MECH 4860 – Engineering Design

Shaft Manufacturing Process Improvement

MacDon Industries Ltd.

Final Design Report

Team 16

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Executive Summary

Team 16 has designed a dedicated manufacturing cell to produce the three types of reel drive shafts used in MacDon's combine headers. The new cell features a CNC lathe capable of machining discs and shafts, as well as a custom welding solution, leaving laser cutting, pressing and painting processes in their current locations. Both an automated and manual handling configuration of the cell were designed. Team 16 proposes MacDon implement the automated handling cell based on the analyses performed which provides a payback period of 2.15 years and will save MacDon $2.3M over a period of 10 years.

MacDon Industries Ltd. tasked the team with designing a process improvement for the manufacturing of reel drive shafts used in MacDon's combine headers. The current manufacturing system for reel drive shafts requires excessive part movement through production facility as well as high amounts of work in progress. The objective of the Shaft Manufacturing Process Improvement project was to design an improved process which reduces part movement, work in progress and non-value-added time. Deliverables to the client include a process layout, bill of materials and manufacturing schedule.

Through concept development and internal research performed during site visits at MacDon's facility, the team's final design groups three of the required drive shaft processes together, reducing unit movement by 51% and limiting work in progress to 54 units. The design also includes a new transport cart designed by MacDon for moving work in progress during production.

Production analysis using the new manufacturing schedule shows that the new process utilizing the manufacturing cell can produce the daily demand of 54 reel driveshafts after 13.8 hours of operation, leaving approximately 2 hours of extra capacity based on two 8-hour shifts per day.

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1 INTRODUCTION

MacDon Industries Ltd. is a Winnipeg based manufacturer and worldwide distributor of agricultural harvesting equipment [1]. Their products include many types of swathers and headers for harvesting a variety of different crops. Combine headers require the use of a drive shaft to power and rotate a reel during operation. Three types of drive shafts are manufactured in MacDon's facility through the same process path.

This report will detail the final design for the Shaft Manufacturing Process improvement project sponsored by MacDon. In order to provide context for the final design, the project objectives and constraints will be reviewed along with the concept generation and selection performed. The report will then present the final design along with economic analysis and future considerations.

1.1 PROJECT BACKGROUND

A header attaches to the front of a combine and cuts the crop being harvested with a cutter bar along the bottom of the header. The crop is then pushed back by a rotating reel with metal teeth to the auger which moves the crop harvested to the center of the header. The crop is then transported by a conveyor into the combine. A MacDon header is shown in Figure 1.

[redacted]

Figure 1. MacDon combine header [2]

All headers manufactured at MacDon require a drive shaft that will rotate the reel during operation. An exploded view of a header with the drive shaft highlighted is shown in Figure 2.

[redacted]

Figure 2. Reel drive components [3]

The current process for manufacturing the reel drive shafts begins with a laser cutting operation to create a blank disc. This disc is then formed in a press to provide its conical shape shown in Figure 3. The disc is machined on a CNC lathe (Lathe 1) to provide a center hole. The disc is then mounted onto a pre-cut shaft using a robotic welding process. Weldments are then brought to the paint line in MacDon’s facility where they are powder coated. After powder coating, the weldments are machined at a second CNC lathe (Lathe 2) located in the same area as the first. This final machining process provides features such as disc holes, threads and slots as shown in Figure 3. At this point production of the reel drive shaft is complete.

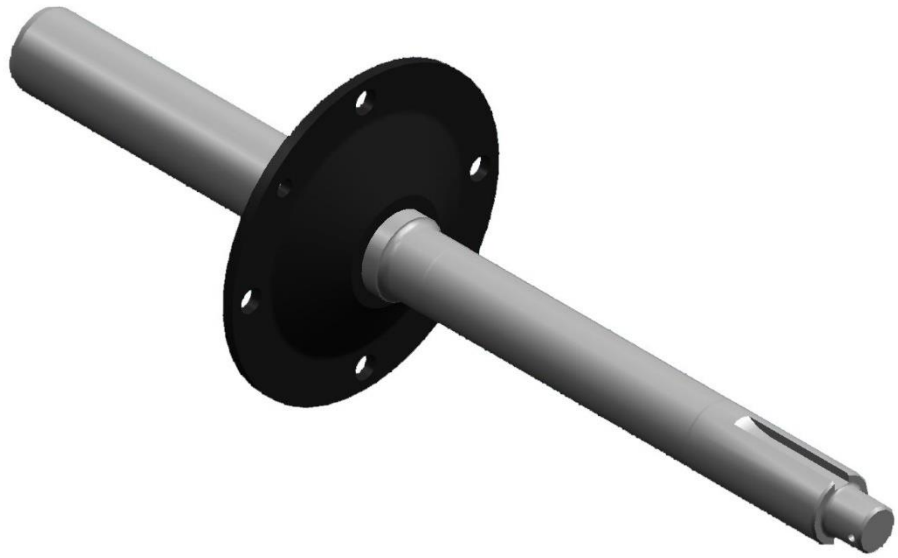

Figure 3. Reel drive shaft render [4]

1.2 PROBLEM STATEMENT

The current process for manufacturing reel drive shafts requires a large amount of movement for work in progress (WIP) through MacDon's facility. This excessive movement is time consuming, labor intensive and results in damaged units during transport and forklift traffic. The current process path is shown in Figure 4. Stations on the facility layout are summarized in TABLE I.

TABLE I: PROCESS STATIONS

Station #	Description
1	Laser Cut
2	Press
3	CNC Lathe
4	Welding
5	Paint
6	Inventory

[redacted]

Figure 4. Current process path [5]

TABLE II breaks down each movement individually by distance. The total distance travelled by units during production is approximately 966m.

TABLE II: PROCESS MOVEMENTS

Movement #	**Distance [m]**
1 (Dark blue)	19.7
2 (Green)	38.6
3 (Light blue)	150.8
4 (Yellow)	198.8
5 (Beige)	256.3
6 (Red)	301.6
Total	**965.8**

Assembly staff report that approximately two drive shafts are found damaged per day. If required, re-work increases non-value-added time to the process. Additionally, current batching practices involve the use of an inventory area where completed units are stored until they are needed for assembly. MacDon would like to move towards a batching system that manufactures quantities to meet the daily demand, removing the need for inventory.

1.3 OBJECTIVES AND CLIENT NEEDS

The objective of this project was to design a process improvement for the manufacturing of reel drive shafts in MacDon's facility. Key aspects of the improvement would include reducing distance traveled by units during manufacturing, reducing WIP and reducing non-value-added time in the process. The process improvement would also facilitate the transition to a manufacturing schedule which meets the daily demand, removing the need for inventory.

Deliverables to the client include:

- A floor plan of the new process layout.
- A bill of materials for the new process.
- A manufacturing schedule to produce the drive shafts.

Client needs were established through interview with the client and site visits. TABLE III shows the finalized list of client needs. Each need was ranked from 1 to 5, with 5 being the highest priority. This list of metrics and rankings would serve as the basis for the criteria in deciding a concept.

TABLE III: CLIENT NEEDS

#	NEED	IMPORTANCE
1	Provide a suitable payback period	5
2	Reduce the distance travelled by the work in progress	5
3	Reduce the amount of work in progress	5
4	Minimize non-value-added time	5
5	Produce the three specified reel drive shafts	5
6	Reduce the amount of handling in transport	4
7	Reduce the number of damaged products in transport	4
8	Simple for operators to use	4
9	Improve the existing storage and transport container system	4
10	Minimize space used in the facility	3
11	Simple to maintain	3
12	Simple to implement into the overall shaft manufacturing process	3
13	Simple to install	2

1.4 METRICS

After client needs were established, metrics were chosen to quantify each need. The relative importance and relationship between each metric were analyzed using a house of quality chart to establish critical metrics. Targets for the metrics were then chosen with input from the client and marginal and ideal benchmarks were set for each. TABLE IV shows which needs are quantified by each metric, the relative importance of each metric and the marginal and ideal target values.

TABLE IV: PROJECT METRICS

Metric #	Need #'s	Metric	Importance (%)	Units	Marginal Value	Ideal Value
1	1,2,5,6, 9,10	Number of movements the part makes between processing	17	Quantity	6	4
2	1,5,6,10	Part distance travelled	13	Meters	598	498
3	3,4,7,12	Operators have positive feedback regarding the process	11	Yes/No	Yes	Yes
4	6,9	Units damaged	7	Qty/8 hr. shift	2	0
5	1,2	Work in progress	8	Qty/day	100	54
6	8,13	Payback period	14	Years	3	2
7	3	Introduction of new hazards	7	Yes/No	No	No

1.5 CONSTRAINTS

Project constraints were established through client interviews and site visits at MacDon's facility. A refined list of constraints is listed below:

- Quality of the product: The final product must adhere to the current manufacturing standards observed at MacDon. The design must be within desired quality levels and a set maximum number of acceptable defects.
- Alteration of the fabrication process: The fabrication process must be completed in the same sequence. The fabrication process has already been optimized and therefore changes could lead to unforeseen lead time in other processes. In addition to this, processes are completed in their current sequence to ensure that machined surfaces are aligned with the axis of the shaft, which could not be guaranteed if all machining processes were to occur first and welding were to occur afterwards.

- Product specifications: The final product must conserve the same specifications required from the engineering team to be able to fit and operate properly. The unique characteristics of the product ensures that features for the 3-reel drive shafts are maintained in the new process.
- Available space: The design can only occupy as much space as currently available on the production floor and therefore the design is limited to a space constraint. This constraint is dependent on the location considered. As multiple locations were available for equipment relocation, space constraints are highlighted in the detailed design section of this report as necessary.
- Safety: The design must not introduce safety hazards to operators. Any new risks that may be introduced from new equipment must be accommodated with the necessary safety features.

2 CONCEPT GENERATION AND SELECTION

Concepts were developed through internal research performed during site visits at MacDon's facility as well as individual brainstorming. A concept development meeting was held with all team members to combine concepts and create a list of finalized concepts. These concepts were then reviewed with the client for feedback.

Concepts were broken into two categories to address multiple requirements of the final design shown in TABLE III. Main concepts were developed to address the highest priority needs such as reducing unit movement during production, non-value-added time and work in progress (WIP). Material handling concepts were developed to address lower priority needs such as improving the system for transporting WIP during production and reducing unit damage during transport. The winning concepts from each category were ultimately combined to form the concept which would be used in final design.

2.1 MAIN CONCEPTS

Main concepts consisted of relocating the second lathe used in the production process of the reel drive shafts (Lathe 2) to a location closer to the inventory and assembly areas in order to reduce the need for backtracking and excess movement in the facility. Three different locations were considered for this concept. Locations included the paint line, a new area opening in the plant due to the removal of assembly equipment as well the welding area. This concept was quite simple but could greatly reduce the required amount of travel during the overall manufacturing of the drive shafts. Specifically, moving Lathe 2 to the paint line could yield a distance reduction of 46% compared to the current process used.

The concept of creating a dedicated manufacturing cell for the drive shafts was also considered. The added benefit of a manufacturing cell concept over simply relocating a lathe, was that WIP could be greatly reduced, as operators would no longer need to wait for WIP to build up at one process before moving it to the next process. Additionally, a batching schedule could be implemented to manufacture the daily required demand of drive shafts each day, eliminating the need for inventory.

Through investigation of the current drive shaft manufacturing processes and discussion with the client, the team was able to determine which processes could be grouped into a manufacturing cell. As laser cutting and pressing equipment used for the drive shaft discs is shared between multiple MacDon products, these processes would need to remain outside of the cell. It was also determined that the specific powder coating process used for the drive shafts would be extremely difficult to replicate on a smaller scale to incorporate into a manufacturing cell, therefore this process would remain at MacDon's paint line. This left three possible processes to include in the cell, the machining of discs, the welding of disc onto shafts, and the final machining of shaft features. Additionally, the current process uses two different lathes to perform machining on discs and shafts. These processes could potentially both be performed on the same lathe if it provided the capability. Three cell concepts were developed featuring different combinations of these processes. The contents of each configuration are summarized in TABLE V.

TABLE V: SUMMARY OF CELL CONCEPT CONTENTS

Configuration #	Cell Contents
1	• Welding • Shaft machining (Lathe 2)
2	• Disc Machining (Lathe 1) • Welding • Shaft Machining (Lathe 2)
3	• Disc and shaft machining (Single lathe) • Welding

The two locations available for a dedicated manufacturing cell were the paint line and the new area opening in the plant where assembly equipment was being removed. Both possible locations for the cell were evaluated to determine the impact on reducing WIP movement during production. All primary concepts are summarized in TABLE VI along with the distance travelled by units during production and the number of movements.

TABLE VI: SUMMARY OF PRIMARY CONCEPTS

#	Primary Concepts	Distance Travelled to Inventory (m)	Distance Travelled to Assembly (m)	Number of Movements
1	Lathe 2 Relocated to Paint Line	541.8	604.3	6
2	Lathe 2 Relocated to Welding Area	803.8	785.0	6
3	Lathe 2 Relocated to New Area	661.3	585.9	6
4	MFG Cell Configuration 1 at Paint Line	531.9	594.4	6
5	MFG Cell Configuration 1 at New Area	639.7	564.4	6
6	MFG Cell Configuration 2 at Paint Line	485.6	548.1	5
7	MFG Cell Configuration 2 at New Area	593.3	518.0	5
8	MFG Cell Configuration 3 at Paint Line	485.6	548.1	5
9	MFG Cell Configuration 3 at New Area	593.3	518.0	5

Project metrics as discussed in Section 1.4 were placed in a head to head comparison to determine the weight of each metric. These weights were then placed into a weighted decision matrix along with each primary concept to determine a winner. The winning concepts included Configuration 2 and 3 of the manufacturing cells located at the paint line.

To determine a single winning concept, a capacity analysis was performed to determine if a single lathe manufacturing cell (Configuration 3) could handle the required amount of machining to meet the daily demand of 54 drive shafts (18 of each type). The capacity analysis is summarized in TABLE VII.

TABLE VII: SINGLE LATHE CELL CAPACITY ANALYSIS

Unit Type	Machining time per unit [hours]	Setup Time [hours]	Daily Demand (QTY)	Required Lead Time [hours]
Shaft Disc	0.033	0.75	54	1.8
Shaft (105364)	0.078	0.75	18	1.4
Shaft (137291)	0.189	0.75	18	3.4
Shaft (137451)	0.148	0.75	18	2.7
Subtotal		3		9.3
Total				**12.3**

Using a production schedule of two 8-hour shifts per day, the single lathe would be more than capable of meeting the daily demand of drive shafts. Based on this analysis along with feedback from the client, it was decided that the Configuration 3 manufacturing cell located at the paint line was the best concept and would be pushed forward into detailed design.

This dedicated manufacturing cell for the reel drive shafts would feature a single lathe capable of performing machining on both the discs and shafts, as well as the welding operation. Both automated and manual operator handling options would be designed and analyzed for this configuration of manufacturing cell.

2.2 MATERIAL HANDLING CONCEPTS

Material handling concepts which would address lower priority needs such as improving the system for transporting WIP during production and reducing unit damage during transport were generated and are summarized in TABLE VIII. Automated solutions such as an autonomous transport cart and robotic loading into carts at each station were considered. Part protection to apply to finished units which could protect machined features during transport was also considered. Transport systems such as overhead gantry or a conveyor belts were considered for the movement of units specifically between the dedicated manufacturing cell and the paint line. Finally, a transport cart concept designed by MacDon was provided to the team and considered. This concept implemented the fixtures required to attach drive shafts to the paint line into a mobile cart, reducing a handling step. A prototype of this cart was manufactured for use in MacDon's facility but was not implemented into their current process.

TABLE VIII: SUMMARY OF MATERIAL HANDLING CONCEPTS

#	Material Handling Concepts
1	Automated cart
2	Robot loading into carts
3	Part protection (after part completion)
4	Use of modified paint line bar for transport
5	Overhead gantry (from cell to paint and return)
6	Conveyor belt (from cell to paint and return)
7	Concept transport cart (Designed by MacDon)

All secondary concepts were placed in a weighted decision matrix to determine the winning concept. The concept transport cart designed by MacDon was the material handling concept winner and would ultimately be combined with the single lathe manufacturing cell to create the final design for the project. The transport cart is shown below in Figure 5.

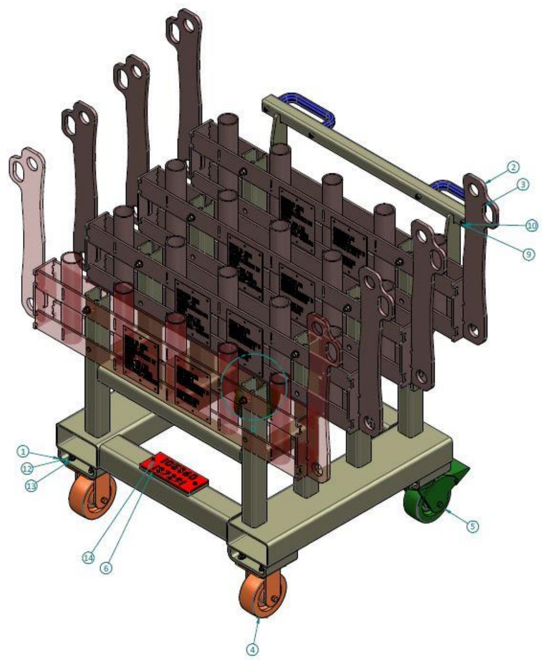

Figure 5. Transportation cart designed by MacDon [4]

Four painting fixtures are mounted to the cart, each capable of holding five-reel drive shafts. This design would provide a large reduction in handling during the painting process as the implemented fixtures allow for the attachment of five draft shafts to the paint line at once. Currently each drive shaft is individually mounted to the paint line one at a time. In addition to this, the cart would be used to transport units to and from the dedicated manufacturing cell. Each fixture holds the drive shafts in an upright orientation and prevents units from touching each other, which would prevent any damage of units during transport.

3 DETAILED DESIGN

The final design features a dedicated manufacturing cell to produce reel drive shafts. The cell includes a single CNC lathe capable of performing all required machining processes on discs and shafts, as well as a custom welding solution for mounting discs onto pre-cut shaft lengths. In combination with the manufacturing cell, a custom transport cart designed by MacDon is used to transport weldments and finished drive shafts during production. This cart incorporates the fixture required for attaching drive shafts on to the paint line, reducing handling, and protects units from damage. