IMPLEMENTATION OF COLLABORATIVE ROBOTS
AT
DETROIT THERMAL SYSTEMS

A Co-op Thesis written for

DETROIT THERMAL SYSTEMS LLC

and submitted to

KETTERING UNIVERSITY

in partial fulfillment
of the requirements for the
degree of

BACHELOR OF SCIENCE IN MECHANICAL ENGINEERING

by

IAN PAUL MAMENTA VILLAROMAN

2017

____
Student

____
Employer Thesis Advisor

____
Faculty Thesis Advisor

DISCLAIMER

This thesis is submitted as partial fulfillment of the graduation requirements of Kettering University needed to obtain a Bachelor of Science in Mechanical Engineering Degree.

The conclusions and opinions expressed in this thesis are those of the student author and do not necessarily represent the position of Kettering University or anyone else affiliated with this culminating undergraduate experience.

PREFACE

This thesis represents the capstone of my five years combined academic work at Kettering University and past work experiences. My Culminating Undergraduate Experience provided the opportunity for me to use the knowledge and skillset learned while at Kettering to manage a project of this magnitude.

Although this thesis represents the compilation of my own efforts, I would like to acknowledge and extend my sincere gratitude to the following persons for their valuable time and assistance, without whom the completion of this thesis would not have been possible:

1. Mr. Daniel Fletcher, Industrialization Engineering Manager, Detroit Thermal Systems LLC, for all his help and guidance with technical aspects of this thesis, while acting as my employer advisor.
2. Mr. Ken Stefanek, Senior New Model Process Engineer, Detroit Thermals Systems LLC, for being a go-to mentor with any questions requested.
3. Dr. Justin Young, Professor of Industrial Engineering and Faculty Thesis Advisor, Kettering University
4. Shaltz Automation of Flint, MI for robot programming

TABLE OF CONTENTS

I. INTRODUCTION

Detroit Thermal Systems (DTS) is a tier one supplier of heating ventilation and air conditioning (HVAC) units for the United States automotive industry. Detroit Thermal Systems specializes in injection molding, the process of taking plastic material and forming it into a shape through the use of high temperature injection mold equipment.

This thesis focuses on the implementation of three new collaborative robots for the injection molding department. The goal is to enhance work production and work process allowing for increased efficiency through labor optimization.

A. The Nature and Purpose of the Project

Since DTS launched in 2012, management continues to strive for new innovative ideas to improve process, save money, and create value for the company's future. The injection mold department consists of thirty-eight injection mold press machines capable of taking resin material and creating plastic housings for automotive HVAC units. Employees of the injection mold department, known as injection mold operators, are trained by DTS to inspect parts for defects and place into injection mold carts.

Detroit Thermal Systems' industrial engineering department reviewed the operator process and found an excess amount of waste in motion and time created through daily input from operators. The introduction of collaborative robots can allow for a reduction in labor and improved operator utilization. Operators will be able to manage more presses with a reduced need to walk to and from each injection mold press. This thesis project will provide the results on implementing collaborative robots and the lessons learned from the overall project.

B. The Background & Literature Review to the Project

Detroit Thermal Systems' (DTS) supplies Ford Motor Company with completed automotive heating ventilation and air conditioning (HVAC) units. Every 60 seconds, DTS's injection mold presses take resin material and thermoplastic molds it into an upper and lower housing for the HVAC unit. A press robot uses vacuum suction cups to remove the upper and lower housing parts off the mold cavity and places them onto a conveyor belt that feeds directly onto the employee's table.

Employees are required to verify that the parts are to customer standard with no traces of excess material, holes, or broken pieces. Once the employees verify the housings, they are placed into injection mold carts. A completed upper housing cart has a quantity of 45 pieces. A completed lower housing cart has a quantity of 30 pieces. Once an injection mold cart is full, employees print out production tags providing information on part name, quantity of parts, and the date they are produced. These production part tags, also known as work-in-process tags, are scanned and recorded into a manufacturing system that tracks injection mold production. Operators are required to place production tags into designated cart tag holders signifying a completed cart counted into the manufacturing system that is ready for production.

All newly injected mold housings are placed into a staging area where carts are in queue to be sent to production located across the injection mold department. The upper housing starts the process of assembly and acts as a base for the HVAC unit allowing for the rest of the production team to assemble the complete HVAC unit with blower motors, heater cores, screws, and evaporators. Thus, it is instrumental for the injection mold process to produce parts in order to fulfill production requirements set by Ford Motor Company.

The proposed solution for the injection molding department is to establish a semi-automated system where the employee and three collaborative robots work together. The three cobots will remain at their assigned stations 24 hours a day, seven days a week completing work for one press consisting of either an upper housing only or a lower housing only. Each cobot will pick up the part from the operator table and place into an injection mold cart.

The employee's responsibility will be to manage their current manual workstation, walk to collaborative robot controlled press stations to verify proper part placement into carts, check part quality, use of the FIFO inventory management process and to swap out full injected mold carts with empty carts. FIFO, referred as first-in, first-out, is the idea where the products that are produced first are utilized in production before the next set of products are consumed, this will increase the number of supervised presses for a single operator from two presses to four.

Shifting the employees down by two to three presses causes one operator to be saved each shift. There are three shifts at DTS, thus a total of three operators will be saved from the injection mold department. One injection mold operator's salary is $60,680 while a total of three operators from injection molding will be a total of $182,040. The salaries once used for operators will now be applied to investment costs of purchasing three collaborative robots at $160,000.

C. The Methodology by Which the Project was Complete

The project was broken up into five phases: Investigation, Evaluation, Pre-Implementation, Implementation, and Next Steps.

Phase 1: Investigation

The first phase defines the application path to improve on. Various collaborative robot options were researched, examining the pros and cons of each collaborative robot. Initial studies for Phase 1 include: operator time studies, average walking distance for operators, and the distribution of labor. During Phase 1, the initial layout was reworked adding three collaborative robots for the future floor layout.

Phase 2: Evaluation

Phase 2 consists of evaluating initial data collected, listing equipment, material and services to complete the project into a bill of materials (BOM) document. The BOM will help draft the request for quote for collaborative robots, cobot integration, floor locators, and chute suppliers. A cost analysis of an injection mold employee’s worth will be conducted to understand the benefits for DTS to exchange operators for robots. Return on investment form, or an ROI form, was created to give an accurate payback time frame in months and to understand how many operators can be saved per shift. Cost minimization will be kept in mind to benefit savings for future/next steps.

Phase 3: Pre-implementation

Phase 3 documents the modifications for the injection mold carts to allow for collaborative robots to repeat the pick and place process of upper and lower housing carts.

Phase 4: Implementation

Phase 4 consists of the product prove out of collaborative robots in the manufacturing plant. The robot path process will be documented to show the step-by-step process of part pick up and part place into injection mold cart.

Phase 5: Next Steps

Phase 5 deals with the next steps DTS will need to take in order to prove out the final two collaborative robots and complete the project.

D. The Criteria by Which the Project was Complete

The criteria used to evaluate project success at the completion of the work are labor cost reduction and the repeatability of the robot process. Next steps and recommendations will also be provided.

II: CONCLUSIONS AND RECOMMENDATIONS

Implementation of collaborative robots at Detroit Thermal Systems allowed for a reduction of operators needed to handle the current layout of injection mold presses. This resulted in decreased labor costs, and increased operator productivity. The total labor cost to have three operators working a full year's salary is $182,040 at $60,680 per operator, compared to the total installation cost to implement three collaborative robots at Detroit Thermal Systems is $160,000. The projected amount in the budget to pay operators is more than the total amount to install the collaborative robots thus return on investment will be under a year (10 months).

Minor limitations to the collaborative robot process will be the inability for the collaborative robot to identify housing defects during pick and place process. Verification of a good part and a defective part will be the responsibility of the injection mold operator. Operator will need to check the first and last part of each injection mold cart the cobot places parts into.

A. Resulting Process Improvement

Collaborative robots reduced the amount of non-value added work an operator exerted for each task. Collaborative robots heavily reduced two of the wastes in the continuous improvement method, Kaizen: motion and waiting

- Operator motion was reduced as an operator will walk to each injection mold press every five minutes versus returning to injection mold press every one-to-two minutes. This is made possible with the collaborative robot ready to pick and place parts into carts. Also, a reduction in operator motion decreased the amount of ergonomic issues when operators have to bend down or stretch to place injection mold parts into carts.

- Operator waiting time per press was reduced: With a reduction in waiting time per press, an operator can work with more injection mold presses resulting in an increased utilization of injection mold operators.

B. Recommendations

- Intensive project planning
  - Develop a project timeline that states all services and equipment needed to be completed by suppliers and contractors. Dates for completion must be agreed upon by both parties. Detroit Thermal Systems needs to hold suppliers and contractors accountable if services or equipment does not follow original timeline set at the beginning of the project.
- Use of the landmark system
  - Using Rethink Robotics' landmark system to save station robot path logic. This can be implemented by taking a special Rethink Robotics' landmark plate and coding it to contain the robot path process for each individual injection mold press. This will be beneficial if the robot path logic is corrupted or sabotaged.
- Industrial shaker for part deployment chutes
  - There are instances where the injection mold part is stuck in the part deployment chutes. Shaker will allow for a stuck part to fall into a proper picking position.

- Additional part present sensor
    - Sensor will signal the collaborative robot that an injection mold part has left the conveyor belt and is on the part deployment chute. This sensor will offer a method of verification if a part was stuck on the conveyor or slide before it reached the final part sensor for robot pickup.
- Collaborative robot part count status screen
    - A part count screen will allow all users to be aware of how many parts the cobot has placed in a cart or in a shift. This will aid in assistance when the cobot faults out due to a collision or retry failure. It will also help operators know if a quick "continue process" start will be beneficial versus having to restart the entire cobot path process.

C. Immediate Next Steps

- Proving out and programming final two collaborative robots
- Improvement to part deployment chute for the reduction of part clog
- Improvement to the injection mold cart peg design for repeatability
- Movable cart underneath conveyor belt to store loose scrap pieces when a part is molded
- Teaching collaborative robot new tasks to pick and place
- Continue to reduce operators for injection mold plant
- Possibility of two 1x6's (one operator with six presses) for presses 1-12

SUBSTANTIVE WRITTEN MATERIAL

III: PHASE I- INVESTIGATION

Potential Need for Collaborative Robots

The main application for the collaborative robot in the injection molding department is to pick up injection mold housings off a part deployment table and place into injection mold carts. This is a simple and repetitive task that robots are suited for. A collaborative robot can count each time it places a part onto a peg, and proceed to fill cart until each peg is filled to the programmed amount for the particular part type. The main part type for this project will be focused on the upper housing injection mold cart. This part is light enough for collaborative robots, which are limited in power and speed due to safety concerns. Collaborative robot would continue to fill injection mold carts only if a part is present in the part deployment table and only if operators refill cart floor locators with empty carts. This scenario relies on both human operators and robots to synchronize activities.

The two types of injection mold parts valued for this project include the P552/P558 upper housing and the P552/P558 lower housing. An upper housing cart consists of twelve pegs at five parts per peg for a total of 45 upper housing parts per cart. A lower housing cart consists of six pegs at five parts per peg for a total of 30 lower housing parts per cart. Once a cart reaches full capacity, the operator will bring the packed out cart to the staging area, retrieve an empty cart and return it to the press work station. Due to timing and project planning issues the collaborative robot thesis project will describe and state the findings for the P552/P558 upper housing only.

Collaborative Robot Comparison

Collaborative robots, known as cobots, are robots capable of working alongside a human without the need for a cage. They are built to be flexible and the cost to own a cobot is more economical than an industrial robot. Introducing cobots into the injection mold department can allow DTS to correctly utilize the current amount of employees resulting in reductions in labor costs for the injection molding department.

Features of cobots include: payload, program ease of use, arm reach, total robot weight, repeatability, and price. Payload of a collaborative robot refers to the weight the cobot can carry through a designated space. A higher payload will allow the cobot to lift heavier objects allowing for a wider range of tasks. Simple programming software will reduce the time to train employees and will lower the costs of hiring highly trained technicians. Cobot arm reach refers to the length the cobot can fully extends its arm. For the application at DTS, a medium to large reach length was needed to reach higher place points on cart pegs. A cobot's ability to repeat the application process in a consistent manner was taken into careful consideration as the injection mold press will be constantly producing a part every 50 to 60 seconds. Lastly, the price of one unit will be considered for budgetary purposes and to estimate the time of payback for Detroit Thermal Systems. After the analysis of collaborative robots, one will be chosen that correctly fits the process of the injection molding department.

There are over 20 collaborative robots currently available on the market (Appendix A). The list was narrowed down to the top three best cobots fit for job.

Option 1. Universal Robots' flagship collaborative robot, UR 10, is the largest tier in the collaborative robot segment. It features a payload of ten kilograms. UR10 is equipped with Java programming software that is relatively difficult to understand but with training instructed by Universal Robotics integrators it can be taught. UR10 has an arm reach of 1,300 millimeters, roughly 52 inches, which is the highest in the larger tier of cobots. UR10 is equipped with a mobile pedestal allowing placement of cobot from location to location to be flexible and quick. UR10 starts at $45,000.00 which is a reasonable price considering the high payload, long arm reach and easy to relocate collaborative robot.

Figure III-1. Universal Robots' collaborative robot, UR10. Note. From Universal Robots, East Setauket New York

Option 2. Rethink Robotics' most popular collaborative robot, Baxter, is a two-armed collaborative robot capable of minimizing the costs of training and labor. Operators are capable of teaching new tasks to Baxter with the simple pick-and-place teach software created by Rethink Robotics. The method allows operators to take Baxter's arms and set a series of points quickly through a small remote on each of Baxter's arms. The series of points is documented into Rethink Robotics' software, Intera

Studio, a continuously updated teaching software made specifically for Rethink Robotics' collaborative robots. A small tablet resides on Baxter's column which streams a live feed of the XYZ position for both of Baxter's arms. The series of points will be compiled into a robot path for Baxter to follow and complete until the operator teaches Baxter a new task or moves Baxter to a previously made task. Intera Studio is a user-friendly software and can be taught to another person in less than thirty minutes. Baxter is equipped with a small-sized payload of 2.2 kilograms, which is ideal for small part assembly and production. When fully extended, Baxter features an arm reach of 1,210 millimeters increase the number of tasks requiring the collaborative robot to spread its arms across a long distance. Since Baxter is equipped with two arms. The base price of Baxter is $25,000.00 which is the lowest price of the three collaborative robots. This price fits the budget at Detroit Thermal Systems and leaves room for installation costs, maintenance fees and modifications.

Figure III-2. Rethink Robotics' collaborative robot, Baxter. Note. From Rethink Robotics Boston, Massachusetts

Option 3. Rethink Robotics second iteration of the collaborative robot, Sawyer, is built on all the lessons learned from Rethink's first collaborative robot, Baxter. Rethink

Robotics decided on a single arm orientation to allow for floor space savings on the production floor and continue to offer the same features from Rethink Robotics' Baxter. Sawyer offers a medium payload of four kilograms and a slightly higher arm reach of 1,260 millimeters allowing to work on small to large part production tasks. The collaborative robot is equipped with Rethink Robotics' software, Intera Studio, but with the additional support of a robot positioning system. Sawyer's robot positioning system works to allow for the collaborative robot to be recalibrated without the need to change the entire robot path and area. The positioning system uses small landmark plates, shown in Figure III-3 below, which are analyzed by the robot's cameras to reset the robot when it malfunctions or when the robot is incorrectly executing the task at hand. In order for the robot positioning software to work, the employee must first scan the landmark to a location where the specific task is completed. Also note, each landmark features a different image allowing for the production team to understand what task will be completed at the desired station. Sawyer is shipped with a movable cart allowing for the robot to complete different tasks at different machines during a production day. The price of one Sawyer unit from Rethink Robotics is $29,000.00 which is affordable for the budget at Detroit Thermal Systems and with features like the robot positioning system, medium payload, and small overall structure allows for an efficient collaborative robot.

Figure III-3. Rethink Robotics' Landmark plate. Note. From Rethink Robotics Boston, Massachusetts

Figure III-4. Rethink Robotics' collaborative robot, Sawyer. Note. From Rethink Robotics Boston, Massachusetts

Selected Collaborative Robot

After comparing the advantages and disadvantages of collaborative robots, Detroit Thermal Systems arrived with the consideration of purchasing Sawyer, from Rethink Robotics. Sawyer's four kilogram payload will be beneficial with Detroit Thermal Systems' automotive parts that weigh roughly three kilograms. Sawyer's programming software, Intera Studio, allows for the cost reduction of robot training for employees and eliminates the need for highly trained technicians. Sawyer is flexible with the movable cart allowing for it to be placed at different machines during different times of the day. Sawyer is capable of learning new tasks quickly. The price of Sawyer is affordable to Detroit Thermal Systems' budget (~$40000) and can see payback from purchase within a year. Teaching a Sawyer from Rethink Robotics will offer Detroit Thermal Systems a new technological approach that will push them in the direction of a robot-tailored workplace.

Target Process Investigation: Initial Time Study

Initial time studies were executed to provide a reference to possible improvements for the job process. The time study establishes a clear understanding of the injection mold operator time per part and cobot operating time per part. The following tasks for the operator were recorded.

i. Cart Swap: Operator takes packed cart and places an empty cart into the cart floor locator
ii. Print Tag: Operator walks over to computer, prints out tag and walks back placing new work in progress tag into cart info sleeve.
iii. Parts to Cart: Operator takes new injected molded parts and places it into cart.
iv. First part inspection: Operator examines first part for a new empty cart before being placed into cart. Time consists of examining part per hour.
v. Last Part inspection: Operator examines last part of a new empty cart before being placed into cart. Time consists of examining part for defects (flash, non-fill, etc)
vi. Walking to press: Time for operator to walk to a desired press.

For the tasks listed above, a minimum of 30 cycles was recorded from both morning and afternoon shift. This resulted in a total of 60 cycles for each operator task.The study observed a total of eight subjects. Four injection mold operators from the morning shift and four from the afternoon shift. Each step in the job process was measured in the unit of seconds.

Figure III-5 displays all average time study measurements for each individual step in the job process. Each point is a measurement of the amount of seconds an operator will work with each part. Notable measurements from the study consisted of the following.

- In the "Parts to Cart" column, for cobots working with press 3 and 4, the timing for parts to cart was recorded zero seconds because the cobot will be conducting the work for the operator.
- In the "Walk to Press" column, press 1 and 2 operator stations are set side-by-side. This allows us to set the amount of time to walk to press 1 and 2 at zero seconds.
- In the "Walk to Press" column, press 3 and 4 are located at a great distance from press 1 and 2, when time study was analyzed a notable difference in walking time for press 3 and 4 without cobot was significantly longer in time.

Figure III-6 takes predicted time study data for cobots at press 3 and 4 from Figure 5 and calculates the total operating time to be 35.5 seconds. Comparing an operator to press setup of without cobots versus with cobots we find that not implementing cobots will arrive at a total operating time of 50.4 seconds while implementing cobots for press 3 and

4 will bring us to a reduced total operating time of 31.7 seconds, a savings of 18.7 seconds for each part processed for the job. Figure III-7 further documents the time study data into a format showing the time that could be saved with the implementation of collaborative robots.

Initial Time Study - Injection Mold Press 1 to 4

		Cart Swap	Print Tag	Parts to cart	First part inspect	Last part inspect	Walk to press	Total
1x4 w/o cobot	Press 1-Distribution w/ hole	1.6	1.2	7	0.5	0.5	0	10.8
	Press 2-Distribution w/o hole	1.6	1.2	7	0.5	0.5	0	10.8
	Press 3-Lower Housing	1.6	1.2	6	0.5	0.5	5	14.8
	Press 4-Upper Housing	1.6	1.2	6	0.5	0.5	4.2	14
1x4 w/ cobot	Press 1-Distribution w/ hole	1.6	1.2	7	0.5	0.5	0	10.8
	Press 2-Distribution w/o hole	1.6	1.2	7	0.5	0.5	0	10.8
	Press 3-Lower Housing	1.6	1.2	0	0.75	0.75	1	5.3
	Press 4-Upper Housing	1.6	1.2	0	0.5	0.5	1	4.8

Figure III-5. Time Study 1x4 without cobot vs with cobot

Predicted Initial Time Study with Cobot

Press 1 w/o Cobot Distribution		Press 2 w/o Cobot Distribution w/ hole	
Cart swap	1.6	Cart swap	1.6
Print tag	1.2	Print tag	1.2
Parts to cart	7.0	Parts to cart	7.0
First part inspect	0.5	First part inspect	0.5
Last part inspect	0.5	Last part inspect	0.5
P1 TOTAL	**10.8**	**P2 TOTAL**	**10.8**

Press 3 w/ Cobot Lower housing		Press 4 w/ Cobot Upper housing	
Cart swap	1.6	Cart swap	1.6
Print tag	1.2	Print tag	1.2
Parts to cart	0.0	Parts to cart	0.0
First part inspect	0.75	First part inspect	0.5
Last part inspect	0.75	Last part inspect	0.5
Walk to press	1.0	Walk to press	1.0
P3 TOTAL	**5.3**	**P4 TOTAL**	**4.8**

1 x 4 w/ Cobot	Time (s)
P1 Total	10.8
P2 Total	10.8
P3 Total	5.3
P4 Total	4.8

→

Operating Time (s)
31.7 seconds

Figure III-6. Predicted Initial Time Study with Cobot

Figure III-7. Setup Comparison of 1x4 without cobot versus 1x4 with cobot

Operator Walking Distance

MODAPTS, known as the Modular Arrangement of Predetermined Time Standards, is the preferred method at DTS when establishing the predetermined time an operator will use to walk the average distance given. Below are the assumed values when calculating the # of MODs, and the predetermined time valued in seconds.

