Letter of Transmittal

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December 8th, 2021

Mr. Vern Campbell, P.Eng.
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Dear Mr. Vern Campbell,

Team 10 is pleased to submit the final report for our capstone project at the University of Manitoba. The capstone project sponsored by DMS Industrial Constructors was to focus on streamlining their current welding fabshop. This report includes the project definition, concept generation and a detailed final design with all required deliverables.

We would like to thank you for the suggestions and support provided as our advisor for the duration of this project. We would also like to thank the following:

- Dr. Paul Labossiere for his design recommendations.
- Ms. Aidan Topping and Jaime Campos Ordonez for their important feedbacks.
- Mr. Sean Coey and Mr. Kevin Kotowich for their insights to help us complete this project.

Sincerely,

Maksym Khoma, Abiodun Koko, Fisayo Olofin and Tan Hung Phan.

Team 10, MECH 4860 – Engineering Design.

Enclosure: DMS Fabshop Welding Streamlining

University of Manitoba

Department of Mechanical and Manufacturing Engineering

MECH 4860 – Engineering Design

Final Report

DMS FABSHOP WELDING STREAMLINING

Submit by

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Prepared for:

Sponsoring Company: DMS Industrial Constructors.

Instructor: Dr. Paul Labossiere, P.Eng.

Advisor: Mr. Vern Campbell, P.Eng.

Date of Submission: December 08th, 2021

Executive Summary

DMS Industrial Constructors is a fast-growing industrial contractor and one of the largest in Western Canada. DMS currently operates a fabshop for prefabrication of structural steel and piping components for its major projects. The current fabshop is reliant on solely manpower and utilizes underdeveloped welding equipment which results in slow manufacturing speed and welding inconsistencies. Aligned with DMS's interest in continuous improvement, Team 10 has been tasked with improving the current welding process and streamlining the overall workflow by incorporating automated or semi-automated technology to a certain degree.

The team is to focus on implementing design changes and analysis to improve the first stage welding aspect of DMS's current workflow which involves circumference welding and welding of smaller pipe components. DMS has also outlined improving the current defect rate of 2%, and welding speeds of 20"- 25" and 40"- 60" per day for stainless steel and carbon steel pipes respectively. DMS has also specified that the recommended solution by the team should be capable of welding pipes ranging from 2" to 12" in diameter, Schedule 10 to Schedule 80 in thickness and up to 40ft in length. Also, the final design should comply with Canadian Standards Association (CSA) while staying within the $1,000,000 budget. The deliverables specified by DMS include a detailed cost summary, bill of materials, failure mode and effect analysis, supplier contact list, payback analysis, and construction drawings of the new system.

To achieve a feasible solution, the welding process was broken down into 3 major systems based on functionality- Welding Robot, Turntable and Roller Stand. Various design concepts were researched, and a final concept that satisfies the needs and target requirement was selected. The selected welding system was the Spool Welding Robot (SWR) manufactured by Novarc Technologies which is adaptable to the existing turntables and has an interface to generate reports that keeps track of quality. The SWR also advertises a defect rate of less than 1% and a welding speed of 200"-350" and 569"– 998" per shift for carbon steel and stainless steel respectively. The current turntable is not efficient for pipes with diameters less than 4". Therefore, the LJ welding 12P-900 portable turntable was selected to efficiently work with pipes with smaller diameters. Lastly, the HD2-300 roller stands also made by LJ welding was selected primarily because of its compatibility with the SWR and turntables.

The final system will cost a sum of $607,184.00 which is within the $1,000,000 budget and will result in a 50% reduction in the current defect rate, more than 300% increase in the current welding speed for both stainless steel and carbon steel pipes. These improvements implies that the current workload can be completed in 76 days rather than 260 days for the existing system (240% improvement). A payback analysis on the system deduced that the payback period is 348 operational days with current workload.

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1. Introduction

DMS Industrial Constructors is an industrial contractor currently operating a fabshop for pre-fabrication of structural steel and piping components. The team has been tasked by the clients to investigate incorporating automated welding in the fabshop and improving the overall workflow process. Summarized in this report is a detailed process of generating a suitable solution for our clients.

In this section, the background and Target Specifications given by the clients are addressed with the constraints and limitations defined by the team. The welding system was broken down into 3 key components with possible solutions generated and the process of selecting a suitable design for each component is discussed in the Concept Generation and Selection. The status of the project and the next milestones are laid out in the Project Schedule. Finally, the last section discussed the summary of the project and concludes the report on addressing transitioning to the next phase of the project.

1.1 Project Background

DMS Industrial Constructors one of Canada's fastest growing industrial contractors and one of the largest contractors in Western Canada. DMS operates a fabshop for prefabrication of structural steel and piping components for major projects. One major component in DMS is their pipe spool manufacturing operation. This manufacturing cell utilizes only manpower to accomplish the fabrication of pipe spools. A solely manpower fabrication process poses a risk due to shift absence, fatigue, and poor productivity [1]. These risks have resulted in a 2% defect rate, leading to loss of time due to rework. DMS has tasked our team with improving their pipe spool manufacturing process to increase overall productivity, weld consistency and quality [2]. Figure 1 below shows the current under-developed manufacturing technique that is used for pipe spool welding. Hence, the goal for our team is to automate their pipe spool fabrication processes to eliminate potential risks and improve throughput, quality, and consistency.

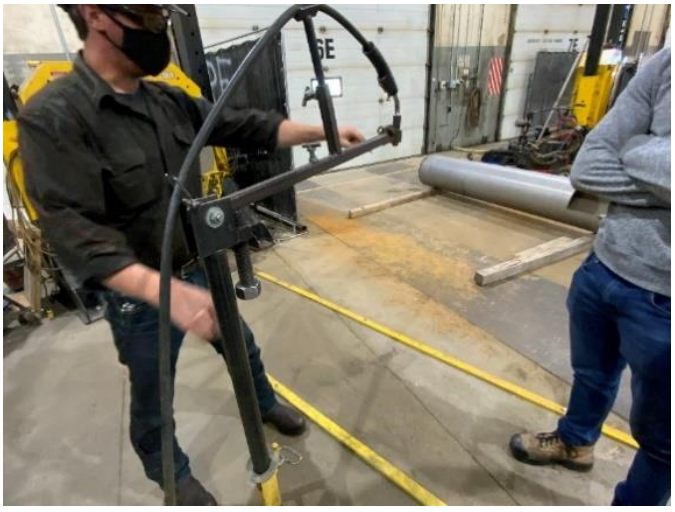


Figure 1: Pipe Spool Welding Torch-Holder

1.2 Project Objective

This section of the report will give clarity on the project objectives, scope, and deliverables:

The objective of this project is to explore incorporating cost effective and safe automated or semi-automated welding technology solutions to:

- Reduce the current defect rate of 2% to improve quality and consistency in pipe welds.
- Increase fabshop productivity and efficiency to aid potential for future project bids.
- Decreasing reliance on manpower.
- Reduce the current set up time and cycle time.

1.2.1 Project Scope

The current manufacturing workflow for DMS is shown in Figure 2 with the focus for this project highlighted. Firstly, the materials are received, and a quality check is performed. Secondly, is the cutting and preparation of pipe spools, fittings, and other components. Thirdly, the materials then go through the first stage welding which involves circumference welding between pipes, joints, and fittings. Then the products undergo a second stage welding which involves inter-pipe connections and more complicated welding. Lastly, the finished products go through a final test and inspections to uncover any defected parts.

Figure 2: Current Process Workflow

The scope of this project is to focus on improving the 1st stage pipe welding (circumference welding) by incorporating automated or semi-automated technology to a certain degree. Improving all other stages are out of scope. Designing a custom robotic or autonomous system is also out of scope and possible solutions can be purchased from established vendors.

1.2.2 Deliverables

Included in the initial description, DMS Industrial has specified that the following deliverables listed are required upon completion of this project.

- Bill of Materials (BOM)
- Detailed Final Floor Plan
- Cost Summary
- Failure Mode and Effects Analysis (FMEA)
- Payback Analysis
- Supplier's Contact List

1.3 Client's Needs and Target Specification

To ensure we have a successful project completion, the team embarked on identifying the client's needs, demanding solutions, and verifying the target specification on those needs.

1.3.1 Client's Needs

The client needs were identified primarily from data collection. We gathered data through meeting with our client, observing and questioning the pipe fabrication process. The team interpreted the data to the client's needs. Lastly, we assigned a value of importance to each need, with #5 indicating a high importance down to #1 as the least important. In Table I below are the client's needs:

Table I: Client's Needs

#	NEEDS	Importance
1	Improve the efficiency of DMS pipe spool welding process	5
2	Capable of welding carbon and stainless-steel material [2]	5
3	Capable of welding a range of pipe diameter sizes [2]	5
4	Compatible with pipes of different length [2]	5
5	Compatible with varying wall thicknesses from SCHD 10- SCHD 80 [2]	5
6	Capable of welding pipe-pipe and pipe-fitting connections [2]	5
7	Design to be user-friendly	5
8	Design to have a fail-safe operation	5
9	Design fits within the provided space	5
10	Increase productivity, weld consistency and quality [2]	5
11	Streamline queue/management/workflow system [2]	4
12	Capable of cutting carbon and stainless-steel material [2]	3
13	Design does not exceed provided budget	3
14	Design provides a reasonable payback period [2]	3
15	Improve the efficiency of DMS pipe spool pre-fabrication process	1

After the team identified these needs, a review was held with our client to ensure the team captured all the needs. Approval was given by our client.

1.3.2 Target Specification

After identifying the client's needs, we developed a list of metrics to ensure the new design satisfies these needs. This list of metrics in Table II was generated based on our client's needs. Afterwards, we assigned a unit to each metric and a target value. The needs in Table I were used for linking the metrics, for the purpose of assigning an importance rating to each metric and identity the quantity of needs that matches each metric. Table II below reveals the outcome:

Table II: Client's Needs and Target Specifications

Metric #	Needs #	Metric	Imp	Units	Target Value
1	1,2,10-12,14,15	Process cycle time	5	in/hour	30" of welding/hr/person (GTAW) 45" of welding/hr/person (SMAW) 80" of welding/hr/person (MCAW/FCAW) [2]
2	4,9,11,14	Total floor area	3	ft^2	< 7680 [3]
3	2,5,12-14	Total cost	4	CAD$	< $1,000,000 [2]
4	1,6-7,10,14,15	Set-up programming	5	mins	< 15
5	6,7,10,14,15	Set-up welding time	4	mins	< 15
6	2,3,12,14	Pipe diameter sizes	5	in	2-12 [2]
7	4,9,14	Pipe length	5	ft	<50
8	2,5,12,14	Pipe thickness	3	SCHD	SCHD 10-80 [2]
9	7,8,14	Risk assessments	2	*List	Adheres to all safe work Manitoba risk assessment
10	7,8,10,14	Safe operations	3	*List	Adheres to Manitoba and company's health and safety policies
11	6,9,10,14,15	Welds different assemblies together	4	*List	Pipe to pipe & pipe to fitting (as client demanded only those) [2]
12	1,5,11,13-15	Payback time	5	years	2 to 5 years [2]

*List- List of requirements

The target specifications were reviewed by our client, verified, and approved. Refer to Appendix A on the outcome of these data used in making a House of Quality.

1.4 Constraints and Limitations

Listed below are the various factors that serve as constraints and limitations to our project:

- The duration of the project is 12 weeks long, with a deadline of December 9th, 2021 [1].
- The total budget including set-up cost, build cost, calibration cost, etc. should not exceed $1,000,000.00 [1].
- The new design must fit within DMS's fabshop area (7680 ft^2).
- The design must meet the safety codes and standards included in DMS rules and regulations.
- The design should be able to weld piping sizes ranging from 2" to 12" in diameter and up to 40ft in length [2].

- The new design should be compatible with varying wall thickness from SCHD 10 – SCHD 80 [2].

2. Concept Generation

After communication and site visits at DMS, our team was able to conclude there are 3 main components that would be part of the automation system. These three components working together would help DMS Industrial Constructors achieve their goal of higher productivity, consistency, and quality.

The first and most important component of the system would be the welding system itself. The welding system, updated and automated, would allow DMS to improve quality and consistency. The welding component would include the robotic welding arm system as well as the welding power source.

The second component of the system would be the turntable. This component is responsible for rotating the pipe components in combination with the robotic welding arm to weld the pipe continuously. One other purpose of the positioner is holding elbow connections to allow for accurate placement and welding onto pipes.

The third and last component of the system are the roller stands. The purpose of the roller stands is to allow alignment and easy rotation of long and multiple sections of pipe. These holders are critical as ensuring proper alignment of piping to ensure quality and consistency.

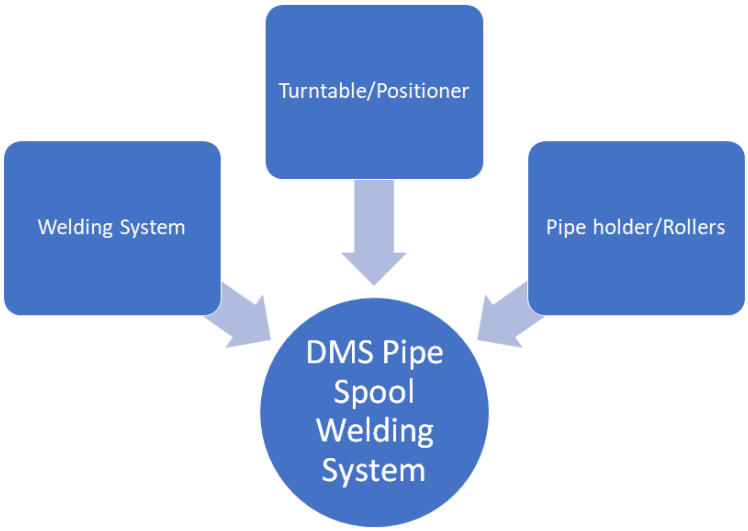


Figure 3: Welding System Breakdown Structure

2.1 Welding Device Concept Generation

According to the automated/semi-automated pipe spool welding discussion above, the welding device or welding robot has an important role in the whole system.

