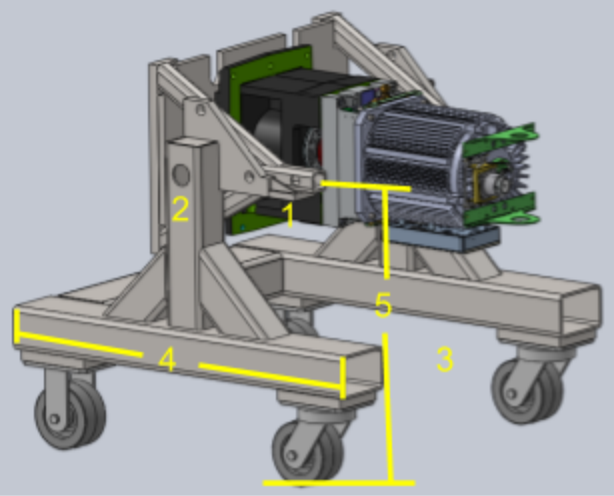


Figure 25. New design of the spindle drive assembly cart

The spindle head casting cart is shown in **Figure 26** with numbers indicating the improvements. First (1) is the rubber pads used to hold the spindle head level and at a comfortable position on the cart. These rubber pads will take the place of the aluminum blocks currently used for this purpose. By using rubber instead of aluminum and attaching the pads securely to the cart, the risk of the

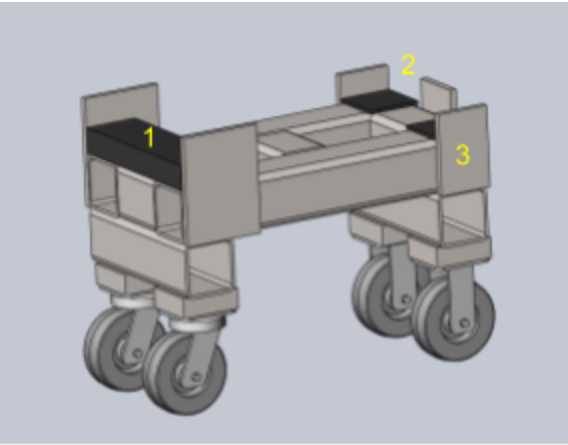


Figure 26. New design of the spindle head casting cart

part slipping and falling, damaging the part or injuring the employee, will be greatly reduced. The second improvement (2) is the use of openings on the supports near the end of the casting. These new supports are open at the corners of the spindle head when it's sitting on the cart, which will allow the employees to insert eye bolts into the corner holes without lifting it first. This will decrease process time, freeing the employee up to work on other processes. The last improvement made to the cart (3) is the use of side supports instead of corner supports in order to keep the casting secure but still minimize the material used to reduce costs.

By implementing these new carts, it is estimated that the processing time for this station can be reduced from 15 minutes to 5 minutes by removing the 10 minutes it takes to use the crane, allowing those extra 10 minutes per assembly to be put to use at other stations. The main focus of this project was not specifically to reduce processing time or increase throughput since, according to Haas employees, they currently only perform this assembly an average of two times per day. However, since this new process will take only a third of the time that it currently takes, throughput may be increased in times of high demand or employees may simply be able to utilize this saved time by working on a different station of the assembly.

# Conclusions

This project addressed the issues of assembly fixtures for the spindle drive casting assembly for Haas Automation's UMC-750 5-axis vertical machining center. After analysis of the spindle drive casting assembly there were several safety and ergonomic issues that needed to be addressed. The analysis and process improvement of this project was carried with the following objectives in mind:

- Joining the two assembly carts
- Optimize work performance height
- Implement hard stops to prevent over rotation of the spindle drive assembly cart
- Reduce the size of the two carts

The solution was reached by addressing a combination of design requirements specified by Haas Automation engineers, assembly line employees, and ergonomic and safety analyses. In order to meet these goals and fulfill the design requirements, knowledge of solid modeling principles were applied to SolidWorks to establish current state models and move forward with designs for new casting carts. An analysis was done in order to show the savings by preventing injuries that would require worker's compensation claims. To further justify the feasibility of the proposed new carts, the team developed an economic analysis based on the monetary costs of obtaining the materials used for the manufacturing of the new carts. This economic analysis showed the cost savings that would be achieved by implementing the newly designed carts.

The four objectives listed above were the desired results, which were achieved with the final designs. The carts have the ability to join together, allowing the assembly of the spindle drive system to be performed without the use of the overhead crane. The work surface height was set at about XX inches which is in the middle of the power work zone. Hard stops were implemented to prevent the carts from rotating past 90°, preventing damage to the parts and employee injury. The spindle drive assembly cart was



reduced by XX% and the spindle head casting cart was reduced by XX%. The overall process has been improved based on the design requirements, with the new designs saving an average of XX minutes per assembly, which can be allocated to work on other stations.

The complications were explored through extensive analysis of the designs. The group had to learn basic design principles, which may have been the most difficult part of the project. Since the group members consist of two Industrial Engineering majors and one Manufacturing Engineering major, a complete knowledge of design is not a major part of their repertoire and therefore no mechanical analysis of the design for the new carts was performed. One of the things that would have been done differently would be to consult with more Mechanical Engineering majors in order to get a better idea of design and to perform a Finite Element Analysis (FEA) with computer software. The team cannot assure the new designs suitability for sustaining the loads of the spindle drive assembly. This leads into the next steps to take, which would be to fully fabricate prototypes of the two newly designed carts for field tests and finally implementation.

The group is confident in the new designs and that they should be prototypes and implemented. Proper and careful steps were carried out in order to come to these improved designs for the spindle drive assembly and spindle head casting carts. Ultimately the main goal was achieved, to have the carts mate as seen in **Figure 27**. It is recommended that Haas automation manufactures the proposed design as prototypes, to then perform testing on the mechanical integrity that may not have been taken into account.

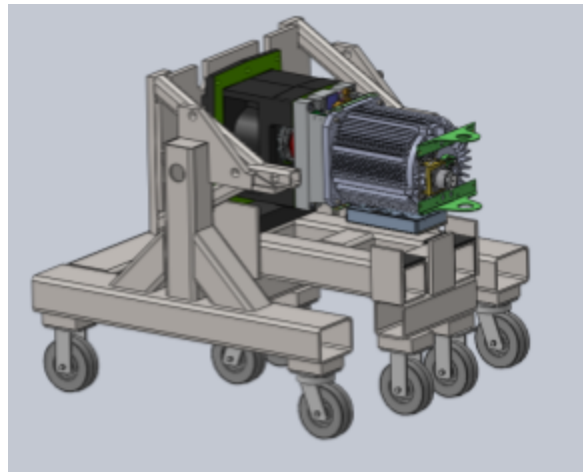


Figure 27. The spindle drive assembly cart and spindle head casting cart joined together

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# Appendix A - Routing Sheet

(cannot show due to Partial Nondisclosure Agreement)

# Appendix B - Uncomfortable Body Positions



Appendix B1



Appendix B2



Appendix B3

Appendix C - Engineering Drawing: New design of the spindle head assembly cart

(cannot show due to Partial Nondisclosure Agreement)

Appendix D - Engineering Drawing: New design of the spindle head casting cart

(cannot show due to Partial Nondisclosure Agreement)

Appendix E - Engineering Drawing: Current spindle head assembly cart

(cannot show due to Partial Nondisclosure Agreement)

Appendix F - Engineering Drawing: Spindle head machined casting

(cannot show due to Partial Nondisclosure Agreement)

Appendix G - Engineering Drawing: Spindle drive machined casting

(cannot show due to Partial Nondisclosure Agreement)

# Appendix H - Engineering Drawing: Ram machined casting

(cannot show due to Partial Nondisclosure Agreement)