Assume given values:

$1\ MOD = 0.129\ Seconds$

$W2.36\ per\ linear\ foot = 2.36\ MODs$

Walking distance travel speed: $3.5\ feet\ per\ second$

Finding # or MODs and predetermined time to walk to cart staging area and return

Formula for # of MODs is: $\boldsymbol{Average\ Distance * 2.36 = \#\ of\ MODs}$

Formula for predetermined time: $\boldsymbol{Predetermined\ Time\ (\mathbf{sec}) =}$

$\boldsymbol{\#\ \mathbf{of\ MODs} * 0.129\ \mathbf{sec}}$

To conduct the walking distance study, press locations one to five were examined to understand the average walking distance an operator will complete when taking a cart from home position to the staging area and then, retrieving an additional cart back to the home position. It was found that the average predetermined walking time for press one to five was about 45 seconds with the highest amount of time spent on press two at 52.86 seconds. An additional time study was conducted through stopwatch measurements to understand the current real-time walking distance time for operators. The time study observed eight injection mold operators with each operator performing 30 timed cycles for presses 1 to 5 (150 cycle times for each press).An estimated total of 1,200 cycle times was performed to provide a comparison of what the current real-time operator can perform versus what MODAPTS predetermined time would calculate in theory. On average, a recorded walking time of about 57 seconds was produced with press five being the longest time period of 75.55 seconds. Figure III-8 shows all recorded data for the walking distance study.

Location	Avg Distance (ft)	# of MOD (using W2.36)	Predetermined Time (sec)	Avg Time through time study (sec)
Press 1	134.82	318.18464	41.05	47.25
Press 2	173.64	409.7904	52.86	60.85
Press 3	140.82	332.3352	42.87	49.35
Press 4	139.66	329.5976	42.52	53.1
Press 5	145.82	344.1352	44.39	75.55

Figure III-8. Operator Walking Distance Time Study and MODAPTS study

Current Operator to Press Layout

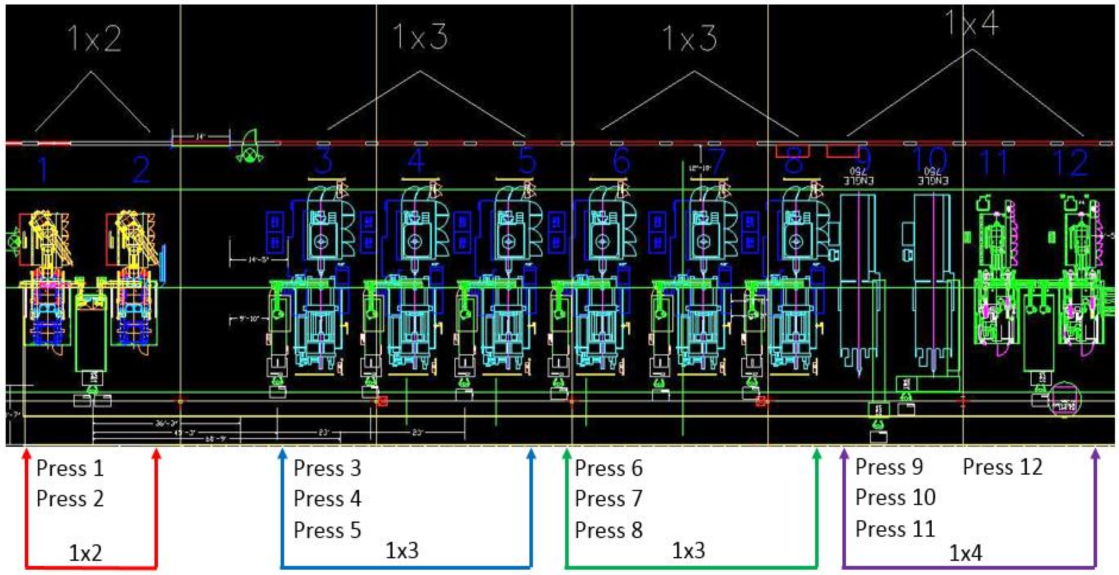


Figure III-9. Current Operator to Press Layout

Figure III-9 is the current operator to press layout of the injection mold department for presses 1 to 12. The nomenclature to describe the number of operators to injection mold presses can be simplified with the first number referring to the amount of operators and the second number referring to the amount of injection mold press machines. For example, a 1x2 setup would translate into one operator working with two presses. The current setup above has one 1x2, two 1x3, and one 1x4 setup. One utility relief operator is required to give twenty minute breaks to each of the four injection mold operators for presses 1 to 12.

Future Operator to Press Layout

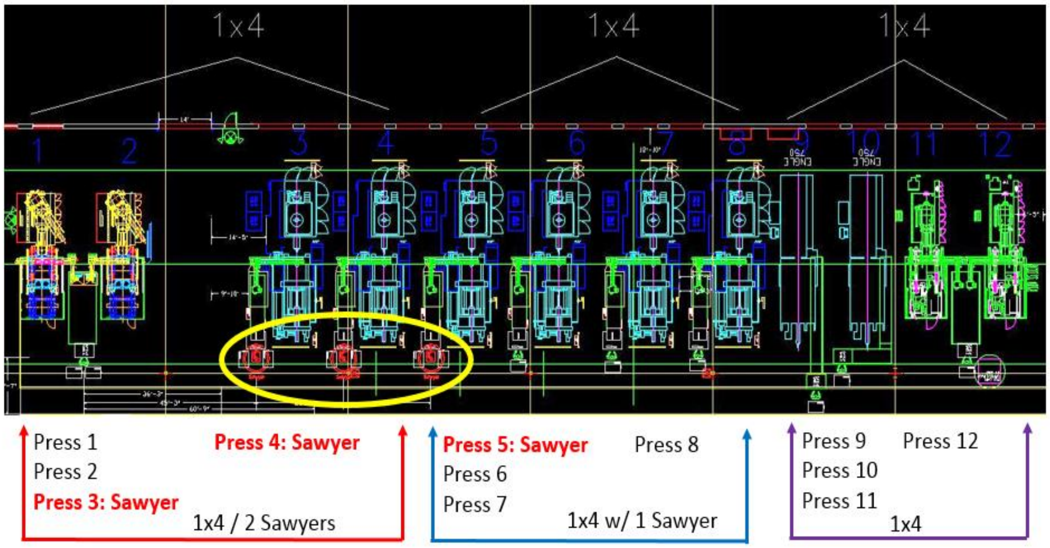


Figure III-10. Future Operator to Press Layout

Implementation of collaborative robots requires an updated operator to press layout. The future layout for presses 1 to 12 would consist of collaborative robots at presses 3, 4, and 5. The new layout shown in Figure III-10 above allows DTS to change the orientation of presses 1 to 4 into a one operator to four press (1x4) setup with two cobots working at presses 3 and 4. Presses 5 to 8 would be updated into a one operator to four press (1x4) setup with one cobot working at press 5. Finally, presses 9 to 12 would remain a one operator to four press setup with no cobots working at the injection mold presses. When comparing the current layout in Figure III-9 to the future layout in Figure III-10 the difference is the amount of operators needed to tend each press decreases from four to three operators. Thus, when taking consideration that DTS runs three shifts of injection mold operators the savings of one operator per shift will give a total of three operators saved.

IV: PHASE II-EVALUATION

Injection Mold Operator Labor Savings

Table 1 outlines the average salary of one injection mold operator working eight hours a shift. A multiplier of 1.2 was applied to all shifts "Employee Yearly Salary" to account for the operator relief employee tasked with giving breaks to five operators in twenty minute time intervals. Taking the average of the three injection mold production shifts will arrive at a final average operator worth of $60,680.00. Multiplying the average operator worth by three for the three shifts will arrive at a total savings in labor of $182,040.00 for three operators.

Table 1 Injection Mold Operator Worth

Finding Injection Mold Operator Worth					
Shift	**Working Hours/Shift**	**Employee Yearly Salary**	**Multiplication factor of 1.2 for actual operator worth**	**Average Operator Worth**	**Labor Cost for 3 operators**
1st	8	$50,000.00	$60,000.00	$60,680.00	$182,040.00
2nd	8	$50,700.00	$60,840.00		
3rd	8	$51,000.00	$61,200.00		

Cost of Cobot Integration

Table 2 documents the purchase order for implementing three collaborative robots through Shaltz Automation of Flint, Michigan. Included in each line item is the quantity, price per item, and the total price per item. The total cost of integration for three collaborative robots was $152,371.00.

Table 2 Purchase Order for 3 Collaborative Robots

Purchase Order for 3 Collaborative Robots			
Item	**Each**	**Quantity**	**Total**
Engineering	$5,860.00	1	$5,860.00
End of Arm Tools - Material	$1,852.00	3	$5,556.00
End of Arm Tools - Labor	$897.00	3	$2,691.00
Part Deployment Chutes - Material	$1,799.00	3	$5,397.00
Part Deployment Chutes - Labor	$1,289.00	3	$3,867.00
Sawyer Items - Robot, Pedestal, Grippers & Equipment	$41,250.00	3	$123,750.00
Support (each day)	$875.00	6	$5,250.00
Total System Implementation			**$152,371.00**

Bill of Materials

Table 3 lists all items needed for the collaborative robot project into a bill of materials, abbreviated BOM, and breaks it down by item description, amount, price per piece and the total cost of project. The cost for the project resulted in a total of $164,783.04 which is about $17,256.96 less than the combined total of three injection mold operators at $182,040.00.

Table 3 Bill of Materials

Bill of Materials			
Item	**Each**	**Quantity**	**Total**
Flat Washer - 3/8" USS Zinc (1 Pack of 150pc)	$11.60	10	$116.00
Bolt - 3/8" - 1-1/2 GRD 5 USS Zinc (1 Pack of 50pc)	$6.92	30	$207.60
Hex Nut - 3/8"-16 GRD 5 Zinc (1 pack of 100pc)	$11.43	8	$91.44
Zip Ties - 8-1/2" x 0.15 (1 Pack of 100pc)	$3.78	17	$64.26
Bolts for Cart - 3/8 x 3-1/4 GRD 5 USS Zinc (1 Pack of 25)	$7.39	68	$502.52
Spacer - 3/4" OD x 13/32" ID x 2-1/4" Length Aluminum	$0.47	3200	$1,492.00
Cart Floor Locators - Design, Material, Sensors, & Paint	$875.00	6	$5,250.00
PVC Sleeve - Chamfer Modification	$1.75	1680	$2,940.00
Unistrut - P4100T 20 PG Unistrut cut to 30"	$5.90	250	$1,475.00
Coral Slotted Shim 0.03" Thick (1 pack of 20pc)	$11.87	2	$23.74
Gray Slotted Shim 0.06" Thick (1 pack of 20pc)	$12.99	2	$25.98
Lightweight Hose - 3/4" ID, 1-1/8" OD, Yellow (1 ft.)	$1.49	150	$223.50
Shaltz Automation - Engineering	$5,860.00	1	$5,860.00
Shaltz Automation - End of Arm Tools - Material	$1,852.00	3	$5,556.00
Shaltz Automation - End of Arm Tools - Labor	$897.00	3	$2,691.00
Shaltz Automation - Part Deployment Chutes - Material	$1,799.00	3	$5,397.00
Shaltz Automation - Part Deployment Chutes - Labor	$1,289.00	3	$3,867.00
Shaltz Automation - Sawyer Items – Robot, Pedestal, etc	$41,250.00	3	$123,750.00
Shaltz Automation - Support (each day)	$875.00	6	$5,250.00
Total Cost of Project			**$164,783.04**

Useful Cobot Lifetime

Table 4 records the steps to find the number of working years for one cobot to be used at the Rethink Robotics' minimum useful life of 35,000 hours. If the cobot worked 24 hours a day seven days a week with no loss in downtime or faults (perfect situation), then the collaborative robot will be able to work four full years until a replacement is needed.

Table 4 Number of Working Years for One Cobot

Find # of working years for One cobot	
Item	**Hours**
Hours/Day - 1 Cobot	24
Paid Lunch (hours)	0
Total hours worked/day	**24**
# of days/week	7
Total # of hours per 1 week	**168**
# of weeks/year	52
Total # of hours per 1 year	**8736**
Cobot useful life (hours)	35,000
# of working years for one cobot	***4.01***

Return on Investment

Appendix B showcases the timeframe for the projected return on investment, abbreviated ROI, for the implementation of three collaborative robots at Detroit Thermal Systems. The ROI was calculated with average weighted labor rate per year, total cost of implementation, amount of shifts per day and the amount of operators replaced per shift. The following values were used

1. Weighted Labor Rate/year: $60,680.00
2. Total Cost of Implementation: $160,000,00
3. Amount of shifts per day: Three
4. Amount of Operators replaced per shift: 1.2

Using ROI formulas outlined in Appendix C and D the payback time for DTS to make the money it spent to purchase three collaborative robots would be nine months. Management will need to be proactive in replacing the cobots during the arrival of the 4th year due to the useful life of the cobots will come to an end.

V: PHASE III- PRE-IMPLEMENTATION

Injection Mold Cart Modifications

Originally, the injection mold carts were designed for humans to place parts into, pull or push across the plant and to take parts out for production. Thus, modifications to the injection mold carts were necessary to enable collaborative robots to consistently pick and place parts into carts allowing for the job process to be completed.

Figure V-1. White PVC Cover

White PVC covers shown in Figure V-1 were designed to decrease the swinging motion when the cobot gripper's suction cups released the part placed on the peg. The sleeves allowed for consistent nesting, placement of parts onto each other, which resulted in greater repeatability. At the end of the PVC shows a chamfered point. The design of this point allows for the fifth part to remain on the peg when

Figure V-2. Rear Steel Unistrut Stiffener

To strengthen cart peg locations during the pick and place process, an additional 4100 steel unistrut piece cut to 2' was bolted horizontally to the back of the injection mold cart (shown in Figure V-2). Increased repeatability for the pegs was noted when the cobot would place parts onto pegs.

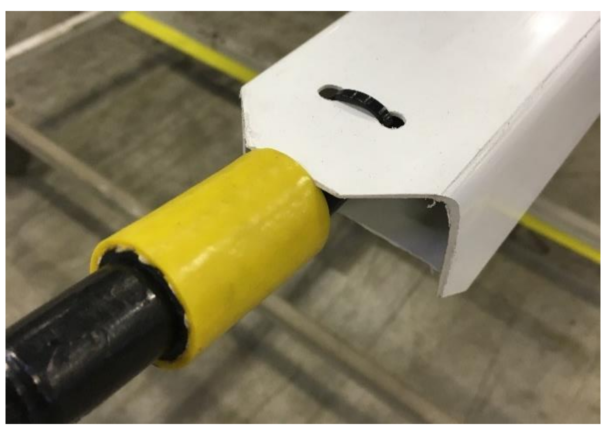


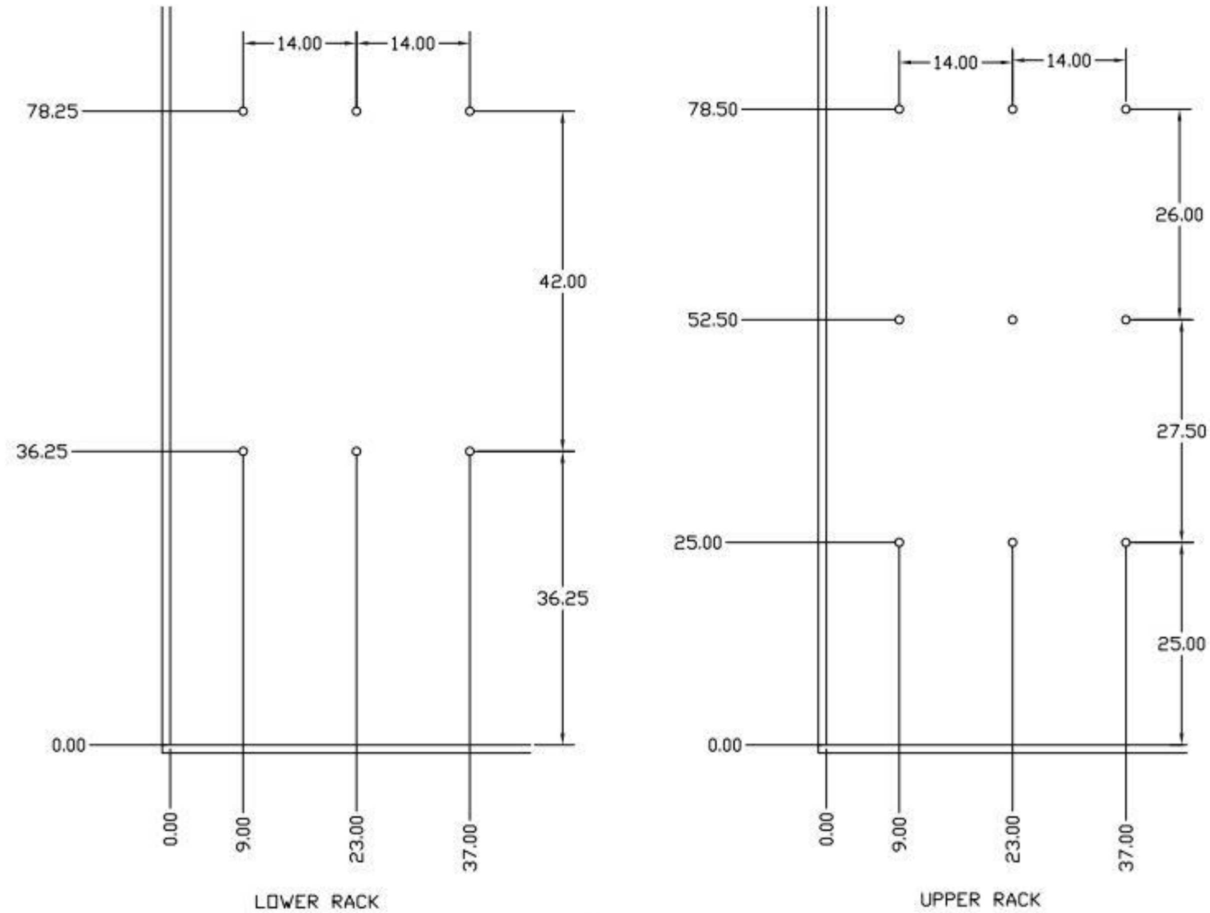
Figure V-3. Industrial Hose for Peg Cover

Yellow industrial hose cut to roughly 1.5 inch pieces were placed on the end of each peg (shown in Figure V-3). The inclusion of the hose prevents a part from falling off during the pick and place process. Also, the hose prevented parts from falling when operators would remove carts from floor locators.

Figure V-4. Aluminum Spacer for Lower Housing Carts

The use of aluminum spacers were used for the lower housing injection mold carts. Spacers allowed for an increase of two and a quarter (2x1/4”) inches to the back end of the peg. The increase in length allows for cobot to place all five lower housing parts into the cart without parts falling on the ground.

Injection Mold Cart XYZ Peg Location Position



Fixture V-5. XYZ Locations of Injection Mold Peg Master Cart

To allow for maximum repeatability of the pick and place cobot process, the cobot's carts needed a master cart to take reference to and apply that design to all injection mold carts in the plant. Figure V-5 provides dimensions on the lower housing (shown left) and the upper housing (shown right). All dimensions are in inches.

Fixture for Peg Locations

Designs for the fixture to verify injection mold cart peg locations are documented in Appendix E, F, and G labeled “Fixture for Injection Mold Cart Peg Verification Page 1 to 3.” All designs use inches as the metric measurement.

Part Deployment Chutes

In order for the cobot to pick up the injection mold part at the same position consistently, the cobot’s station must have a controlled part deployment chute. This part deployment chute will allow for the injection mold part to slide down the conveyor belt and funneled into a slide that positions the part into a repeatable position. The finished part deployment is shown in Figure V-6.

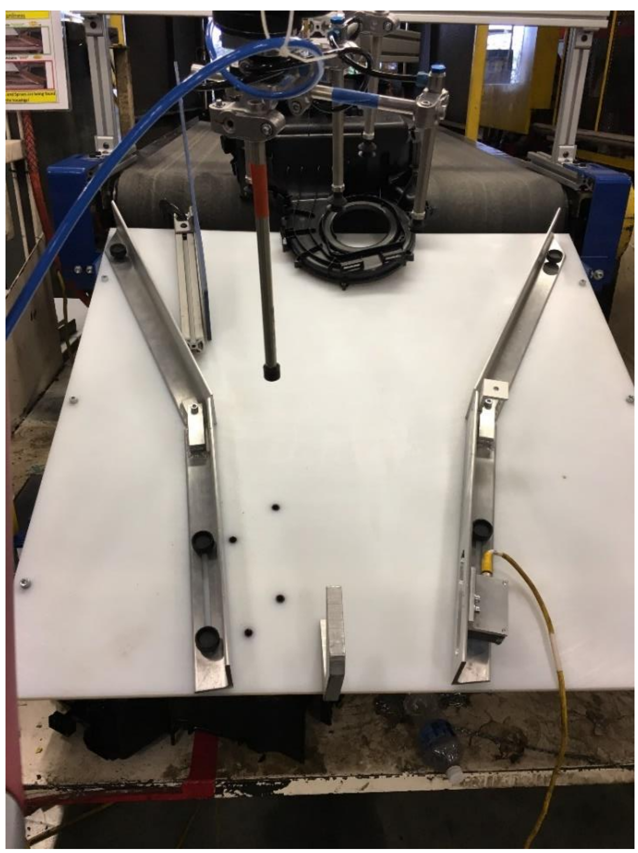


Figure V-6. Part Deployment Chute

Cart Floor Locators

Floor Locators are designed as a location to place the injection mold carts into. It consists of a cart present sensor, hinge cutout for the injection mold cart, cart lead ins and magnets. Figure V-7 shows the final design of the cart locators.

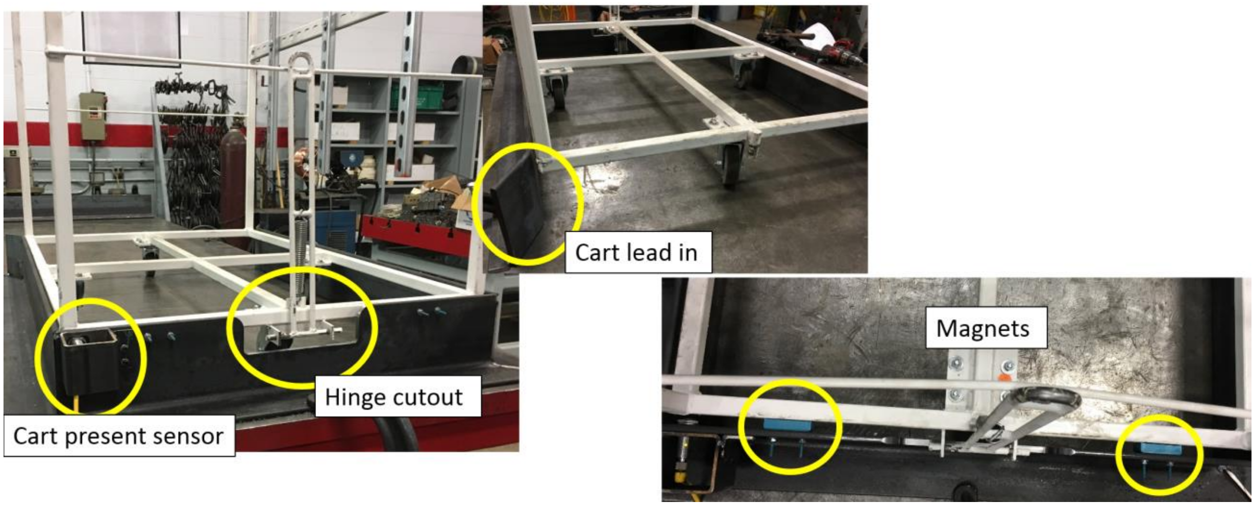


Figure V-7. Cart Floor Locators

VI: PHASE IV- IMPLEMENTATION

Phase four of the thesis project will discuss the prove out of Shaltz Automation's robot program in the plant, troubleshooting and experimentation of collaborative robot.

Robot Path Process

The pick and place process is as follows:

1. Part comes off conveyor and into the part deployment slides

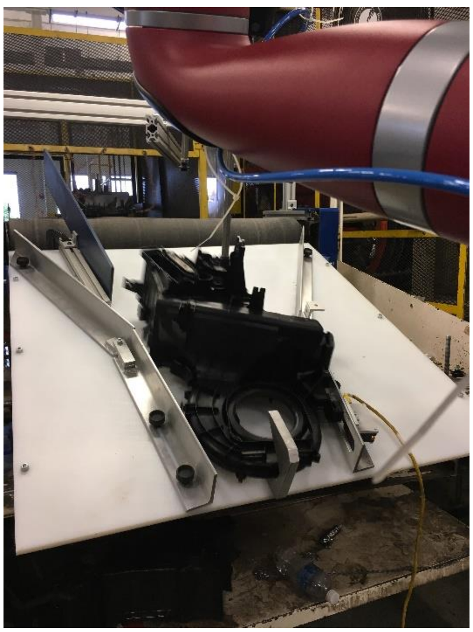


Figure VI-1. Cobot Process- Part Slides into Part Deployment Chute

2. Cobot brings in arm and uses a combination of suction cups and compressed air to lift injection mold part off of part deployment table.

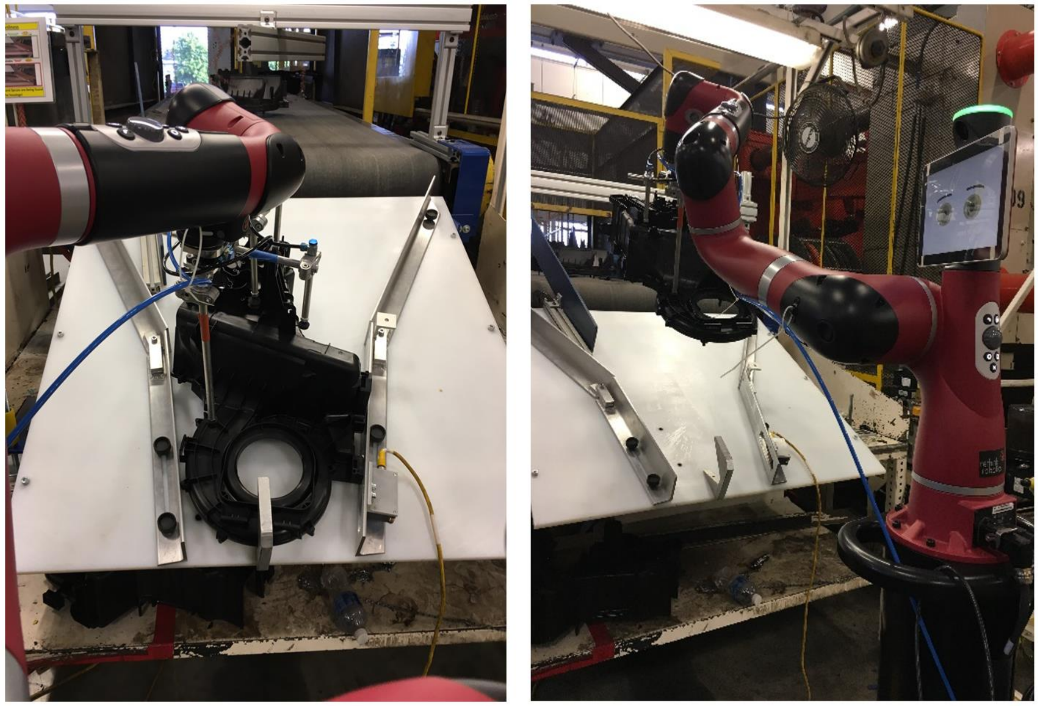


Figure VI-2. Cobot Picks up Part

3. Cobot brings part to cart peg and slowly places it onto peg

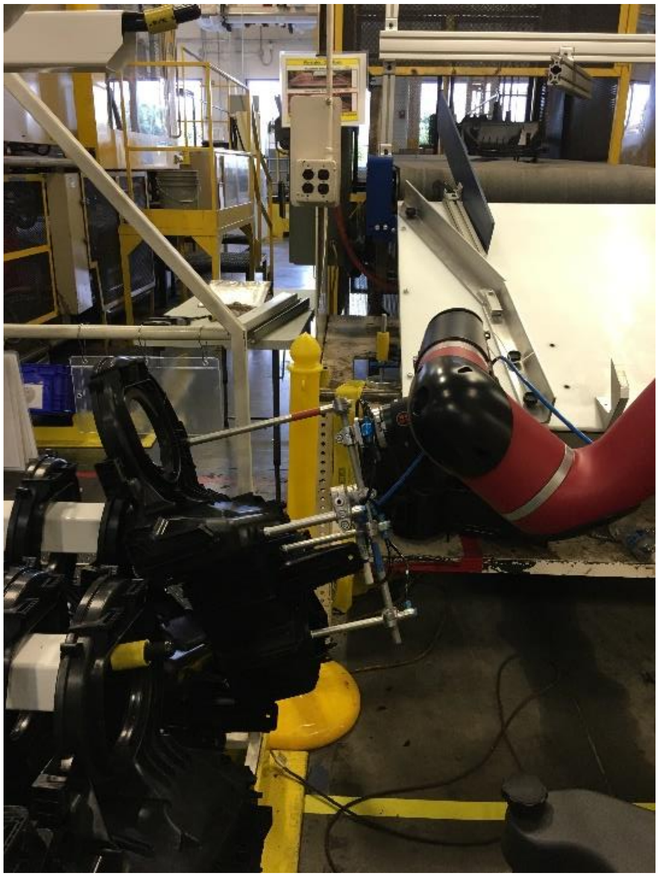


Figure VI-3. Cobot Places Part onto Cart Peg

4. Cobot returns to part deployment home position ready to pick up next injection mold part. Cobot will repeat the process until the completion of an upper housing cart. From there, cobot will continue to place parts into cart position to the right of the cobot.

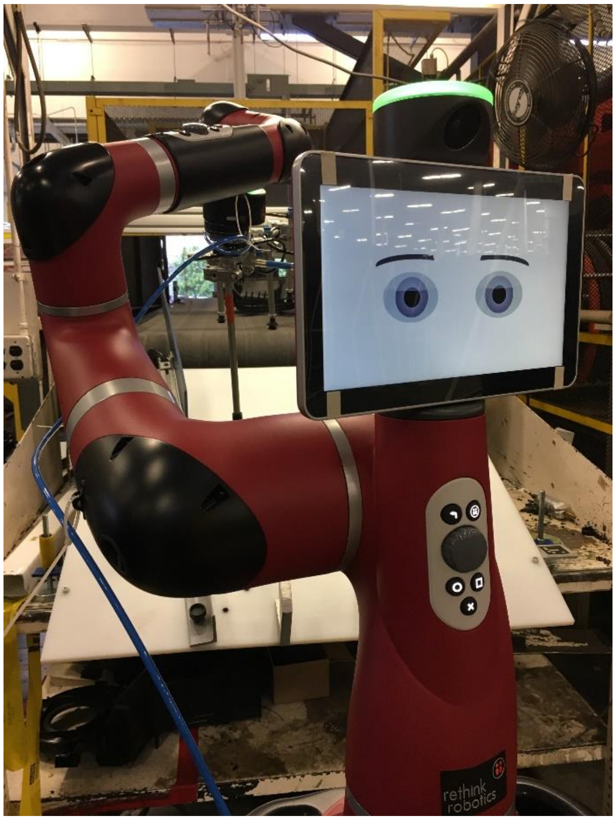


Figure VI-4. Cobot Returns to Home Position

A collaborative robot light system guide, Appendix H, was created to give a troubleshooting table for the possible problems that can arise when the collaborative robot is running in the injection mold plant. These “colored-light” status readouts are documented in the troubleshooting table and give solutions for how to fix the problem.

Operator Instruction manual for the collaborative robot was created to give operators and engineer’s basic information to allow for a step-by-step instruction sheet to start or restart the cobot, featured in Appendix I, and a proper step-by-step method for troubleshooting an injection mold part stuck, Appendix J.

Troubleshooting

A problem was observed where the robot task not ready to run.

- Robot screen informing user that pick and place points are all invalid. This was due improper shut down of cobot by removing the power cord from power source. The solution to the problem was to follow steps to restart cobot.

Lessons Learned

- Slow down robot speed for programming
    - This allows programmers to understand each node and move that the cobot must go through to complete a pick and place process.
- Need for operator training
    - Operators working with the cobots need to understand how to start and restart collaborative robot, fix issues when cobot faults occur, stop the cobot in the event of an emergency, and troubleshoot cobot fault lights.
- Lock collaborative robot
    - Reduce the amount of production sabotage and it will simplify menus for users that do not need to have full access to cobot programming privileges.

V: PHASE V-NEXT STEPS

Next Steps

The implementation of the addtional collaborative robots at Detroit Thermal Systems is ongoing. One of the three collaborative robots was implemented and proved out to work injection mold press four production. Steps are as follows:

1. Fixture for XYZ locations must be updated to verify lower housing cart peg locations.
2. Lower housing carts must be updated with cart modifications. Cart modifications include: aluminum spacers, rear unistrut stiffener, PVC sleeve additions and unistrut cut for PVC stability.
3. Cart floor locators for press three and five must be bolted and anchored to production floor.
4. Shaltz Automation to return to DTS and prove out final two collaborative robots.

GLOSSARY

Collaborative Robot:	Industrial robot with the ability to work alongside a human without the need for a closed cage also known as a cobot
Flash:	Term used in the injection mold process for finished products with excess material
First In First Out:	Abbreviated FIFO
I.M.:	Injection Molding
Non-Fill:	Term used in the injection mold process for an unfinished injection mold product that has experienced an incomplete fill. This results in a visible hole in the produced part.
Operator:	Employee working at a specified station with an assigned job
P552/P558:	Ford Model program for the F-150 pickup truck
Packed out:	When an injection mold cart is completely filled to its maximum capacity. Can also be used when an injection mold press has successfully filled all available injection mold carts related to the injection mold tool
Robot fault:	An error that stops the robot during the robot path process
Sprue:	Term used in the injection mold process for an additional plastic piece used to connect runners for the I.M. part

REFERENCES

Heyde, G. (1990). MODAPTS Modular Arrangement of Predetermined Time Standards. Southern Shores, NC: International MODAPTS Association.

Robotics, R. (n.d.). Baxter Image. Retrieved June 24, 2017, from http://www.rethinkrobotics.com/jp/landing-page-test/baxter-2/

Robotics, R. (n.d.). Sawyer Collaborative Robots for Industrial Automation. Retrieved June 10, 2017,

from http://www.rethinkrobotics.com/sawyer/

Robotics, U. (n.d.). UR10 robot. Retrieved June 25, 2017, from https://www.universalrobots.com/products/ur10-robot/

APPENDICES

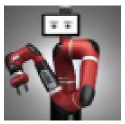
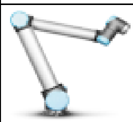
APPENDIX A

COLLABORATIVE ROBOT COMPARISON

Collaborative Robot Comparison

20-Sep-16 Ian Villaroman

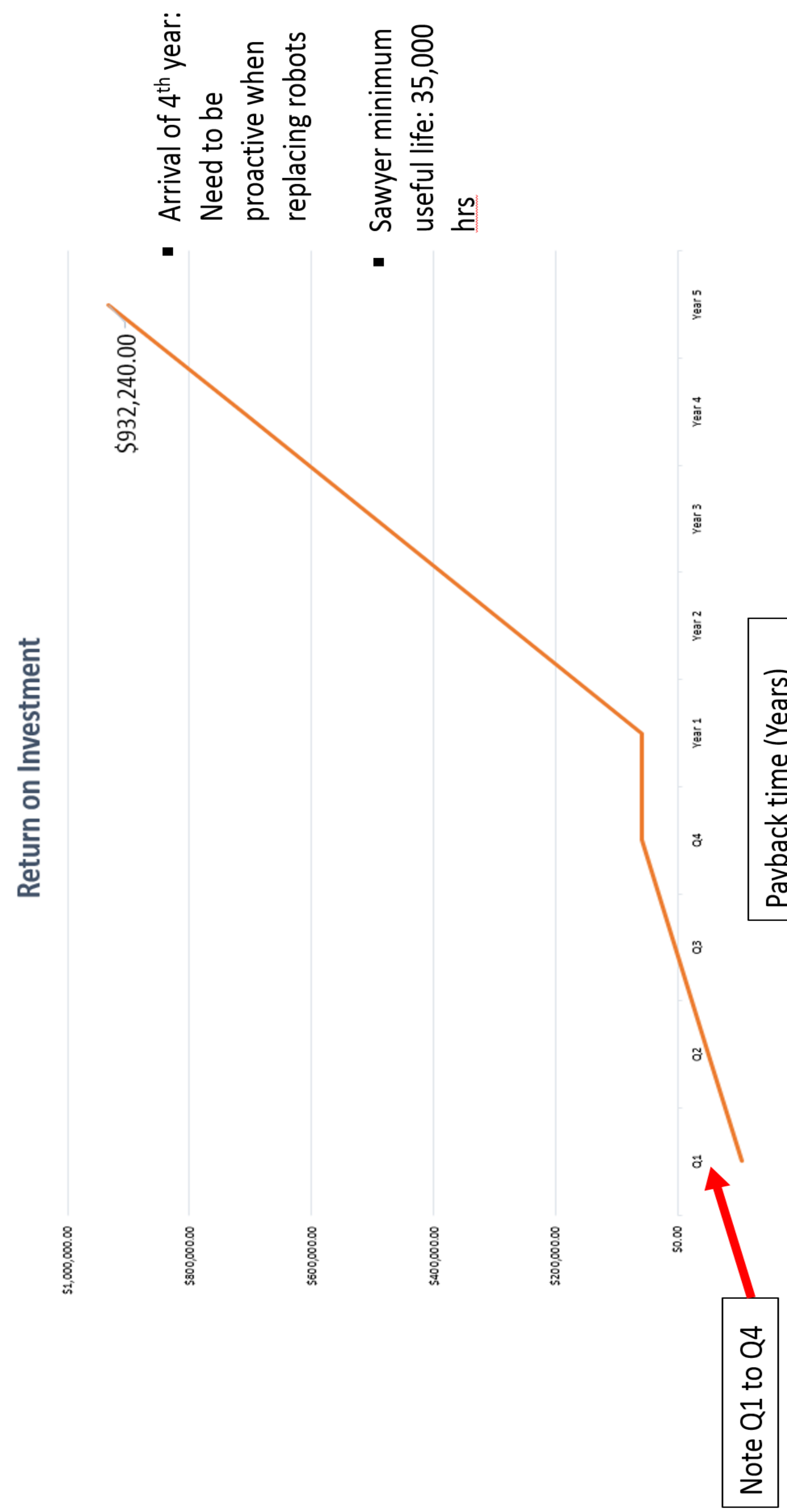
Collaborative Robot Comparison Guide

		Payload	Software Ease of Use	Reach	Flexibility	Weight	Repeatability	EOA Change	Price		Quick Advantages & Disadvantages
Baxter- Rethink Robotics		2.2 kg (5lbs) each arm	INTERA 3- Can be taught to anyone within a day	1210 mm	Mobile Pedestal, Landmark System, and can store tasks	165lbs (w/o Pedestal) 306 lbs (w/ pedestal)	± 0.1 mm	Yes. Mounting Plate capable of new end effectors	$25,000.00	Adv	Evolving Intera3 software, simple easy to use pick and place, LANDMARK system great reach and price. Use of the feel system to allow for proper position when dealing with delicate parts. No teach pendant which allows for that great low price. Will complete its task after the operator steps away from the robot.
										Disadv	Low payload (2.2 kg) and large real estate also does not have the manueverability that Sawyer has. Cables used to drive the machine is exposed outside of the robot
Sawyer- Rethink Robotics		4 kg (8.8 lbs)	INTERA 3- Can be taught to anyone within a day	1260 mm	Mobile Pedestal, Landmark System, and can store tasks	42 lbs (w/o pedestal	± 0.1 mm	Yes. Mounting Plate capable of new end effectors	$29,000.00	Adv	Evolving Intera3 software, simple easy to use pick and place, LANDMARK system great reach and price. Use of the feel system to allow for proper position when dealing with delicate parts. No teach pendant which allows for that great low price. Will complete its task after the operator steps away from the robot.
										Disadv	Payload could be improved to rival the UR10 and the KUKA. Cables used to drive the machine is exposed outside of the robot
UR10- Universal Robotics		10 kg (22lbs)	Pick and Place software. Easy to learn	1300 mm	Mobile Pedestal, requires teach pendant	28.9 kg (63.7lbs)	± 0.1 mm	Yes. Mounting Plate capable of new end effectors	$45,000.00	Adv	High payload, Long reach and Fair price
										Disadv	Also, camera and grippers do not come with robot you must buy it seperately. Cables used to drive the machine is exposed outside of the robot
LBR IIWA 14 R820- Kuka		14 kg (30.86 lbs)	Previous Programming experience required	820 mm (32.28 in)	Mobile Pedestal, requires teach pendant	65.9 lbs	± 0.15 mm	Yes. Capable of new end effectors	$85,000.00	Adv	High payload. All cables (air, electric etc.) used to drive unit are located inside the robot
										Disadv	No capability of a horizontal pick and place. Only able to conduct vertical pick and place. Need for previous programming experience. Lower end of robot reach. Price is too high for what is given. After operator bumps into robot there is a need to go into teach pendant (or tap robot) to allow for the continuation of job.
duArdo- Kawasaki		2 kg each arm	Tablet software called Robot teacher	760 mm	Mobile cart	Not Available	± 0.05 mm	Yes	$22,500.00	Adv	2 arms. Robot will never give up its job. Slow down near the presence of a human
										Disadv	Weak Payload (2kg per arm). 4 Axes x 2 (Max. 6 axes x 2). Angles of Freedom (AOF) very low. Flexibility and robot radius is at the low tier.
CR-35iA - Fanuc Robotics		35 kg	Requires previous programming experience	1813 mm	Bolted to floor	990 kg	± 0.08 mm	Yes it is interchangable	Not available	Adv:	Large payload, largest reach, great repeatability
										Disadv:	Robot is bolted to the floor , programming exp required, not really a collaborative robot. Price is high with the given specs. Not fit for the application at DTS.
Motoman HC10- Yaskawa		10 kg (22lbs)	Simple hand-guided pick and place, Teach pendant required	1200 mm	Mobile Pedestal, w/ teach pendant	45 kg	± 0.1 mm	Yes. Capable of new end effectors	$45,000.00	Adv	Simple pick and place. High payload and high reach. Interchanable end of arm tooling
										Disadv	**Not available until May 2017.** The need for a teach pendant

APPENDIX B

PROJECTED RETURN ON INVESTMENT CHART

Projected Return on Investment Chart



Weighted Labor rate/year	$60,680.00	Total Cost of Implimentation	$160,000.00
Weighted Labor rate/hr	$29.17	Lifetime Robot Cost/hr	$4.57
Shifts/Day	3	Total Lifetime Savings	$861,058.00
Operators replaced/shift	1.2	ROI in Months	9

APPENDIX C

ROI DOCUMENTATION PAGE 2 – FORMULAS

ROI Documentation Page 2- Formulas

G	Weighted Labor rate/year	$60,680.00		Total Cost of Implimentation	$160,000.00	G
#1	Weighted Labor rate/hr	$29.17		Lifetime Robot Cost/hr	$4.57	#2
G	Shifts/Day	3		Total Lifetime Savings	$861,058.00	#3
G	Operators replaced/shift	1.2		ROI in Months	9	#4

Legend

- G Given
- # Formula

Formulas

#1 $$\frac{Weighted\ Labor\ rate}{hr} = \frac{\frac{Weighted\ labor\ rate}{year}}{52 * 40}$$

#2 $$\frac{Lifetime\ Robot\ Cost}{hr} = \frac{Total\ Cost\ of\ Implimentation}{Useful\ Life\ of\ Sawyer}$$

#3 Total lifetime Savings= $\left[\frac{Weighted\ labor\ rate}{hr} - \frac{Lifetime\ Robot\ Cost}{hr}\right] * (useful\ life)$

#4 ROI in Months= $\frac{Total\ Cost\ of\ Implimentation}{\left(\frac{Weighted\ labor\ rate}{year}\right)\left(\frac{shifts}{day}\right)\left(\frac{operators\ replaced}{shift}\right)} * (12)$

APPENDIX D

ROI DOCUMENTATION PAGE 3- FORMULAS WITH WORK

G	Weighted Labor rate/year	$60,680.00	
#1	Weighted Labor rate/hr	$29.17	
G	Shifts/Day	3	
G	Operators replaced/shift	1.2	

Total Cost of Implimentation	$160,000.00	G
Lifetime Robot Cost/hr	$4.57	#2
Total Lifetime Savings	$861,058.00	#3
ROI in Months	9	#4

Legend
- G Given
- # Formula

Formulas with work

#1 $$\frac{Weighted\ Labor\ rate}{hr} = \frac{\$60{,}680.00}{52 * 40}$$ → $29.17

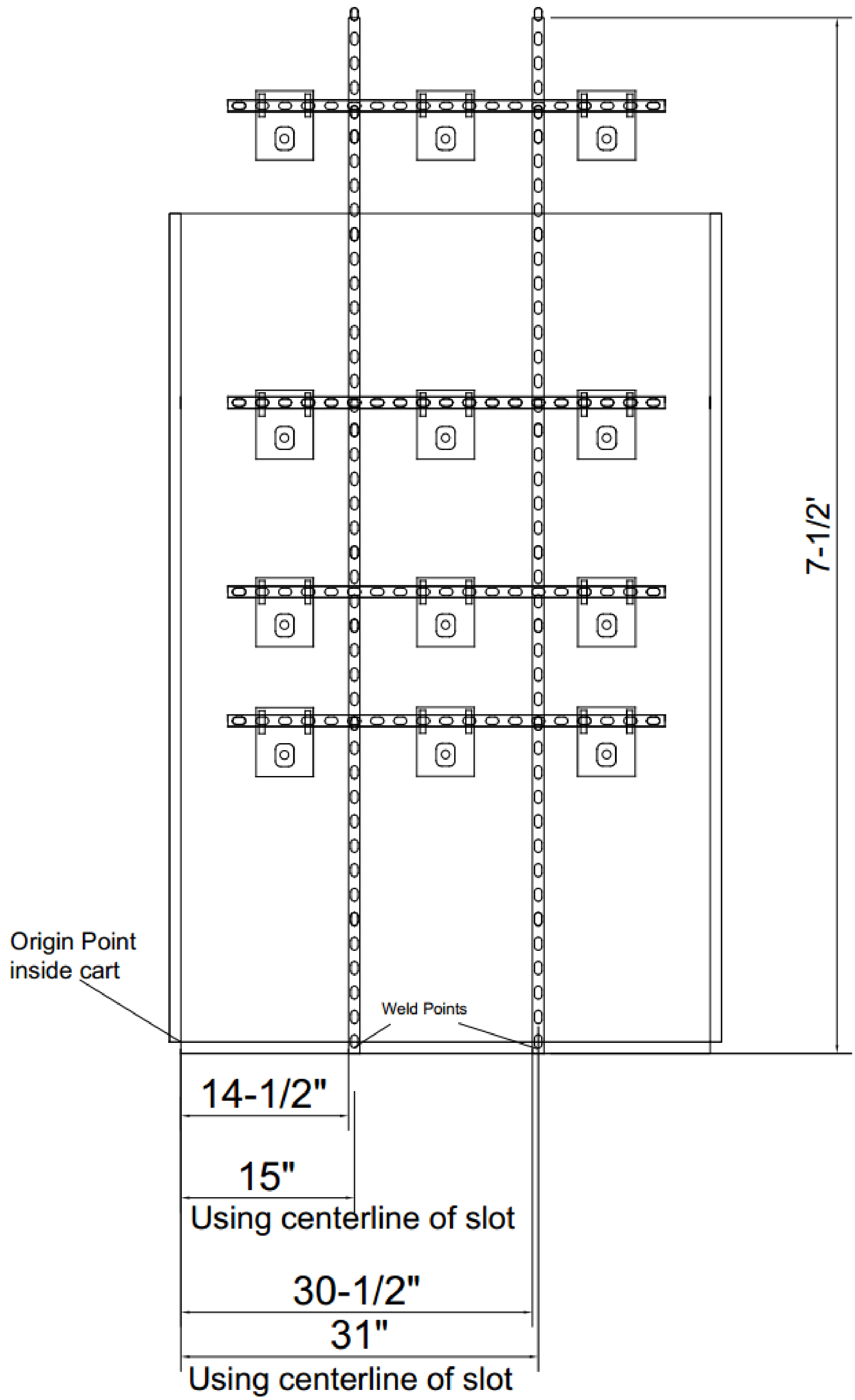
#2 $$\frac{Lifetime\ Robot\ Cost}{hr} = \frac{\$160{,}000.00}{35{,}000\ hrs}$$ → $4.57

#3 Total lifetime Savings= $[\$29.173 - \$4.57] * (35{,}000 hrs)$ → $861,058.00

#4 ROI in Months= $\frac{\$160{,}000.00}{(\$60{,}680.00)(3\ shifts)(1.2\ op\ replaced)} * (12)$ → 8.7892 months= roughly 9 months

APPENDIX E

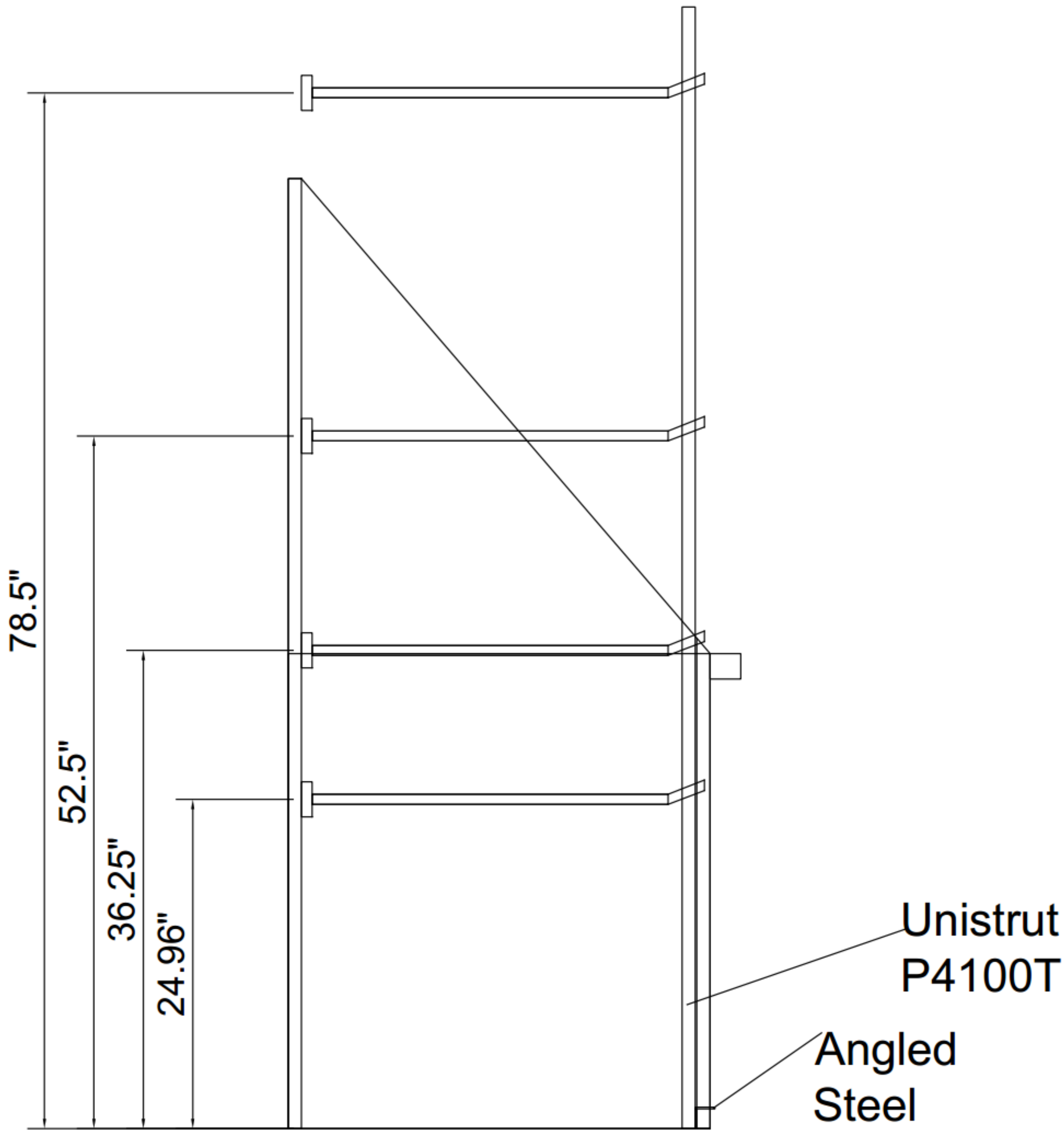
FIXTURE FOR I.M. CART PEG VERIFICATION PAGE 1


7-1/2'
Origin Point
inside cart
Weld Points
14-1/2"
15"
Using centerline of slot
30-1/2"
31"
Using centerline of slot

APPENDIX F

FIXTURE FOR I.M. CART PEG VERIFICATION PAGE 2

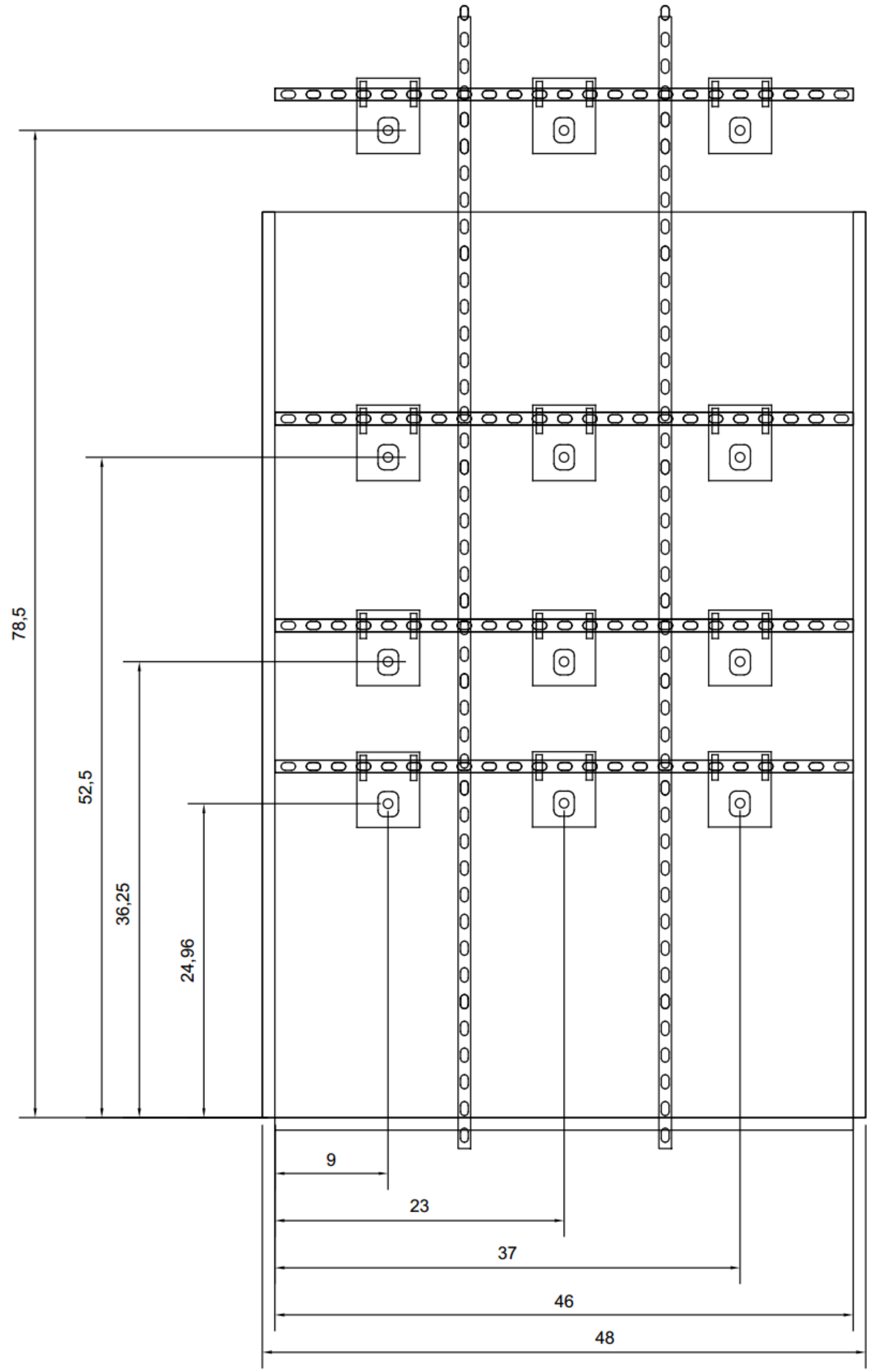
Fixture for I.M. Cart Peg Verification Page 2



APPENDIX G

FIXTURE FOR I.M. CART PEG VERIFICATION PAGE 3

Fixture for I.M. Cart Peg Verification Page 3



XYZ Locations for Injection Mold cart pegs

APPENDIX H

COBOT ALARM LIGHT SYSTEM SHEET

Cobot Alarm Light System Sheet

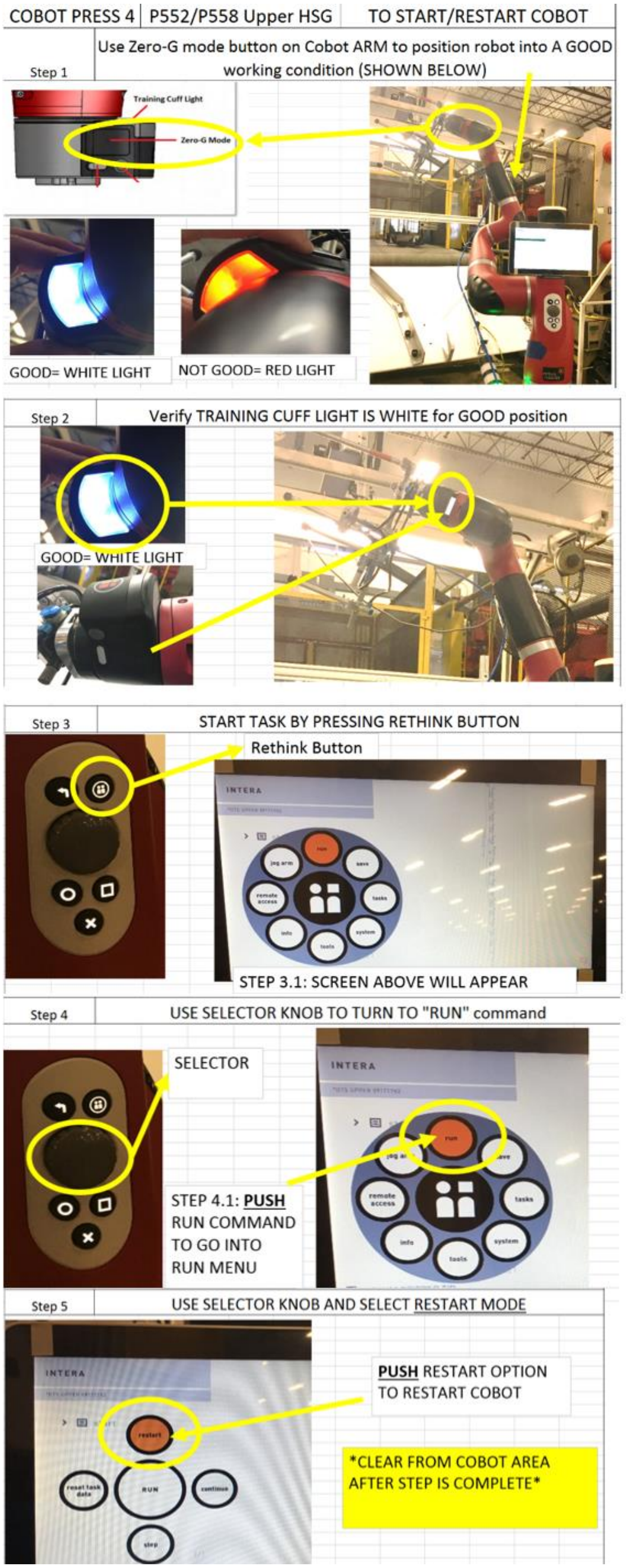
COLLABORATIVE ROBOT ALARM LIGHT SYSTEM

RED	YELLOW	GREEN	BLUE	ALARM	PROBLEM AND SOLUTION
X				X	**Problem: Collision of robot arm on a peg**
					Solution: Restart cobot , Pull both carts, add new empty carts
					Problem: Cobot senses NO parts breaking part present sensor
					Solution: Remove stuck parts, place new part in tray and bump robot to RUN COBOT
					Problem: Pick failure, Pick lost suction OR part place failure
X	X			X	Solution: Grab part, bump cobot arm, cobot will release part, place part on rack, and cobot will CONTINUE TO RUN
X			X	X	**Problem: One cart is missing/One cart is full**
					Solution: RESTART THE COBOT, Pull both carts, add fresh empty carts
					Process is running when GREEN
		X			Will run with ONE CART/BOTH CARTS
					Loading will begin with cart FIRST placed (if both are placed simulataneously then LEFT first)
					Blue light is shown when
					A Cart is FULLY PACKED OUT **OR** CART IS OUT
					One cart is FULLY PACKED **OR BOTH** carts full
					NO cart in placed when task restarts
			X		CART PULLED during process
					Solution: Grab part and RESTART COBOT , need empty racks

APPENDIX I

COBOT INSTRUCTION MANUAL – TO START/RESTART

Cobot Instruction Manual – To Start/Restart



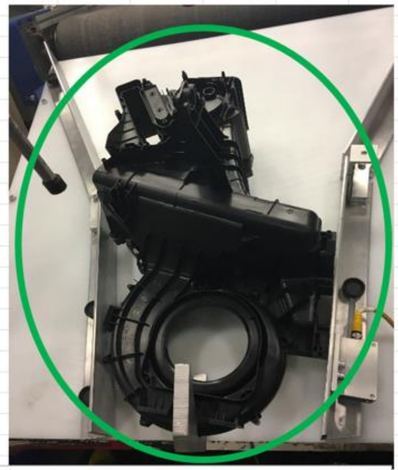
APPENDIX J

COBOT INSTRUCTION MANUAL-PART STUCK

Cobot Instruction Manual-Part Stuck

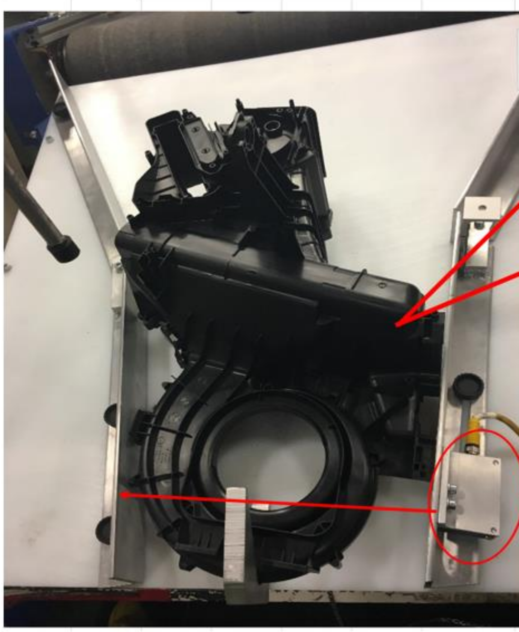
COBOT PRESS 4	P552/P558 Upper HSG	EMERGENCY STOP
Step 1	PART IS STUCK ON PART SLIDE TABLE. OPERATOR MUST MOVE PART INTO CORRECT POSITION	

PART IN NOT GOOD POSITION, OPERATOR MUST MOVE PART



PART IN GOOD POSITION FOR COBOT PICKUP

Step 2	TO VERIFY IF A PART IS IN GOOD POSITION CHECK IF PART BREAKS PART PRESENT LIGHT AND CHECK IF SENSOR HAS GREEN AND YELLOW LIGHT



GREEN LIGHT = Sensor

GREEN &YELLOW light= PART IN SLIDE, BREAKS SENSOR LINE

PART PRESENCE SENSOR: Part must break line of sensor