2.1.1 Spool Welding Robot (SWR) from Novarc Technologies

The first one is Spool Welding Robot from Novarc Technologies. Novarc welding robots is a semi-automated robot that has six-axis as shown in Figure 6. Therefore, the operators can easily control such as positioning the welding gun, start, stop, or change the welding motion, etc. This device is design for Human-Machine interface that is very useful for the operator during the welding process and ensure the consistent quality of the welding process.

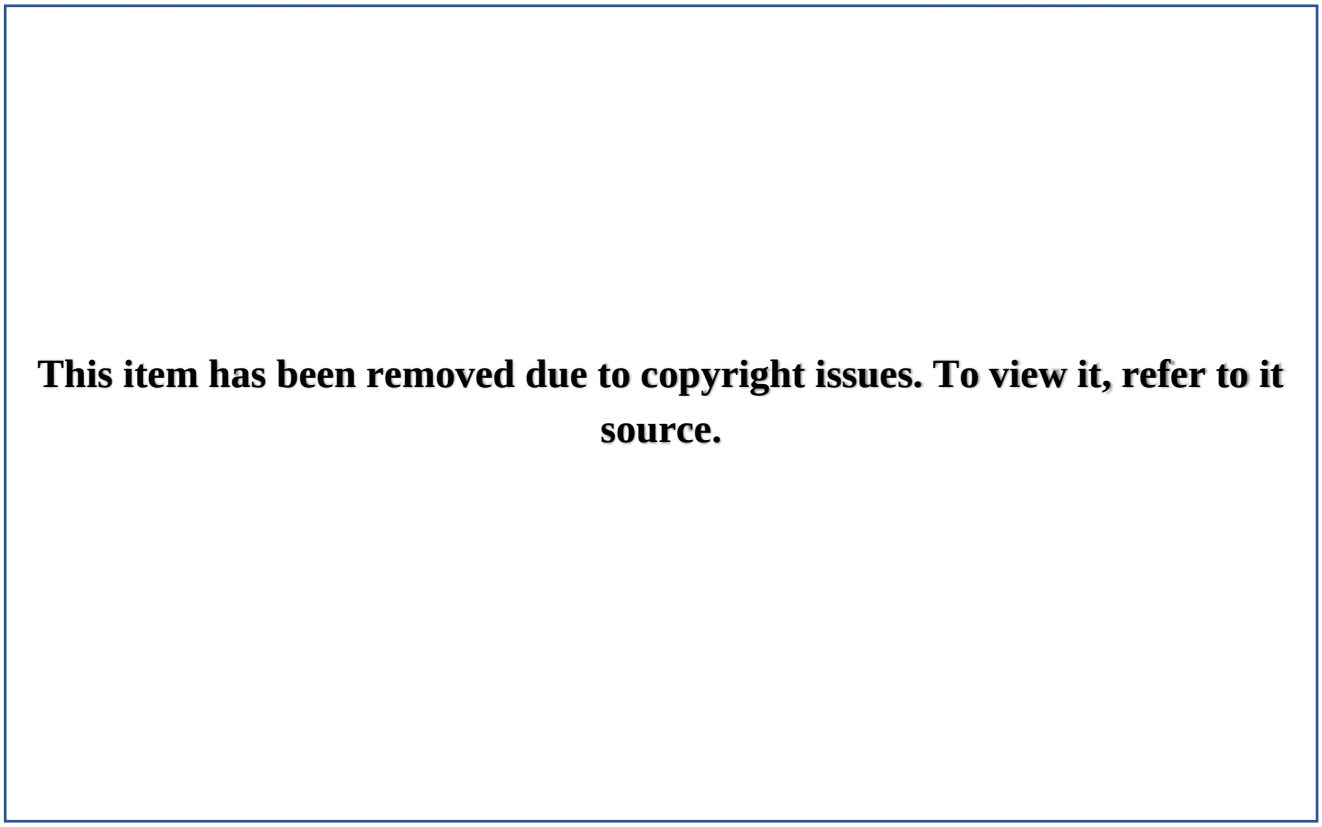


Figure 4: Overall SWR Design from Novarc Technology [4]

Additionally, this design has a high flexibly criteria in the layout mapping as shown in Figure 7. The Novarc robot can integrate with 2 to 5 turntables depending on the pipe spool dimensions, or facility layout. Due to the welding preparation time and setup time are typically higher than the welding time for small pipe dimension (less than 6”), the set-up layout of more than three turntables can give a huge benefit in term of productivity. This is instrumentation allows for both welding and cut & prep to be done at the same time.

Figure 5: Novarc Spool Welding Robot's Sample Layout [4]

Novarc robot has some advanced technologies such as Welding Vision System as shown in Figure 8. It has a camera to record the welding motion during the welding operation. Using this system, the operators can easily keep track of the welding process and settings ensuring the quality of the welds.

Figure 6: Novarc Welding Robot's Advanced Technologies [4]

In conclusion, Novarc welding robot can satisfy almost key design requirement such as pipe's diameter (2'' to 12''), pipe's material (Carbon, Stainless Steel), pipe's thickness (SCHD:10 -80). The detailed specifications and evaluation are discussed in Table E-I Appendix E and the weighted decision matrix.

2.1.2 Welding Manipulators from LJ Welding Automation

The other welding robots' concept is the Welding Manipulators from LJ Welding Automation. LJ Welding automation is a well-known company in the pipe spool welding industry. Currently, DMS has owned two turntables, and several pipe rollers stands from LJ Welding as mentioned in Section 2. LJ Welding robot is designed based on the Gantry robot configuration. The robot also provides some similar Novarc's feature such as the operational user-friendliness, camera system, welding operation tracking system. Figure 9 shows some keys feature from LJ welding robot.

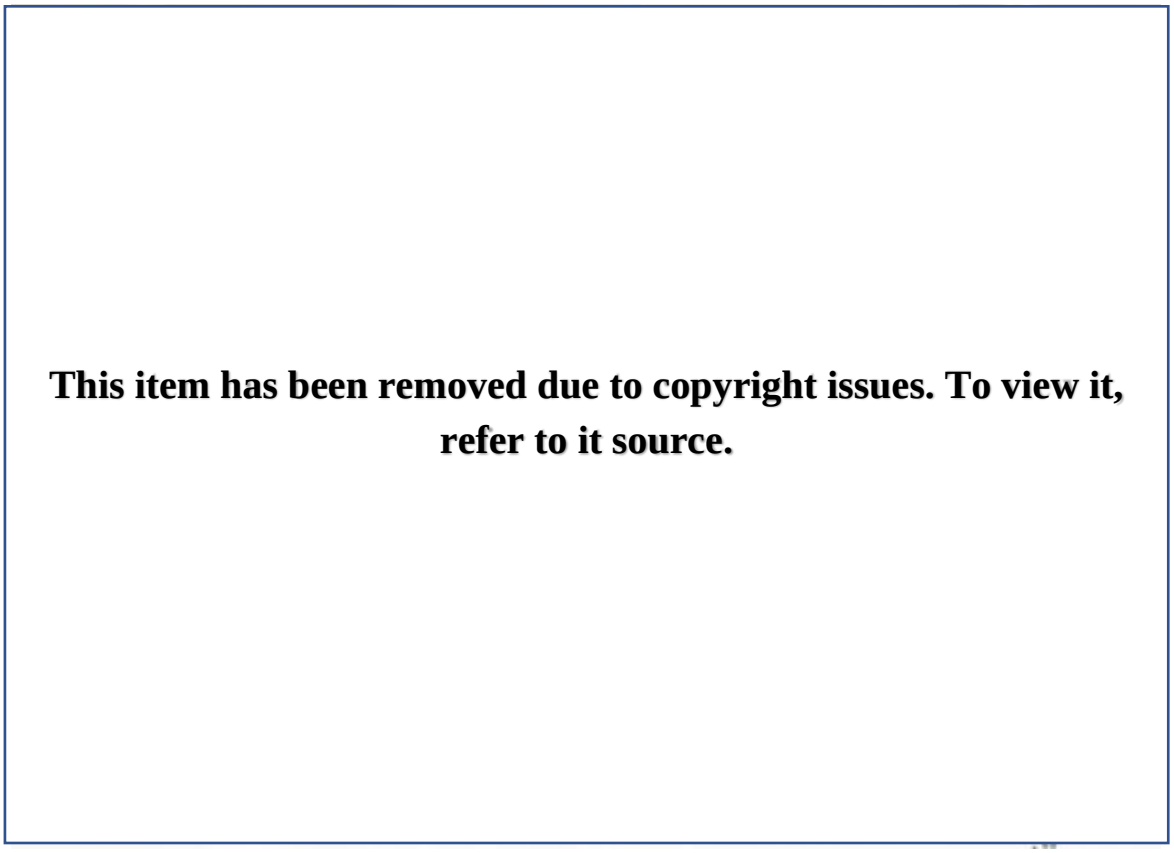


Figure 7: LJ Welding's Manipulation and Gantry Robot Option [5]

Overall, LJ Welding robots has also satisfied some design requirement such as pipe material (Carbon, Stainless Steel), pipe thickness (SCHD:10 -80), pipe length (up to 40ft). Besides, it also has some disadvantages such as not suitable for small pipe diameter (less than 16"), less flexibility, high floor area and required special turntable and pipe roller stand. The detailed specifications and evaluation of this design will be provided in Table E-II Appendix E and the weighted decision matrix table. Figure 10 shows a sample system of LJ automated welding system.

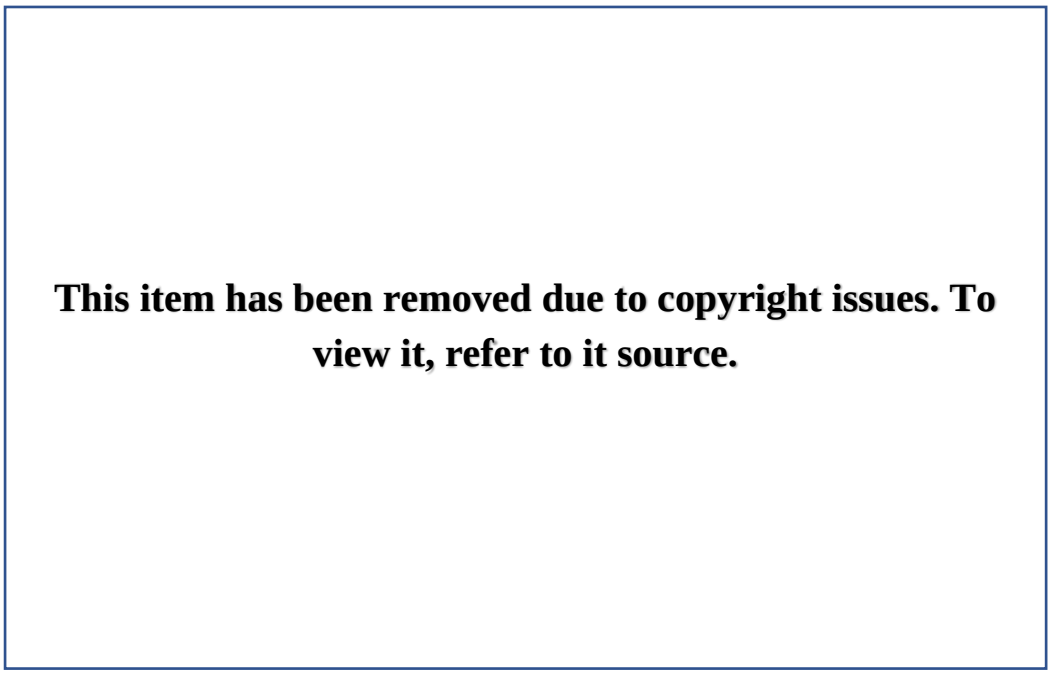


Figure 8: LJ Welding Robot Sample Layout [6]

2.1.3 Orbital Welder from Lincoln Electric

The third concept design is Orbital Welder from Lincoln Electric. This welding system design is totally different than the two robots from Novarc and LJ Welding. Lincoln welding robot does not require a turntable during a welding process. It includes the weld head and track ring as shown in Figure 11 below. During the welding operation, the tracking ring will be installed around the circumference of the pipe, then the weld head will move around the tracking ring to weld between 2 pipe sections.

Figure 9: Weld head (left) and Tracking Ring (right) from Orbital Welder [7]

Besides the weld head and tracking ring, the setup of Lincoln welding device required a special pipe support stand as well as a welding controller. Overall, the Lincoln welding meets almost

design key requirement such as pipe's material (Carbon, Stainless Steel), pipe's thickness (SCHD:10 -80), pipe's length (up to 40ft), small floor area, easy-for-use. But it has some disadvantages such as this device requires different tracking ring for different pipe diameter or high setup and preparing time. The more detail in Lincoln welding device specifications and evaluation will be provided in Table E-III Appendix E and welding weighted decision matrix section.

Figure 10: Overall Set-up of Orbital Welder [7]

2.1.4 RotoWeld from Tecnar

The last concept design introduced in this report is RotoWeld from Tecnar. Different than the previous concepts above, Tecnar welding system is a fully automated system. It can achieve a very high welding quality, low rework rate and high welding productivity [8]. Figure 13 shows the overall Tecnar welding system.

Figure 11: Tecnar's Fully Automated Pipe Spool Welding System [8]

Although, the Tecnar welding system is similar to the LJ welding concept, Tecnar does not use a gantry configuration robot but uses a 6-axis rotation design like the Novarc welding robot. Since the system is fully automated, it requires special turntables and pipe roller stands from the same manufacturer.

In summary, Tecnar welding system satisfies most of the requirements such as pipe diameter, pipe thickness, length, and material. But some downside of this system includes high programing and training time and large floor area. The detailed specifications and evaluation are discussed in Table E-IV Appendix E and the weighted decision matrix.

2.2 Welding Device Concept Analysis

From generating the concepts, the team applied the use of a weighted decision matrix to analysis each concept and select the optimum one. This sub-section works through how this analysis was done.

2.2.1 Welding Weighted Decision Matrix

The welding weighted decision matrix is constructed based on the customer needs and target specification. The decision matrix includes 4 subgroups, 14 criteria that ranked from the highest weight to the lowest weight. Below is the definition of the criteria:

Pipe spool diameter (2”-12”): the welding devices/systems are evaluated based on their ability to weld pipe spool diameter (2”-12”). Which links to need #3, measured by metric #6.

Pipe thickness (SCHD 10-80): the welding devices/systems are evaluated based on their ability to weld pipe thickness (SCHD 10-80). Which links to need #2,5,12,14, measured by metric #8.

Material (Carbon and Stainless Steel): the welding devices/systems are evaluated based on their ability to weld carbon and stainless-steel pipe. Which links to need #2.

Pipe length (up to 40ft): the welding devices/systems are evaluated based on their ability to weld a pipe length up to 40ft. which links to need #4,9,14, measured by metric #7.

Set-up time: the welding devices/systems are evaluated based on their set up time (less time is better). Which links to needs #1, 10,11 and 14, measured by metrics #5 and 12

Programming time: the welding devices/systems are evaluated based on their programming time (less time is better). Which links to needs #1, 6, 7, 10, 14, 15 measured by metrics 4.

Welding time: the welding devices/systems are evaluated based on their welding time (less time is better). Which links to needs # 6, 7, 10, 14, 15 measured by metrics 5.

Safety: the welding devices/systems must comply with CSA. Which links to needs # 7, 8,10, 14, measured by metrics #10.

Maintenance: the welding devices/ system are reliable and easy to maintain. Which links to needs #7 and 8, measured by metrics #9 and 10.

Configuration: capability of being customized to meet the client's needs. Which links to needs # 4, 9, 11, 14, measured by metrics #2.

Budget: Cost of the devices/systems. Which links to need #13, measured by metric #12.

Easy-of-access: the devices/systems is evaluated based on ease of loading of pipes. Which links to need #1, 2, 12, 14, measured by metric #1.

Quality: In quality perspective, the criterion mainly focuses on the defect rate of welding process (the lower defect rate is better). Which links to need #6, 9, 10, 14, 15, measured by metric #11.

Footprint/ Floor area: The amount of space required for installing the devices/systems. Which links to needs #9, 11 and 15, measured by metrics #2, 5 and 12.

To evaluate the importance and weight of each criterion, the criteria weighting matrix was constructed. This method is comparing each criterion to each other after that calculating each corresponding weight as shown in Table III.

Table III: Welding Robot Criteria Weighting Matrix

Criteria	**(A) Pipe spool diameter (2"-12")**	**(B) Pipe thickness (SCHD 10-80)**	**(C)Material (Carbon and Stainless Steel)**	**(D) Pipe length (up to 40ft)**	**(E) Set up time**	**(F) Programing time**	**(G) Welding time**	**(H) Safety**	**(I) Maintenance**	**(J) Configuration**	**(K) Budget**	**(L) Easy-of-access**	**(M) Quality**	**(N) Footprint/ Floor area**	
(A) Pipe spool diameter (2"-12")		A	A	D	A	A	A	A	A	A	A	A	A	A	
(B) Pipe thickness (SCHD 10-80)			B	D	B	B	B	B	B	B	B	B	B	B	
(C)Material (Carbon and Stainless Steel)				C	C	C	C	C	C	C	C	C	C	C	
(D) Pipe length (up to 40ft)					D	D	D	H	D	D	D	D	D	D	
(E) Set up time						E	G	H	E	E	E	E	E	E	
(F) Programing time							G	H	F	F	F	F	F	F	
(G) Welding time								H	G	G	G	G	G	G	
(H) Safety									H	H	H	H	H	H	
(I) Maintenance										I	I	L	I	I	
(J) Configuration											K	L	J	J	
(K) Budget												K	M	K	
(L) Easy-of-access													M	N	
(M) Quality														M	
(N) Footprint/ Floor area															
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	
Total Hits	12	11	11	11	7	6	8	10	4	2	3	2	3	1	**91**
Weightings	13	12	12	12	8	7	9	11	4	2	3	2	3	1	**100**

The resulting weights were rounded-up to the nearest integer number and reflected on Table IV.

Table IV: Welding Weights

Criteria	Weight
Pipe spool diameter (2”-12”)	13
Pipe thickness (SCHD 10-80)	12
Material (Carbon and Stainless Steel)	12
Pipe length (up to 40ft)	12
Safety	11
Welding time	9
Set up time	8
Programming time	7
Maintenance	4
Budget	3
Quality	3
Configuration	2
Easy-of-access	2
Footprint/ Floor area	2

	1st most important
	2nd most important
	3rd most important
	4th most important

2.2.2 Concept Evaluation

In this section, each of the concepts is evaluated under 14 criteria that are mentioned in Table IV. The grade is given from the highest 10 to the lowest 1 for each criterion related to each concept. To avoid bias, the rating scale for each criterion is constructed as shown in Appendix B.

The rating result for each concept is shows in Appendix E (welding robot rating result). After recording the grade from the 4-design concept, the total score for each design concept is calculated by multiplying the weight of each criterion with its respective grade. Table V below shows the overall result of 4 design concept. Based on Table V, Novarc welding robot has the highest score (942) and it will be chosen to continue investigation in a final design report.

Table V: Welding Weighted Decision Matrix

		Concepts							
		I		II		III		IV	
		Novarc		LJ welding		Lincoln welding		Tecnar	
Criteria	Weight	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Pipe spool diameter (2”-12”)	10	10	100	2	20	9	90	8	80
Pipe thickness (SCHD 10-80)	10	8	80	8	80	8	80	8	80
Material (Carbon and Stainless Steel)	10	10	100	9	90	9	90	9	90
Pipe length (up to 40ft)	10	8	80	9	90	10	100	9	90
Set up time	7.5	10	75	8	60	2	15	2	15
Programing time	7.5	10	75	9	67.5	8	60	5	37.5
Welding time	7.5	10	75	10	75	10	75	10	75
Safety	7.5	10	75	8	60	7	52.5	9	67.5
Maintenance	6	10	60	9	54	9	54	5	30
Configuration	6	8	48	8	48	8	48	8	48
Budget	6	9	54	8	48	10	60	7	42
Easy-of-access	4	10	40	9	36	8	32	5	20
Quality	4	10	40	8	32	8	32	10	40
Footprint/ Floor area	4	10	40	5	20	8	32	5	20
Total			942		780.5		820.5		735
Rank		1		3		2		4	
Continue?		Yes		No		No		No	

Concept I: Novarc welding robot (Selected)

This concept ranked 1st and will be selected. Although this concept requires a special layout set up to meet the 40ft pipe length welding. It is still feasible for our application, and it works well with the specified pipe diameter ranges, pipe thickness and pipe material. The smallest footprint and low setup and programing time gave it an edge over the other concepts.

2.3 Turntable

Turntables are useful for welding pipe spool, this helps assist the welder in automatically rotating and locating the pipe for welding, thus improving key factors like ergonomics. For the welder will have a comfortable position for operation.

2.3.1 Turntable Overview

Currently at DMS, there are two big turntables manufactured by LJ welding, for welding a minimum of 4” pipe outer diameter size. This has not been able to fully meet the need of our client’s target value for welding pipe outer diameter sizes ranging from 2” to 12” seen in Table II. Therefore, it is imperative to have a turntable compatible with a minimum of 2” to 4” outer diameter sizes.

2.3.2 Concepts

The team searched for products that are compatible with smaller outer diameter sizes. Each concept is explained below:

Concept I: Vevor 55lbs Rotatory Table

This turntable is design for welding operation. The structure is tiltable, allowing operation to be done between 0 to 90^{o} and transportable to various location on the production floor and if desired it can be mounted onto a working table [9]. Below is a list of interested specifications [9], that will be factored in our weighted decision matrix:

- Load capacity of 110.2lbs / 44.1lbs
- Tiltable between 0 to 90^{o}
- Footprint of 1.5ft^{2}
- Compatible with 2” to 6” pipe outer diameter sizes
- Rotation speed: 0.5 to 5 rev/min

Figure 12: Vevor 55lbs Rotatory Table [9]

Concept II: LJ Welding 12p-900

The LJ welding 12p-900 allows for different size elbow jigs to be installed [10]. This allows for 90^{O} bend pipe to be positioned for welding a straight pipe. Most importantly, a 3-jaw chuck can be installed for rotating a straight pipe for welding [10]. Below are the interested specifications [10], that will be factored in our weighted decision matrix:

- Load capacity: 1,000 lbs
- Footprint of $3.51ft^2$.
- Compatible with 2” to 12” pipe outer diameter sizes.
- Rotation speed: 0.5 to 5 RPM.
- Grounding Capacity: 800 Amps.
- Turntable mass: 280 lbs.
- Elbow jigs/ 3 jaw 12” chuck can be mounted.
- Transportable.

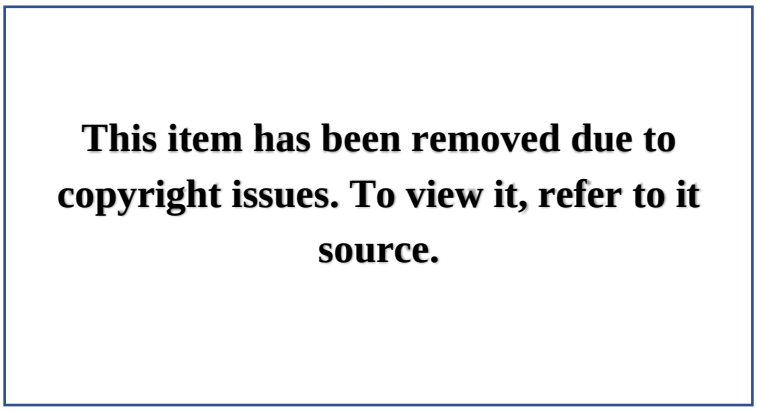


Figure 13:LJ welding 12p-900 Portable Turntable [10]

Concept III: LJ Welding 16p-700

The LJ welding 16p-700 can operate with heavy pipes, with a load capacity of 3000 lbs [11]. This is also transportable like the rest and below are the interested specifications, that will be factored in our weighted decision matrix:

- Load capacity: 3000 lbs.
- Footprint of $21ft^2$.
- Compatible with 2” to 6” pipe outer diameter sizes.
- Rotation speed: 0.3 to 3.0 RPM.
- Grounding Capacity: 400 Amps.
- Turntable mass: 1,820 lbs. (excluding gripper)
- Transportable.

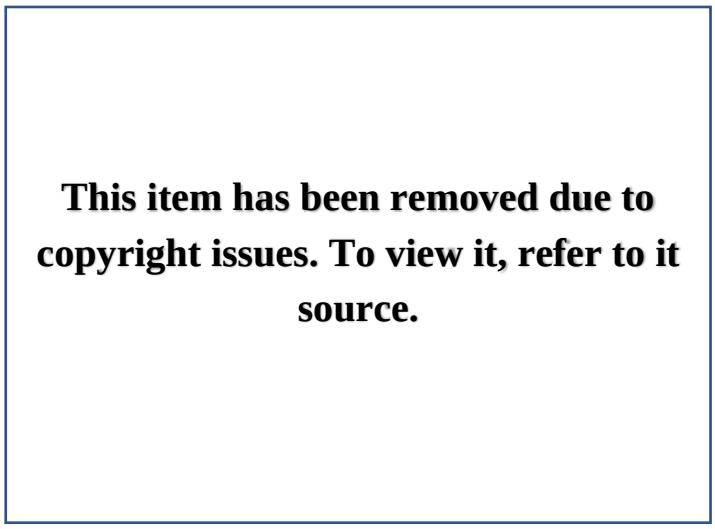


Figure 14:LJ Welding 16p-700 Turntable [11]

Concept IV: Arc-Zone A-PT-051 Pro Positioner

The Arc-Zone A-PT-051 Pro Positioner is a heavy-duty performance machine, that comes with center purging capabilities [12]. Below is the interested specification, that will be factored in our weighted decision matrix s:

- Load vertical capacity: 110 lbs.
- Load horizontal capacity: 66 lbs.
- Footprint of 0.83 ft^2
- Tilt ranges from 0 to 90^o
- Compatible with 2” to 6” pipe outer diameter sizes
- Rotation speed: 0.4 to 10 RPM
- Grounding Capacity: 200 Amps
- Turntable mass: 22 lbs.
- Transportable

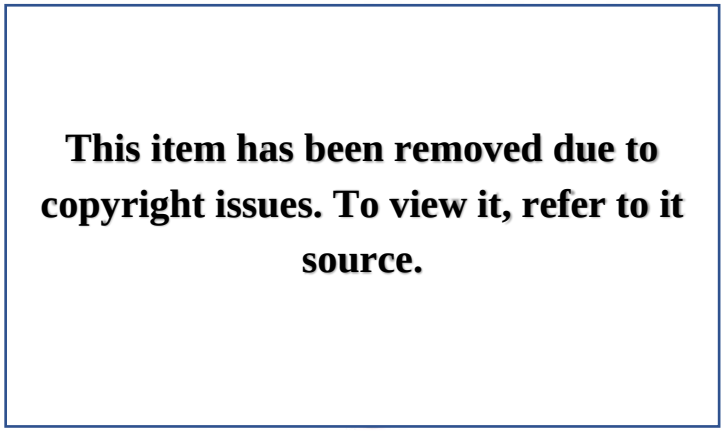


Figure 15:Arc-Zone-A-PT-051 Pro Positioner [12]

2.4 Turntable Concept Analysis

The team analyzed the concepts that offers the optimal solution for our client needs. A useful tool applied here was a weighted decision matrix for evaluating the concepts together and determine which concept ranked the highest.

2.4.2 Definition of Criterion

Capability with SWR: The turntable to collaborate with the welding robot welding speed and produce good quality welds. Which links to needs #1, 2, 3, 7, 8, 10, 11, measured by metrics #4, 5, 9 and 10.

Weight capacity: How much weight the turntable can operate with. Which links to need #8 measured by metric #10.

2" to 6" outer diameter size range: The turntable is compatible with pipe outer diameter sizes from 2” to 6”. Which links to need #3, measured by metric #6.

Adapters: If the turntable allows for installment of different adapters like a 90^{o} elbow, to position a 90^{o} bent pipe to be welded onto a straight pipe. Which links to needs #3, 6, 7 and 10, measured by metrics #5 and 11.

Set-up time: How much time it takes to install a pipe into the turntable and be ready for operation. Which links to needs #1, 10,11 and 14, measured by metrics #5 and 12

Safety: The level of safety provided by for operating the turntable. Which links to need #8, measured by #10.

Mobility/footprint: How much space the turntable will occupy on the provided space. Which links to needs #9, 11 and 15, measured by metrics #2, 5 and 12.

Maintenance: The level of skill needed for maintaining the turntable. Which links to needs #7 and 8, measured by metrics #9 and 10.

Budget: How much the turntable will cost. Which links to need #13, measured by metric #12.

2.4.1 Turntable Weighting Criteria

Based on the identified client’s needs, metrics and research done by the team, the selection for the optimal turntable consists of nine criteria. The team compared each criterion to each other and calculated the corresponding weights based on Table VI:

Table VI: Turntable Weighting Criteria Matrix

Criteria	(A) Capability with SWR	(B) Weight Capacity	(C) 2" to 6" outer diameter size range	(D) Adapters	(E) Set up time	(F) Safety	(G) Mobility/footprint	(H) Maintenance	(I) Budget	
(A) Capability with SWR		B	A	A	A	F	A	A	A	
(B) Weight Capacity			B	B	B	F	B	B	B	
(C) 2" to 6" outer diameter size range				C	C	F	C	C	C	
(D) Adapters					E	F	D	H	I	
(E) Set up time						F	E	E	E	
(F) Safety							F	F	F	
(G) Mobility/footprint								H	G	
(H) Maintenance									H	
(I) Budget										
	A	B	C	D	E	F	G	H	I	
Total Hits	6	7	5	1	4	8	1	3	1	**36**
Weightings	17	19	14	3	11	22	3	8	3	**100**

2.4.3 Concept Ratings

The team held a meeting and decided a rating between “1” to “10”, with “1” being the lowest and “10” as the highest. This scale is compared to a rating scale explained in Appendix C to produce an object analysis. This was done for each criterion on a given concept based on the provided information on the product. The outcome is seen in Appendix F.

A weighted decision matrix in Table VII is the overall result. The result produced by the weighted decision matrix is calculated by multiplying the rating to the weighted score and do a total summation for each concept. The highest score is the LJ Welding 12P-900, with a total score of 942.

Table VII: Turntable Weighted Decision Matrix

		Concepts							
		I		II		III		IV	
		Vevor 55lbs rotatory table		LJ welding 12p-900		LJ welding 16p-700		Arc-Zone A-PT-051 Pro Positioner	
Criteria	**Weight**	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Capability with SWR	17	10	167	10	167	10	167	10	167
Weight Capacity	19	2	39	10	194	10	194	1	19
2" to 6" outer diameter size range	14	10	139	10	139	10	139	10	139
Adapters	3	5	14	10	28	10	28	2	6
Set up time	11	10	111	8	89	5	56	10	111
Safety	22	2	44	10	222	10	222	5	111
Mobility/footprint	3	10	28	8	22	2	6	10	28
Maintenance	8	8	67	8	67	8	67	8	67
Budget	3	10	28	5	14	4	11	10	28
Total score		636		942		889		675	
Rank		4		1		2		3	
Continue?		No		Yes		No		No	

Concept II: LJ Welding 12p-900 (Selected)

This concept ranked 1st and selected. This concept has a high rating with the 1st most important criteria and DMS is familiar with LJ welding turntable, as they have a larger LJ welding turntable making it easy for the operators to adjust to. Also, the fact that we confirmed from Novarc that the SWR is compatible with LJ turntables.

2.5 Roller Stands Final Selection

This section discusses the selection of a roller stand that will work with previously selected welding system and turntables. The primary function of the roller stand is to provide support to the pipe spool at a comfortable height to ensure harmony between the welding system and turntables. The selected roller stand should also be easy to use and cost effective while maintaining a minimal footprint on the shop floor area and adhering to the safety standards. Listed below are the 3 possible initial concept solutions resulting from our research.

2.5.1 Concepts

Concept I: LJ Welding - HD2-300U

The HD2-300 roller support stand by LJ welding is designed to provide optimal solutions to welding applications, reduce strain on operators and increase productivity. It utilizes urethane rollers to prevent scarring of pipe spools and minimize drag. It has quick vertical height adjustments which ensures a low set-up time. Listed below are other specifications for this product [15]:

- Load Capacity: 4000lbs
- Diameter Range: 2”-48”
- Height Range: 39”-63”
- Footprint (Length x Width x Height): 34” x 31” x 40”
- Weight: 165lbs

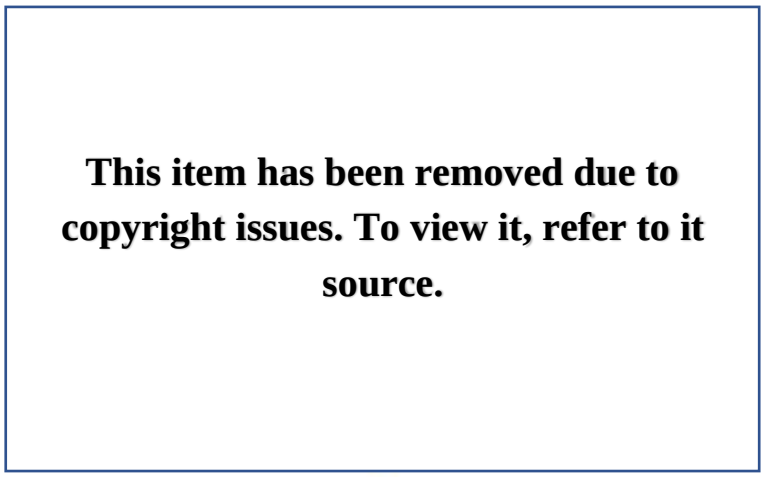


Figure 16: LJ Welding HD2-300U Roller Stand [13]

Concept II: Pro roll Stand

The Pro Roll Stand is a rigid design with stainless steel wheels with roller adjustments on both sides. It includes interesting features such as brakes to lock load for a set lay-out. Listed below are other specifications for this product [17]:

- Load Capacity: 2000lbs
- Diameter Range: 0.5” – 36”
- Height Range: 29”-43”

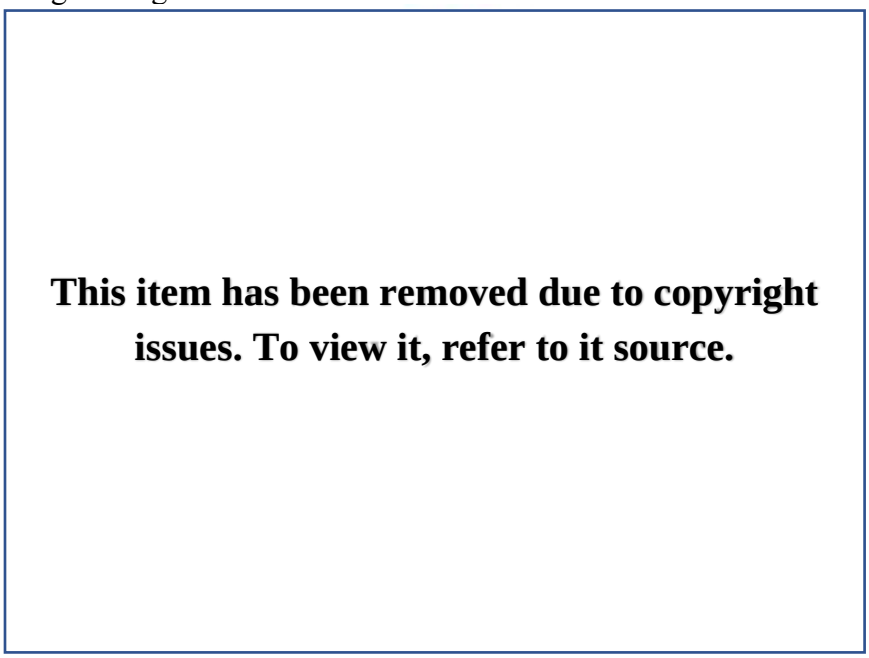


Figure 17: Pro roll Stand [14]

Concept III: LJ Welding SHD-850 8000LB

The SHD-850 roller support stand by LJ welding is designed to have geared height adjustability which allows for smooth transitions even when the pipe support is under a load. This allows for less human error and allows operators to easily raise and lower the pipe spool to the same as other equipment. Listed below are other specifications for this product [16]:

- Load Capacity: 8000lbs
- Diameter Range: 4”-48”
- Height Range: 30”-42”
- Footprint (Length x Width x Height): 36”x50”x29”-42”
- Weight: 450lbs

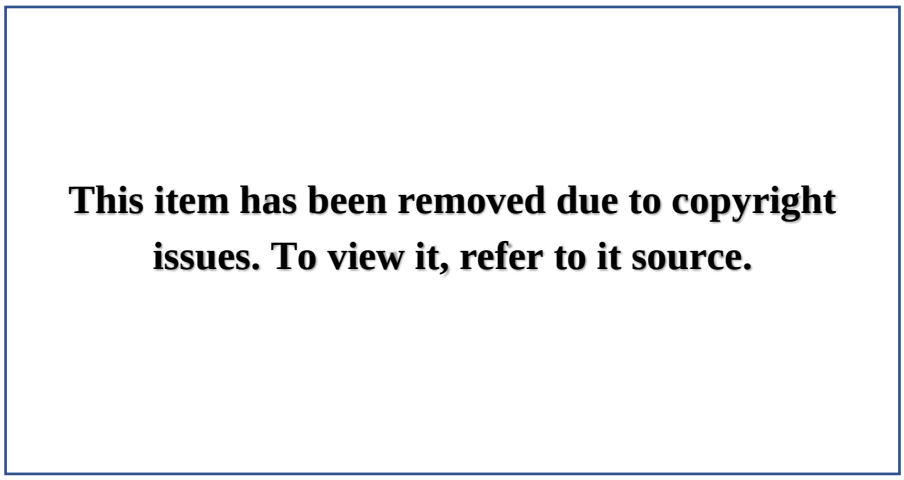


Figure 18: LJ Welding SHD-850 Roller Stand [15]

2.6 Roller Stands Concept Analysis

The different concepts generated for the roller stands were compared by using a weighted decision matrix and a final solution was selected.

2.6.1 Definition of Criterion

2"-12" outer diameter range: This criterion is used to check how the stands can be adjusted to fit the variability in pipe spool diameters.

Weight capacity: How much load the roller stands can operate support.

Compatibility: This checks how compatible the selected stands will be able to function with the welding system and turntables. This focuses more on the design of the stands and how it's features will not hinder the functions of the other system.

Safety: The selected system is expected to agree with the existing safety standards of the clients and related governing bodies. This criterion checks to make sure the stands do not violate any safety codes.

Footprint (Floor Area): This criterion compares the total area of the fabshop the stands will cover.

Ease of use: This looks at how the easy it is to understand and utilize the stands. The goal is to select a concept that the fabshop employees are comfortable using.

Set up time: As explained in the objectives for this project, reducing the overall equipment set up time is vital. Therefore, this criterion scores how quickly the equipment can be set up whenever it is needed.

Maintenance: The criterion looks at how easy and feasible it is to perform routine checks and maintenance on the stands.

Budget: This criterion factors on the market price for the concepts and how it aligns with the current budget of the clients.

2.6.2 Roller Stand Weighting Criteria

After consulting the client's needs and specifications, the following Criteria were assigned a weight score. The table below shows the criteria and their assigned weight.

Table VIII: Roller Stand Weighting Criteria Matrix

Criteria	(A) 2"-12" outer diameter range	(B) Weight capacity	(C) Compatibility	(D) Safety	(E) Footprint (floor area)	(F) Ease of use	(G) Set up time	(H) Maintenance	(I) Budget	
(A) 2"-12" outer diameter range		B	C	D	A	A	A	A	A	
(B) Weight capacity			B	D	B	B	B	B	B	
(C) Compatibility				D	C	C	C	H	C	
(D) Safety					D	D	D	D	D	
(E) Footprint (floor area)						E	G	H	I	
(F) Ease of use							F	H	F	
(G) Set up time								G	G	
(H) Maintenance									H	
(I) Budget										
	A	B	C	D	E	F	G	H	I	
Total Hits	5	7	5	8	1	2	3	4	1	36
Weightings	14	19	14	22	3	6	8	11	3	100

2.6.3 Concept Evaluation

Table below shows the weighted decision matrix used in selecting a final concept for the roller stands support system.

Table IX: Roller Stand Weighted Decision Matrix

		Concepts					
		I		II		III	
		LJ welding- HD2-300U		Pro roll Stand		LJ welding- SHD-850	
Criteria	Weight	Rating	Score	Rating	Score	Rating	Score
2"-12"	14	10	140	10	140	8	112
Weight capacity	19	10	190	8	152	10	190
Compatibility	14	10	140	7	98	8	112
Safety	22	8	176	7	154	8	176
Footprint (floor area)	3	9	27	10	30	7	21
Ease of use	6	9	54	9	54	7	42
Set up time	8	9	72	9	72	10	80
Maintenance	11	10	110	9	99	8	88
Budget	3	8	24	10	30	7	21
Total Score		933		829		842	
Rank		1		3		2	
Continue?		Yes		No		No	

Concept I: LJ Welding HD2-300U (Selected)

This concept ranked 1st and will be selected. Although this concept does not have the highest weight capacity, it is still feasible for our application, and it works well with the specified pipe diameter ranges. The moderate footprint and ease of maintenance gave it an edge over the other concepts.

3. Final Design Details

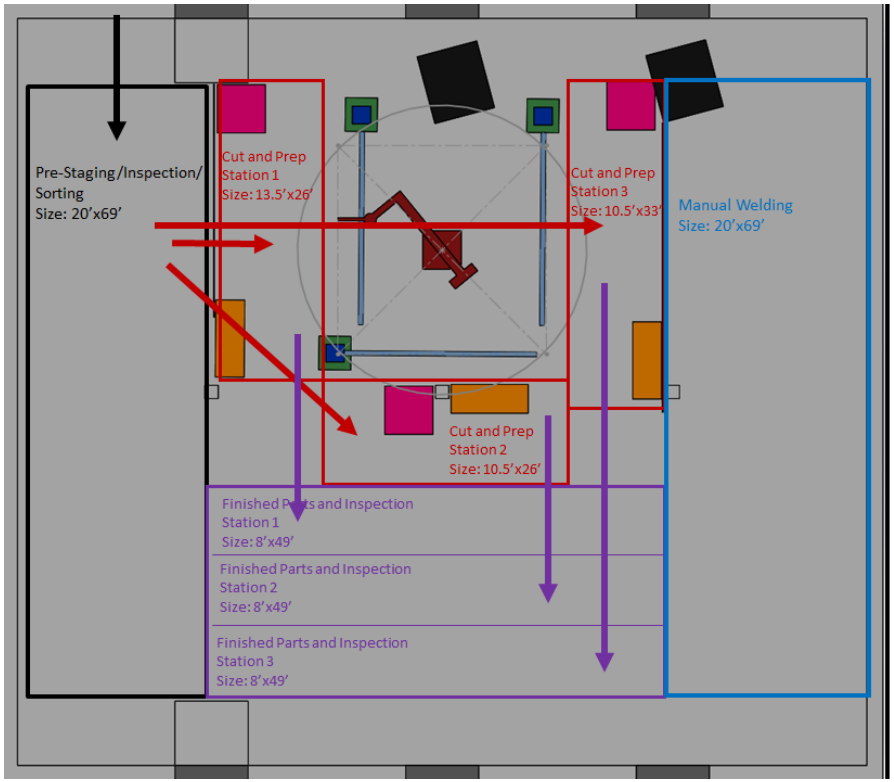
This section includes the detail floor plan design for the new system, Failure Mode Effect and Analysis (FMEA), Bill of Material (BOM)/cost summary, payback analysis and Novarc features/safety features.

3.1 Floor Plan

The system that we have chosen, Novarc, is a small footprint welding automation system that is able to integrate with multiple turntables. This allows the Novarc system to be integrated anywhere in the shop to allow the highest amount of arc-on time, welding time.

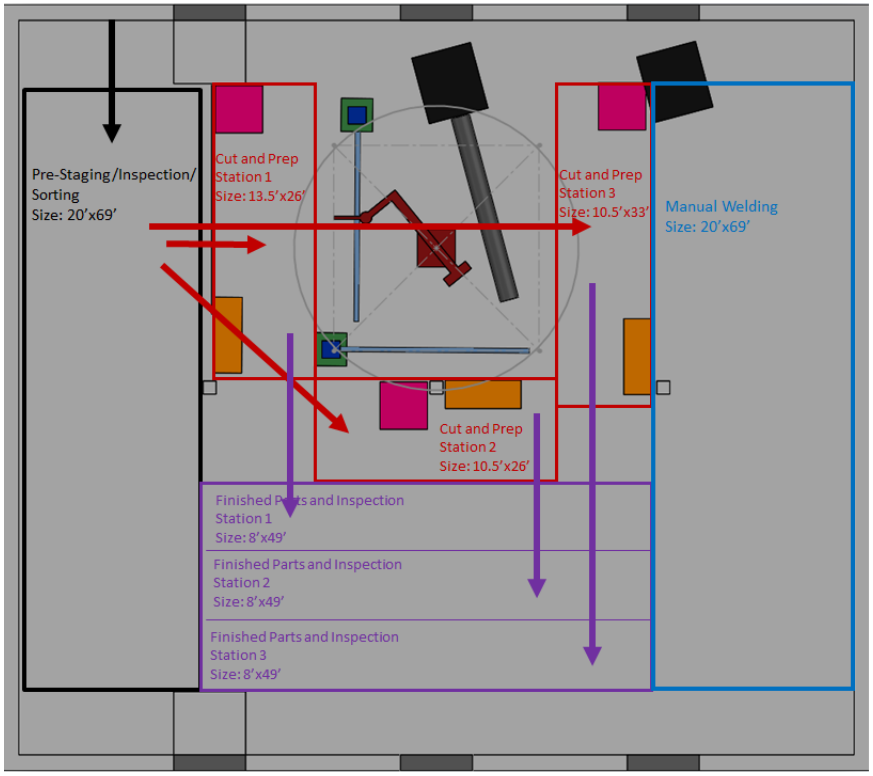
The layout possibilities for DMS are widely variable and dependent on the type of welding work they will be working on. The equipment that was chosen for our welding system are flexible and on wheels allowing for quick modifications of the layout to allow maximum adjustability. DMS creates custom pipe spool that are all unique, making flexibility a necessity.

Our team came up with 4 possible layouts that would meet all the requirements DMS has set forth. Switching between layouts would only take several minutes and would depend on the fabrication needs. Below are only 4 of the infinite possible layouts:



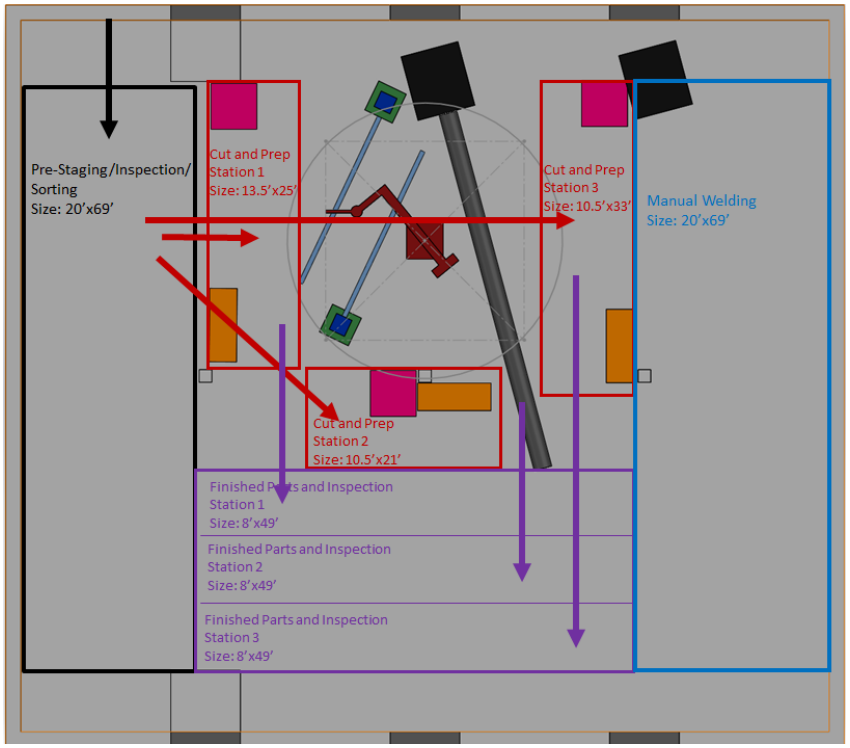
Configuration of Layout 1:

- 3 Turntables 2-12" diameter
- 24 feet length capacity
- 3 cut and prep zones ones
- 3 Finished product and Inspection Zones
- Pre-Staging/Inspection/Sorting zone
- Utilizes existing worktables
- Large manual welding zone



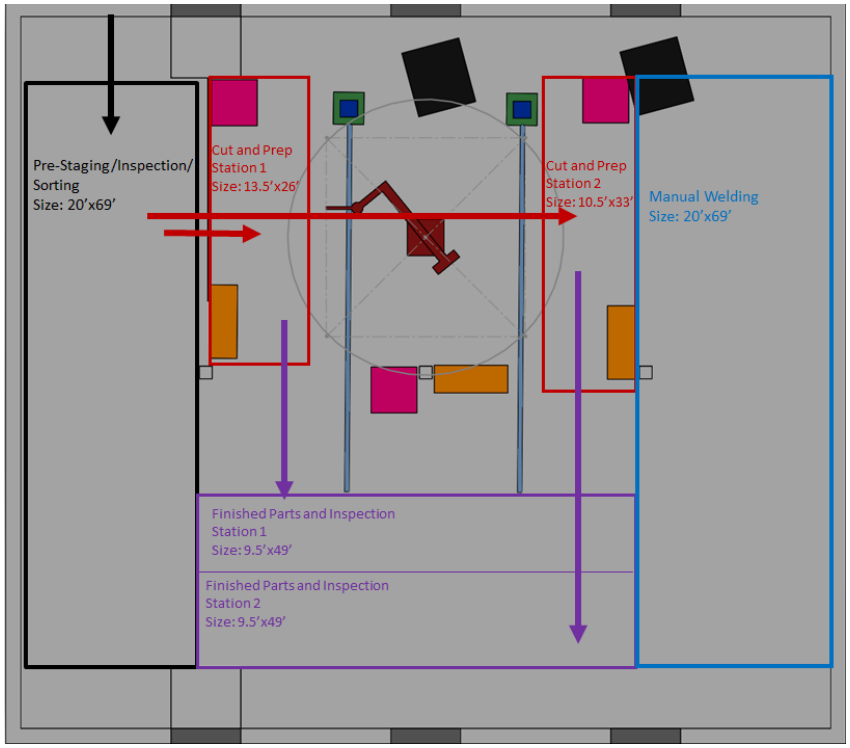
Configuration of Layout 2:

- 2 Turntables 2-12" diameter
- 1 Turntable 4" + diameter
- 24 feet length capacity
- 3 cut and prep zones
- 3 Finished product and Inspection Zones
- Pre-Staging/Inspection/Sorting zone
- Utilizes existing worktables
- Large manual welding zone



Configuration of Layout 3:

- 2 Turntables 2-12" diameter
- 1 Turntable 4" + diameter
- Qty 2: 24 feet length capacity
- Qty 1: 40 feet length capacity
- 3 cut and prep zones
- 3 Finished product and Inspection Zones
- Pre-Staging/Inspection/Sorting zone
- Utilizes existing worktables
- Large manual welding zone



Configuration of Layout 4:

- 2 Turntables 2-12" diameter
- 40 feet length capacity
- 2 cut and prep zones
- 2 Finished product and Inspection Zones
- Pre-Staging/Inspection/Sorting zone
- Utilizes existing worktables
- Large manual welding zone

The flow of material through the manufacturing area was thought of to ensure an efficient but fully traceable system. Material would arrive at the pre-staging/inspection/sorting area where it would be inspected to ensure quality material has arrived and sorted depending on what cut and prep station it would move to next. This allows for a common area where all material arrives and gets sorted/inspected preventing any misplaced material, wrong material and out of spec material.

After it has been inspected and sorted it would arrive to its assigned cut and prep station. There are three cut and prep stations, in layout 1, as this was found to be the bottle neck in the Novarc welding system. Three separate zones separated fully allow for minimal possibility of cross contamination of pipe spool parts between zones. This also declutters the pipe fitters working area to only his parts allowing for higher efficiency and lower defect rate.

These three separate cut and prep zones feed the three separate turntables to ensure only the correct parts arrive and get welded on each pipe spool. Three separate turntables allow for more orders at a time and increases the maximum arc on time, welding time. This allows the pipe fitters to be able to set up pipe spools during welding operation.

After the parts are complete and finished, they would arrive in their own dedicated finished parts and inspection area. This prevents any pipes getting missed placed in the manufacturing area ensuring less rework is needed for misplaced parts. It also gives DMS a fast way to check quality of each turntable zone ensuring that there is higher traceability in the system.

A large manual welding area was left with a large turntable for custom work that the Novarc system might not be able to do or for future expansion with another Novarc system. These zones form a conveyor style of manufacturing flow through the area to allow greater efficiency, throughput, and traceability.

A detailed engineering drawing of the location of the Novarc robot and large LJ welding turntables is in Appendix H.

3.2 Failure Mode Effect and Analysis (FMEA)

A FMEA, failure mode and effect analysis were used to evaluate how the proposed system will function effectively and identify all possible failures in the design that may occur when the system is in service. The various failure modes were outlined, and a risk priority number (RPN) was calculated based on the Occurrence, Severity and Detection associated with these modes. Recommended actions suggested to mitigate the consequence of these failure modes is included in the table.

Table X : Definition of "Severity" Scale = Likely Impact of Failure [16]

Impact	Rating	Criteria: A Failure Could
Bad	10	Injure the welder or damage the welding system
V	9	Cause the defect in material/welds
V	8	Cause some significant downtime or maintenance requirement
V	7	Cause some moderate downtime/loss of profit
V	6	Increase defection rate or cycle time
V	5	Cause some potential risk in safety/ operator fatigue
V	4	Cause minor performance loss
V	3	Cause a minor defect; can be overcome with no loss
V	2	Be unnoticed; minor effect on performance
Good	1	Be unnoticed and not affect the performance

Table XI: Definition of "Occurrence" Scale = Frequency of Failure [16]

Impact	Rating	Time period	Probability of Occurrence
Bad	10	More than once per day	> 30%
V	9	Once every 3-4 days	≤ 30%
V	8	Once per week	≤ 5%
V	7	Once per month	≤ 1%
V	6	Once every 3 months	≤ 0.3 per 1000
V	5	Once every6 months	≤ 1 per 10,000
V	4	Once per year	≤ 6 per 100,000
V	3	Once every 1-3 years	≤ 6 per million (approx. Six Sigma)
V	2	Once every 3-6 years	≤ 3 per 10 million
Good	1	Once every 6-100 years	≤ 2 per billion

Table XII: Definition of "Detection" Scale = Ability to Detect Failure [16]

Impact	Rating	Definition
Bad	10	Detect caused by failure is not detectable
V	9	Occasional units are checked for detects
V	8	Units are systematically sampled and inspected
V	7	All units are manually inspected
V	6	Manual inspection with mistake proofing modification
V	5	Process is monitored with control charts and manually inspected
V	4	Control charts used with an immediate reaction to out-of-control condition
V	3	Control charts used as above with 100% inspection surrounding out-of-control condition
V	2	All units automatically inspected, or control charts used to improve the process
Good	1	Defect is obvious and can be kept from the customer or control charts are used for process improvement to yield a no-inspection system with routine monitoring

Table XIII: RPN Number and Risk Severity [17]

RPN	Overall Risk
RPN <9	Insignificant
RPN 9- 64	Minor
RPN 65 -216	Moderate
RPN 217 - 729	Major
RPN >729	Extreme

After reviewing the Severity, Occurrence, and Detection, the FMEA for the new semi-automated system was constructed. The FMEA focuses on the two critical parameters that are the cut and preparation stage and the 1st stage welding (Circumference welding, pipe to pipe, and pipe to connections). The FMEA will include

- Potential failure mode that explains and describes the failure mode
- Potential failure effect that discusses the effect of the failure mode on the overall process
- Potential causes that show the consequences/ causes of the failure to the system/process.
- Current control explains how the failure is mitigated or solved.
- Recommended action is the new plan to solve or avoid failure.

Table XIV below shows the initial failure mode of the new welding system. It will include the current severity, occurrence, detection, and the RPN. The new RPN will be recorded by the process operators after doing the process recommendation.

Table XIV: FMEA summary and result

1	2	3	4	5	6	7	8	9	10
Critical parameter	**Potential failure mode**	**Potential failure effect**	**Severity**	**Potential causes**	**Occurrence**	**Current control**	**Detection**	**RPN**	**Recommended action**
Cut and Prep	Turntable does not rotate	Loss of time as no work can be done	8	Turntable is not connected to a welding system, weak connection or a power supply	9	Check the welding system notification or connection	4	288	Inspection before usage to ensure all proper connections are made
Cut and Prep	Turntable shaft bends	Loss of time as no work can be done and repair is needed	8	Weight limits are not followed	5	Check the weight of the pipe before loading it to turn-table	4	160	Work Instructions clearly highlighting weight limits and capacity
Cut and Prep	Turntable falls over	Turntable breaks and need repair, piping attached damaged	9	Pipe holders were not used, and weight limit exceeded	4	Set up the turntable based on the current SOP	3	108	Work Instructions clearly highlighting weight limits/capacity or to use pipe holder
Cut and Prep	Electronics get fried	Turntable is broken and needs repair	9	Proper grounding was not connected during welding operation	5	Current SOP for electric device connection and Safety	6	270	Inspection before usage to ensure all proper connections are made
Cut and Prep	Operator Crashes welding arm into pipe/turn-table/pipe rollers	Welding tips and sensors are damaged	8	Operator is not properly trained or becomes complacent	9	Complete the SWR user training before operating	1	72	Periodic training, SOP revision, and safety assessment
Cut and Prep	Difficult to move welder	Operator gets fatigue or injured	5	Schedule maintenance is not performed or performed properly	6	Maintenance based on the manufacturer schedule	6	180	Periodic inspections of all moving components to ensure proper functionality

Cut and Prep	Robotic Vision system breaks, or shows unclear the vision display	Decrease in quality and performance of the welding system	6	Debris impact, improper settings	6	Maintenance based on the manufacturer schedule	7	252	Periodic cleaning and ensure the good distance between the vision system and the welding touch.
Cut and Prep	Pipe Holder Collapses	Drops a section of pipe, possible human danger, and causes the damage in the turntable	10	Weight capacity is not followed or not properly locked	6	SOP for pipe holder setup and maintenance	10	600	Work Instructions clearly high-lighting weight limits and capacity, inspect the pipe holder before using
Cut and Prep	Pipe Holder casters do not rotate	Fatigue to operator	5	Debris damages bearings	6	SOP for pipe holder setup and maintenance	1	30	Periodic cleaning and inspection check-list
1st stage welding (Circumference Welding, Pipe to pipe, Connections)	Welding unit does not create arc	Loss of time as no work can be done	8	Improper Grounding or settings	7	Current Novarc welding robot instruction	3	168	Inspection before usage to ensure proper connections, proper settings are used, and ensure proper training
1st stage welding (Circumference Welding, Pipe to pipe, Connections)	Robotic arm system tips over during the welding process	Potential human risk and equipment damage	10	Improper Installation/setup of equipment or forklift/ moving object crashes into the welder robot	4	Current Novarc welding robot instruction	10	400	Installation by certified people, put the barrier around the welding area
1st stage welding (Circumference Welding, Pipe to pipe, Connections)	Pipe Holders do not rotate	Fatigue to operator and alignment issues	6	Debris damages bearings or over-weight loading capacity	6	SOP for pipe holder setup and maintenance	1	36	Periodic cleaning and inspection check-list

The current FMEA shows some potential risk from the new welding system and process. The most severe risk come from the pipe holder collapse (RPN= 600) and the robotic arm system tips over during the welding process (RPN= 400), both failure modes have the severity and detection rated 10. The two failure modes require immediate action to ensure the failure does not occur for the system as well as human injury is avoided. Therefore, the team has requested for a maintenance checklist from Novarc Technologies to help the fabshop supervisor prepare the SOP and recommended actions. This maintenance checklist will be delivered to DMS upon purchase of the system.

3.4 Bill of Materials and Cost Summary

The Bill of Materials highlights the various parts and corresponding quantities needed to put together the overall system. While, the cost summary reveals the total cost of procurement, based on our quote in Appendix G. Below in Table XV shows the outcome:

Table XV: Bill of Materials & Cost Summary

BILL OF MATERIALS & COST SUMMARY						
Item Number	**Component**	**Supplier**	**Model Number**	**Unit Cost (CAD)**	**QTY**	**Ext. Cost (CAD)**
01	Welding System					
01-1	Spool Welding Robot	Novarc Technologies	N/A	$553,880.00	1	$553,880.00
02	Positioner					
02-1	Portable Welding Turntable	LJ Welding	12P-900	$7,650.00	3	$22,950.00
02-2	12" Chuck	LJ Welding	12C	$1,490.00	3	$4,470.00
02-3	Foot Switch	LJ Welding	FS-FR	$990.00	3	$2,970.00
02-4	Portable Scissor Lift Cart	LJ Welding	12LT-200	$3,950.00	3	$11,850.00
02-5	2" OD Elbow Jig	LJ Welding	02E-200	$140.00	3	$420.00
02-6	3" OD Elbow Jig	LJ Welding	03E-200	$155.00	3	$465.00
02-7	4" OD Elbow Jig	LJ Welding	04E-200	$163.00	3	$489.00
02-8	5" OD Elbow Jig	LJ Welding	05E-200	$245.00	3	$735.00
03	Roller Stands					
03-1	Roller Stands	LJ Welding	HD2-300U	$995.00	9	$8,955.00
				TOTAL	**34**	**$607,184.00**

These items are based on the selected concepts and along with other items that enhances the productivity of pipe spool welding. For example, the elbow jigs will help in positioning a 90^{o} elbow to a straight pipe for welding. The scissor lift helps in adjusting the height and transporting the portable welding positioner. A total of 34 components will need to be ordered at a total cost of $CAD 607,184.00.

3.5 Payback Analysis

To evaluate the viability of our design and proposed solution a payback analysis was performed. The payback analysis section was created with multiple conversations with DMS to ensure that all necessary variables and constraints were considered.

Criteria for Payback Analysis

1. Input fields highlighted for ease of use
2. Separating crew composition to allow tailoring of workforce
3. Separating crew costs to allow ease of modification
4. Consider cut and prep bottleneck for Novarc system
5. Allow for weld and cut and prep speeds to be adjusted
6. Have a payback of less than 5 years

The payback analysis section considered the above criteria. With this criterion we were able to formulate the tables below that can calculate the payback time period, as well as the increase in possible work that the Novarc system is able to provide.

Table XVI: General Inputs for Payback Analysis

General Inputs	
Hourly Rate Welders	$60.00
Hourly Rate Pipe Fitter	$60.00
Blended Hourly Rate Apprentice	$50.00
Day Length (Hr)	8
Steel to Stainless Ratio	50%
Days In a Year	260

In the payback analysis general inputs were created that would apply and affect the analysis of both systems. The salary of the workers was split to allow finer detail of analysis options as well as allow future proof of the analysis. The salary cost of the workers was gathered from DMS. Other general inputs include their workday and days working in the year. One other major input is the ratio of steel to stainless; this is the ratio of steel piping to stainless that they process throughout the year, 50% was the average.

Table XVII: Current Manpower Inputs for Current Manufacturing Method

Current Manpower		
Efficiency		65%
Welders Per Crew		1
Pipe Fitter Per Crew		1
Apprentice Per Crew		1
Crews Per Shift		1.5
Weld Per Hour (in)	Carbon	10
	Stainless Steel	3.75

Current welding method inputs go into more specifics, this includes the efficiency, crew size and speed. The efficiency refers to the overall productivity factor for the process throughout the year, this value was obtained from DMS. The crew was broken down into individual people to be able to tailor based on the needs of the jobs, as well as crews per shift. All these values were obtained from DMS's current operational average. The welding per hour was obtained through time studies conducted, as well as conversations with workers and shop floor managers.

Table XVIII: Proposed Solution is Novarc Welding System Inputs

Proposed Solution		
Efficiency		65%
Operator/Welder Per Crew		1
Pipe Fitter Per Crew		2
Apprentice Per Crew		1
Crews Per Shift		1
Weld Per Hour Ideal(in)	Carbon	31.25
	Stainless Steel	62.5

The Novarc system inputs are the same as the current welding methods, but the origin of the information is from suppliers and approximation. The efficiency, or productivity factor, was kept the same but allowed to be easily modified to keep a level playing field. The crew size is limited to only one due to one Novarc system, but the crew composition is modified with the increase of more pipe fitters to decrease the bottle neck. The weld speed is the slowest ideal weld speed of the Novarc system.

Table XIX: Cut and Prep Limitations that Affect's Novarc Welding System

Cut and Prep Limitation		
Cut and Prep / Hr / Person (in)	Carbon	20
	Stainless Steel	7.5
Cut and Prep / Day / Person (in)	Carbon	160
	Stainless Steel	60
Max Cut and Prep / Day / Crew(in)	Carbon	320
	Stainless Steel	120

The cut and prep limitation table calculates the amount of piping that pipe fitters can prepare for welding per day as this will be the limiting factor on the Novarc system. The cut and prep times were gathered from conversations with the shop floor manager and estimations based on some previous time studies, see appendix. With multiple turntables and layout, the workers can weld + cut/prep simultaneously which could further increase productivity.

Table XX: Outputs for Payback Analysis of Both Welding Systems

Current Welding Method			**Novarc Welding System**		
Weld Per Day (in)	Carbon	80	Weld Per Day (in)	Carbon	250
	Stainless	30		Stainless	120
Weld Per Year (in)	Carbon	20280	Weld Per Year (in)	Carbon	42250
	Stainless	7605		Stainless	20280
Weld Per Year Total With Ratio (in)		13942.5	Weld Total Per Year With Ratio (in)		31265
Total Cost To Weld Per Year (CAD)		$530,400.00	Total Cost To Weld Per Year (CAD)		$478,400.00

The two tables calculate the amount of pipe inches that can be welded by both systems considering cut and prep limitations on the Novarc system. We can calculate the cost of operation by calculating the cost of running the crew's year long, for each system. We can see that the cost of running Novarc is cheaper and is able to weld 3.4 times more pipe inches.

Table XXI: Comparing Novarc and Current Manufacturing System

Comparison Current Welding Method VS Novarc	
Novarc Production Capacity	17322.5
Novarc efficiency Compared to Current	342%
Cost to run Novarc for 76 days	$138,671.35
Cost Savings to weld current 1yr work	$391,728.65
Cost Summary	$523,940.64
Payback Period With Current Workload (Operational Days)	348

From the above payback analysis, the entire Novarc system can be paid off in 1.338 years. This was calculated by evaluating the cost of welding DMS current workload, with the current welding method and the Novarc system. With the Novarc system DMS can weld their current workload in just 75.36 days vs 260 days for their current welding method.

This would allow DMS industrial group to be able to bid on more jobs and accept more work as they have 184.64 more days available. This would help DMS grow their business and help decrease the payback period to even shorter as it would allow for more jobs through their pipe spool manufacturing area.

3.6 Novarc Technology and Robot Built-in Safety Features

This section includes the Novarc system and safety feature and optional add-on packages.

3.6.1 Novarc System and Safety feature

The Novarc system comes with multiple systems to help the operator weld and engineering team keep track of quality and data.

The Vision system can help the operator monitor welds from root to cap during the weld. The NovData is the add-on software that helps to record the weld and motion parameters such as voltage, current, WFS, travel speed, true head input, etc. with 50ms time stamps and creates a log file for each weld [18]. In addition, it can generate daily summary reports automatically. The data provided by the system will be more precise, consistent compared with the traditional data recording. The recording data will give DMS more opportunities to improve further productivity of the welding process. For QA/QC purposes, it can reduce the defect rate of the welding process as well as the proof of defect for future improvement.

The SWR robot has built-in safety technology that includes zero backlash gearboxes, mechanical drop-down stand that provides more stability to the arm, eliminates the robot arm tip over during the control or welding process. SWR robot also immediately stops welding as well as the positioner turning when it detects any impact of the torch or arm. The SWR robot has multiple emergency e stops on the machine that are all interconnected with the turntables as well.

3.6.2 Optional Add-on Packages:

The Novarc SWR robot also offers two optional purchasing packages: NovSync and NovEye. NovSync is compatible with NovData, it can sync the data (daily production reports, weld logs) on the cloud. Then this data can be easily accessible by any internet browser, this technology also guarantees return data in 1-5 minutes for every data past 12 months, and 12 to 48 hours for any data beyond 12 months [18]. NovEye is a new AI technology that provides automated welds with no operator intervention beyond 3 seconds after the start of the weld. This technology is currently compatible with the pipe range 8” to 24”, standard pipe thickness, and carbon steel material. Features included [18]:

- Automated Tack Detection
- Automated Root Save
- Automated Root Seam Tracking
- Automated Fill Seam tracking
- Automated Cap Seam Tracking
- Insufficient Weave Adjustment
- Excessive Arc Cone Adjustment

4. Recommendations to Finish the Project

With this final report DMS will have all the knowledge needed to determine if this system is what DMS wants to take them to the next level of pipe spool fabrication. There are a few recommendations that DMS should undertake before cutting PO, purchase orders, to vendors and getting all the equipment in.

The first recommendation would be to have a Novarc representative fly out to Winnipeg and speak with DMS to ensure that DMS has confidence in Novarc and its meets DMS standards. Novarc has expressed that this is something they are willing to do if DMS wants to move forward with this project.

The second recommendation would be to reach out to Companies that have used this system and discuss with them about the pros and cons of them switching to the Novarc system. Our team has reached out to companies and were not able to get a response before the completion of this project.

Once DMS completes the above two recommendations and everything is up to par. DMS should have confidence to be able to move forward with purchasing the system.

5. Reflection

This section includes the benefits and difficulties experienced and lesson learned for the project.

5.1 Benefits and Difficulties Experienced

The benefits the team realized are as follows:

1. Improved our technical writing and communication skills.
2. How to accurately make a design selection and as well satisfy our client's needs.
3. The required steps to follow to meet the client's needs.
4. Improved our team working skills and efficiently handled team meetings with the aid of an agenda and meeting minutes.

The difficulties the team realized are as follows:

1. The team faced difficulties on visiting the sites due to no pipe spool welding operation, as a result we could not gather data on those occurrences.
2. The time delay of interested companies responding to our query via email.
3. Rude and unethical responses from a supplier.

5.2 Lessons Learned

One of the most important aspects of the Capstone experience is to learn to work with industry and create a formula or checklist on ways to succeed handling projects.

1. Follow the methods explained in class. It helps pave the path in deriving a solution to the project.
2. Have regular communication with the client and ensure the progress made satisfies the client's needs.
3. Ensure the problem statement is well understood, before moving forward, because you cannot solve a problem you lack understanding on.
4. The importance of meeting with the people fabricating the parts as they have a lot of insight into the process and are very valuable.

6. Conclusion

The main goal of this project is to introduce a new welding system for the DMS pipe spool welding fabshop. The new system must be compatible to weld the pipe that has a diameter range from 2” to 12”, pipe thickness SCH 10-80, pipe length up to 40ft, and material Carbon and Stainless Steel. The new system must also meet/exceed the current welding process performance in terms of welding time, product quality, and acceptable setup time. The other criteria such as safety, maintenance, floor area, and budget have been mentioned and discussed in detail in the above report.

The final system design is composed of the following items.

1. Spool Pipe Welding Robot from Novarc Technology
2. LJ welding 12P-900 - Turntable
3. LJ welding- HD2-300U – Roller Stands
4. Layout

With these 4 parts working together the entire pipe spool welding manufacturing process will meet the goals that DMS has given us.

Goals of DMS	What is achieved
Reduce the welding defect Rate of 2%	Novarc welding system with 1% defect rate
Reduce the process set-up time	Seconds between steel and Stainless, Multiple turntable locations
Increase current welding speed	Welding 3.4 times more pipe inches per year
Improve quality and consistency	NovData, NovEye, NovSync

With the system outlined in this report DMS can weld 3.4 times more pipe inches per year. Not only does this system help increase the amount of pipe spools per year throughput it decreases the defect rate to below 1%, but it also allows for high amount of traceability. With the Novarc system and current workload the system has a return on investment of only 1.338 years.

With the massive increase in productivity that is achievable with the welding system, DMS can bid on more jobs and increase the workload amount per year. This will help DMS move into the next level of Pipe spool welding fabrication.

In this report, the final design is presented of the new welding system. Our team has high confidence in the design presented that it meets or exceed all requirements that DMS has.

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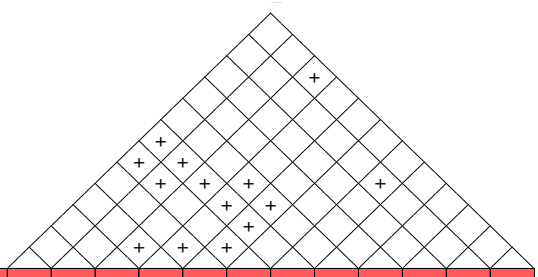
Appendix A: House of Quality

A House of Quality was implemented to summarize the needs and target specification together and show their relationship. Each identified client need on the left column was matched with the metrics on the top row. The House of Quality also, shows the correlation between the metric, whether it is a positive, negative or no correlation.

Table A- I: House of Quality [19]



Row #	Customer Importance	Customer Requirements \ Metrics	1 Process cycle time	2 Total floor area	3 Total cost	4 Set-up programming	5 Set-up welding time	6 Pipe diameter sizes	7 Pipe length	8 Pipe thickness	9 Risk assessments	10 Safe operations	11 Assembly welding	12 Payback time	Row #
		Column #	1	2	3	4	5	6	7	8	9	10	11	12	
		Direction of Improvement	◇	▼	▼	▼	▼	◇	▼	◇	◇	◇	◇	◇	
1	5	Improve the efficiency of DMS pipe spool welding process	●			●								●	1
2	5	Capable of welding carbon and stainless-steel material	●		●			●		○					2
3	5	Capable of welding a range of pipe diameter sizes						●							3
4	5	Compatible with pipes of different length		○					▽						4
5	5	Compatible with varying wall thicknesses from SCHD 10- SCHD 80			●					○				●	5
6	5	Capable of welding pipe-pipe and pipe-fitting connections					●						●		6
7	5	Solution to be user-friendly					●				▽	○			7
8	5	Solution to have a fail-safe operation									▽	○			8
9	5	Solution fits within the provided space		○		●			▽				●		9
10	5	Increase productivity, weld consistency and quality	●			●	●					○	●		10
11	4	Streamline queue/management/workflow system	●	○										●	11
12	3	Capable of cutting carbon and stainless-steel material	●		●			●		○					12
13	3	Solution does not exceed provided budget			●									●	13
14	3	Solution provides a reasonable payback period	●	○	●	●	●	●	▽	○	▽	○	●	●	14
15	1	Improve the efficiency of DMS pipe spool pre-fabrication process	●			●	●						●	●	15
		Target	Refer to Table II	< 7680 [3]	< $1,000,000 [2]	< 15	< 15	2-12 [2]	<50	SCHD 10 - 80	Refer to Table II	Refer to Table II	Refer to Table II	2 to 5 years [2]	
		Target Importance Rating	5	3	4	5	4	5	5	3	2	3	4	5	
		Column #	1	2	3	4	5	6	7	8	9	10	11	12	

Table A- II: House of Quality correlation legend [19]

Correlations	Direction of Improvement	Relationships
Positive +	Maximize ▲	Strong ●
Negative —	Target ◇	Moderate ○
No Correlation	Minimize ▼	Weak ▽

The direction of improving the metric and correlation is demonstrated using the symbols indicated in Table A-II. Each need was linked to a metric, which explains that all needs are needed and can be measured. In Table A-II, it is seen that the team plan on targeting the values on columns 1, 6, 8 to 12, while we plan to decrease the values on columns 2 to 5 and 7 to satisfy the customer requirements.

Appendix B: Welding Robot Rating Scale

Table B- I: Welding Robot Rating Scale

Criteria	Specification 1	Rating 1	Specification 2	Rating 2	Specification 3	Rating 3	Specification 4	Rating 4
Pipe spool diameter (2”-12”)	able to weld 2"-12" and beyond	10	able to weld 2"-12"	8	able to weld 2"-8"	5	able to weld 2"-5" or 8"-12+"	2
Pipe thickness (SCHD 10-80)	able to weld SCHD 10-80 and beyond	10	able to weld SCHD 10-80	8	able to weld SCHD 10-60	5	able to weld SCHD 10-40	2
Material (Carbon and Stainless Steel)	Carbon and steel	10	-	8	Carbon or steel	5	-	2
Pipe length (up to 40ft)	40+(ft)	10	30(ft)	8	20+(ft)	5	20(ft)	2
Set up time	Easy to set up (less than 3 mins)	10	Easy to set up (less than 7 mins)	8	medium set up (less than 15 mins)	5	special set up (less than 20 mins)	2
Programing time	Don’t have or minimum programing time	10	requires basic programing time	8	requires some special programing	5	-	2
Welding time	manual	10	rate	8	-	5	-	2
Safety	and regulation (no special training)	10	Requires special training for users to avoid accident	8	-	5	-	2
Maintenance	Easy to maintenance (less time and cost)	10	Intermadiate to maintenance (medium	8	Special maintenance (Special schedule and	5	-	2
Configuration	No need customize	10	Requires special	8		5		2
Budget	Less than 400k	10	Less than 500k	8	Less than 600k	5	Less than 1 million	2
Easy-of-access	Easy to train and operate	10	Special training or special operation	8	Special training & special operation	5	-	2
Quality	Defect rate less than 1%	10	Defect rate less than 2%	8	-	5	-	2
Footprint/ Floor area	Small footprint	10	Intermediate footprint	8	Large footprint	5	Does not fit DMS facility	2

~10	Beyond the target
~8	Meets more than 90% target
~5	Meets 80% target
~2	Meets less than 50% target

Note that, the rating point for each concept can fluctuate between the fixed rating point. For instance, if the two concepts have the same rating of 10, the concept that has the better specification will have 10 points in rating and the other will have 9 points in rating.

Appendix C: Turntable Rating Scale

Table C- I: Turntable Rating Scale

Criteria	Specification 1	Rating 1	Specification 2	Rating 2	Specification 3	Rating 3	Specification 4	Rating 4
Capability with SWR	Able to function with the SWR on its own	10	Able to function with the SWR with minor additions	8	Able to function with SWR with moderate additions	5	Able to function with SWR with major additions	2
Weight Capacity	Compatible with 600lb and above	10	Compatible with 600lb	8	Compatible with less than 450lb	5	Compatible with less than 300lb	2
2" to 6" outer diameter size range	Can work with 2" to 6" diameter and beyond	10	Can work with 2" to 6" diameter	8	Can work with 2" to 5" diameter	5	Can work with 2" to 4"	2
Adapters	Compatible with numerous adapters	10	Compatible with adapters	8	Can work with one adapter	5	Cannot work with adapters	2
Set up time	Takes less than 5mins	10	Takes less than 7mins	8	Takes less than 10mins	5	Takes less than 15mins	2
Safety	Ground capacity is greater than 500 Amps	10	Ground capacity is greater than 300 Amps	8	Ground capacity is greater than 200 Amps	5	Ground capacity is greater than 100 Amps	2
Mobility/footprint	Footprint is less than 400in^2 and transportable	10	Footprint is less than 550in^2 and transportable	8	Footprint is less than 700in^2 and not transportable	5	Footprint is greater than 700in^2 and not transportable	2
Maintenance	Easy to maintain	10	Intermediate level of maintenance	8	Requires special maintenance	5	Extremely difficult to maintain	2
Budget	>4,000USD	10	> 6,000USD	8	>8,000USD	5	> 10,500USD	2

~10	Beyond the target
~8	Meets more than 90% target
~5	Meets 80% target
~2	Meets less than 50% target

Note that, the rating point for each concept can fluctuate between the fixed rating point. For instance, if the two concepts have the same rating of 10, the concept that has the better specification will have 10 points in rating and the other will have 9 points in rating.

Appendix D: Roller Stands Rating Scale

Table D- I: Roller Stands Rating Scale

Criteria	Specification 1	Rating 1	Specification 2	Rating 2	Specification 3	Rating 3	Specification 4	Rating 4
2"-12" diameter	Can work with 2" to 12" diameter and beyond	10	Can work with 2" to 12" diameter	8	Can work with 2" to 8" diameter	5	Can work with 2" to 6"	2
Weight capacity	Compatible with more than 600lb	10	Compatible with less than 600lb	8	Compatible with less than 450lb	5	Compatible with less than 300lb	2
Compatibility	Able to function with the SWR with no additions	10	Able to function with the SWR with minor additions	8	Able to function with SWR with moderate additions	5	Able to function with SWR with major additions	2
Safety	Ground capacity is greater than 500 Amps	10	Ground capacity is greater than 300 Amps	8	Ground capacity is greater than 200 Amps	5	Ground capacity is greater than 100 Amps	2
footprint/floor area	Footprint is less than 500in^2 and transportable	10	Footprint is less than 650in^2 and transportable	8	Footprint is less than 750in^2 and not transportable	5	Footprint is greater than 900in^2 and not transportable	2
Ease of use	Very simple and straight forward to understand	10	Requires basic training to understand	8	Requires advanced training to use	5	Requires training and tests before use	2
Set up time	Takes less than 5mins	10	Takes less than 7mins	8	Takes less than 10mins	5	Takes less than 15mins	2
Maintenance	Very easy to maintain	10	Intermediate level of maintenance	8	Requires special maintenance	5	Extremely difficult to maintain	2
Budget	>500USD	10	> 1,000USD	8	>1,500USD	5	> 2,000USD	2

~10	Beyond the target
~8	Meet more than 90% target
~5	Meet 80% target
~2	Meet less than 50% targry

Appendix E: Welding Rating Analysis

Table E- I: Concept I: Novarc Welding System Rating Result [4]

#	Criteria	Concept I: Novarc Welding Robot	Grade
1	Pipe spool diameter (2”-12”)	Capable to weld pipe diameter (2” to 60”)	10
2	Pipe thickness (SCHD 10-80)	Capable to weld pipe thickness (SCHD 10-80)	8
3	Material (Carbon and Stainless Steel)	Carbon and low alloy steel Stainless and nickel alloys	10
4	Pipe length (up to 40ft)	Working envelop 30ft	8
5	Set up time	Flexible layout, easy to move, 2-3 minutes between joins	10
6	Programming time	No special program requires	10
7	Welding time	200”-350”/ shift (Carbon pipe) 569”-998”/ shift (stainless steel pipe)	10
8	Safety	Built-in safety system eliminating the need for fencing	10
9	Maintenance	Provide maintenance package	10
10	Configuration	Customization requires for welding pipe 40ft long	8
11	Budget	Approximately $USD 300,000	9
12	Easy-of-access	Online training for system operation Operational (5 days) including 2 days installation	10
13	Quality	Less than 1% defect rate Meet the requirements of ASME B31.1, B31.3, EN 13445 and EN 13480	10
14	Footprint/ Floor area	4ft x 4ft	10

Table E-II: Concept II: LJ Welding System Rating Result [5] [6]

#	Criteria	Concept II: LJ Welding Robot	Grade
1	Pipe spool diameter (2”-12”)	Prefer welding pipe 16’’ up	2
2	Pipe thickness (SCHD 10-80)	Capable to weld pipe thickness (SCHD 10-80)	8
3	Material (Carbon and Stainless Steel)	Carbon and Stainless steel	9
4	Pipe length (up to 40ft)	Working envelop more than 40ft depends on the roller standing set up	9
5	Set up time	Easy to move, HMI touch screens to control all function	8

6	Programming time	No special program requires	9
7	Welding time	65% decreases in cycle times for circumference welding	10
8	Safety	Boom manipulator with high stability and rigid. Preventing unwanted movement.	8
9	Maintenance	Provide maintenance support	9
10	Configuration	May need some special set up	8
11	Budget (*)	(don't have information yet)	8
12	Easy-of-access	Training for system operation by LJ team	9
13	Quality	High precision of aligning robot for welding.	8
14	Footprint/ Floor area	Required large floor area due to fixed set up for 40ft welding pipe	5

Table E-III: Concept III: Lincoln Welding System Rating Result [7]

#	Criteria	Concept III: Lincoln Welding Robot	Grade
1	Pipe spool diameter (2"-12")	Capable to weld pipe diameter (2" to 28")	9
2	Pipe thickness (SCHD 10-80)	Capable to weld pipe thickness (SCHD 10-80)	8
3	Material (Carbon and Stainless Steel)	Carbon and stainless steel	9
4	Pipe length (up to 40ft)	Working envelop more than 40ft depends on set up	10
5	Set up time	Required special set up every time	2
6	Programming time	No special program requires	8
7	Welding time	Increase productivity by reducing time consumed	10
8	Safety	Tested to IP21, IP23 and IP23S standard	7
9	Maintenance	3 Year Warranty plus extended warranty	9
10	Configuration	Customization requires for welding pipe 40ft long	8
11	Budget (*)	~$USD90,000-$100,000	10
12	Easy-of-access	No special installation required	8
13	Quality	Consistent and repeatable weld quality (don't have specific data)	8
14	Footprint/ Floor area	Depends on pipe spool welding Fixed Floor area for pipe holding stand	8

Table E-IV: Concept IV: Tecnar Welding System Rating Result [8]

#	Criteria	Concept IV: Tecnar Welding Robot	Grade
1	Pipe spool diameter (2”-12”)	Capable to weld pipe diameter (2” to 12”)	8
2	Pipe thickness (SCHD 10-80)	Capable to weld pipe thickness (SCHD 10-80)	8
3	Material (Carbon and Stainless Steel)	Carbon and Stainless steel	9
4	Pipe length (up to 40ft)	Working envelop 40ft	9
5	Set up time	System setup, automated setup	2
6	Programming time	Require special program requires	5
7	Welding time	An average of 25 joints of 12-inch diameter pipes in a 10-hour shift	10
8	Safety	Emergency stop/industrial built	9
9	Maintenance	Provide maintenance package Automated system required special maintenance	5
10	Configuration	May need some special set up	8
11	Budget	$USD250,000- $USD500,000	7
12	Easy-of-access	Required special training for the operators	5
13	Quality	Low rework rate, high quality guarantee	10
14	Footprint/ Floor area	Required large floor area due to fixed set up for 40ft welding pipe	5

Appendix F: Turntable Rating Analysis

Table F- I:Vevor 55lbs Rotatory Table Rating Result [9]

#	Criteria	Concept I: Vevor 55lbs rotatory table	Rating
1	Capability with SWR	Confirmed from a staff from SWR, that their robots work well with most turntables and not specific ones.	10
2	Weight Capacity	Capable of carrying load of 50kg in the vertical direction and 20kg in the horizontal direction. Which is insufficient.	2
3	2" to 6" outer diameter size range	Turntable is compatible with 2” to 6” pipe outer diameter sizes.	10
4	Adapters	Turntable only allows for a 3-jaw chuck.	5
5	Set up time	Turntable allows for operator to easily insert pipe into 3-jaw chuck with no complication.	10
6	Safety	Specification does not specify the ground capacity, which is crucial for welding.	2
7	Mobility/footprint	Turntable only covers a footprint of 216.05in^2, which is not cumbersome.	10
8	Maintenance	Designed with well-known parts, that involves little or no complexity	8
9	Budget	Turntable cost a total of CAD$830	10

Table F- II: LJ Welding 12p-900 Rating Result [10]

#	Criteria	Concept II: LJ welding 12p-900	Rating
1	Capability with SWR	Novarc partners with LJ welding and allows for their robots to collaborate well with LJ welding.	10
2	Weight Capacity	Capable of carrying load of 1,000 lbs, which is more significant than concept I.	10
3	2" to 6" outer diameter size range	Compatible with 2” to 12” pipe outer diameter sizes.	10
4	Adapters	Allows for different adapters to installed, like elbow jigs.	10
5	Set up time	Allows for operator to easily insert pipe into 3-jaw chuck.	8
6	Safety	High grounding capacity of 800 Amps, good for working with welding operation.	10
7	Mobility/footprint	Covers a footprint of 506in^2, which is not cumbersome.	8
8	Maintenance	DMS has a larger LJ welding turntable, therefore maintenance department will find it easy working with a smaller turntable.	8
9	Budget	~ $CAD 7,5000	5

Table F- III:LJ Welding 16P-700 Rating Result [11]

#	Criteria	Concept III: LJ welding 16P-700	Rating
1	Capability with SWR	Novarc partners with LJ welding and allows for their robots to collaborate well with LJ welding.	10
2	Weight Capacity	Capable of carrying load of 3000 lbs, which is more significant than concept I.	10
3	2" to 6" outer diameter size range	Compatible with 2” to 6” pipe outer diameter sizes.	10
4	Adapters	Allows for different adapters to installed, like elbow jigs.	10
5	Set up time	Allows for operator to easily insert pipe into 3-jaw chuck.	5
6	Safety	High grounding capacity ranging from 200 to 1500 Amps, good for working with welding operation.	10
7	Mobility/footprint	Takes the most footprint of 3024in^2	2
8	Maintenance	DMS has a larger LJ welding turntable, therefore maintenance department will find it easy working with a smaller turntable.	8
9	Budget	~ $CAD 9,000	4

Table F- IV: Arc-Zone A-PT-051 Pro Positioner Rating Result [12]

#	Criteria	Concept IV: Arc-Zone A-PT-051 Pro Positioner	Rating
1	Capability with SWR	Confirmed from a staff from Novarc, that their robots work well with most turntables and not specific ones.	10
2	Weight Capacity	Load capacity is a low with a capable load of 110 lbs in the vertical direction and 66lbs in the horizontal direction.	1
3	2" to 6" outer diameter size range	Compatible with 2” to 6” pipe outer diameter sizes.	10
4	Adapters	Turntable only allows for the use of a 3-jaw chuck.	2
5	Set up time	Easy to use and have pipe inserted in the 3-jaw chuck for operation.	10
6	Safety	High grounding capacity of 200 Amps	5
7	Mobility/footprint	Small footprint of 119.7in^2	10
8	Maintenance	Designed with well-known parts, that involves little or no complexity	8
9	Budget	Cost of USD$1,300	10

Appendix G: Equipment Quotation

Table G- I: LJ Welding Turntable Quotation

Item	Model Number	Description	Purchase	Rental	Ext Purchase		Discount Price			Lead Time	
			Unit Price	4 weeks	QTY	Ext. Price	Discount	Unit Price	Ext. Price	In Stock	Back Order
1	12P-900	12P-900, 1,000 lbs capacity, Portable Welding Positioner, c/w Air Purge Fitting, (110V/1Ph standard voltage)	$7,650	$1,074	1	$7,650	15.0%	$ 6,503	$ 6,503	used avail only today	Only used available today-new is about 3 weeks out
2	12C	12" Chuck, c/w reversible top jaws	$1,490	$186	1	$1,490	15.0%	$ 1,267	$ 1,267	new used avail	
3	HD2-300U	HD2 Roller Stand (urethane wheels, 2-48" OD, 4000 lbs capacity, 40-65" height range)	$995	$225	1	$995	15.0%	$ 846	$ 846	new used avail	
4	FS-FR	Foot Switch- Heavy Duty, Forward/Reverse, 50' cable	$990	$102	1	$990	15.0%	$ 842	$ 842	new used avail	
Optional & Accessories											
5	12LT-200	12LT-200, Portable Benchtop Positioner Scissor Lift Cart	$3,950	$412	1	$3,950	15.0%	$ 3,358	$ 3,358	new used avail	-
7	02E-200	Elbow Jig (2" OD, 250 lbs capacity)	$140	$47	1	$140		$ 140	$ 140	new only	-
8	03E-200	Elbow Jig (3" OD, 250 lbs capacity)	$155	$53	1	$155		$ 155	$ 155	new only	
9	04E-200	Elbow Jig (4" OD, 250 lbs capacity)	$163	$55	1	$163		$ 163	$ 163	new only	
10	05E-200	Elbow Jig (5" OD, 250 lbs capacity)	$245	$85	1	$245		$ 245	$ 245	new only	
11											
		TOTAL			CAD	$ 15,778	<- purchase new		$ 13,517	+ Tax	<-used if available at time of purchase

Table G- II: Novarc Technologies Quote

Description	Quantity	Optional	Unit Price	Total
Dual Torch Spool Welding Robot (SWR)	1		$510,070.00	$510,070.00
Positioner Integration (max 5)	3		$12,350.00	$37,050.00
Cable Management	1		$6,760.00	$6,760.00
Option: NovEye (annual subscription)		$6,550.00		
Option: NovSync (annual subscription)		$3,900.00		
Option: 12 Months NovCare Preventative Maintenance Gold		$19,500.00		
Option: 12 Months NovCare Preventative Maintenance Silver		$13,000.00		
Totals (CAD)				$553,880.00

Prices include: training and installation
Price excludes: Shipping

Appendix H: Risk Assessment

The team identified possible risks that could occur during the progress of the project. Each identified risk was given a risk number. First, the team rated the chances of such risk occurring, with "1" being low, "3" as moderate and "5" as the high. Same approach was applied when it came to rating the impact of each risk. A risk number was given, by multiplying the likelihood of occurrence by the consequence. Once this was done, the team brainstormed on actions to take to mitigate such risks. Table D-I explains the risk number, while Table D-II below is the outcome:

Table H- I: Risk Priority Number

Risk Number	Overall Risk
< 6	Insignificant
6-9	Moderate
10-13	Major
>15	Extreme

Table H- II: Risk Assessment Table

#	Risk Description	Likelihood of Occurrence	Consequence	Risk Number	Mitigation Action
		[1,3,5]	[1,3,5]	LXC=RN	
1	COVID-19 Risk: Risk of team members being exposed to COVID-19	3	5	15	Mitigate by wearing masks and adhere to COVID safety protocols.
2	Safety Risk: Welding flash and flying debris	3	3	9	Mitigate by keeping a proper distance from welding operation and ensure PPE is worn
3	Production Schedule Risk: Due to production times conflicting with teams' available times.	3	3	9	Mitigate by regular communication with our clients and plan for time opportunities for site visit
4	Project Time Allocation Risk: Team members not being able to accommodate for the project due to other primary commitments.	1	5	5	Mitigate by dedicating an agreed team meeting time

This act is keeping the team organized and draws our attention on possible dangers and obstacles that can hinder the progress of the project. Risk number 1 is our highest risk number, while risk number 2 and 3 comes in with a tie and risk number 4 as our lowest risk number.

Appendix I: Construction Drawing

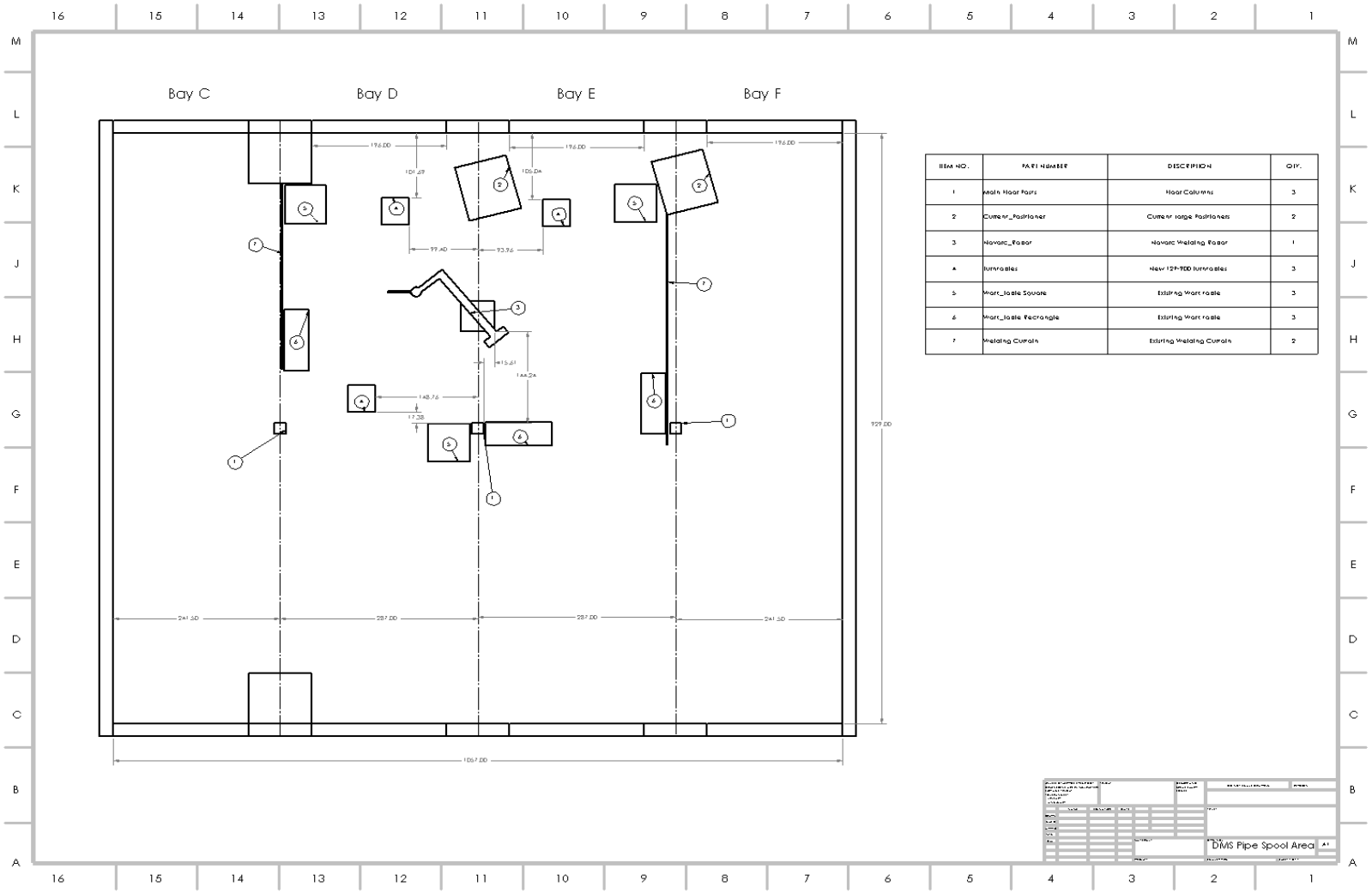


Figure I- 1: Construction Drawing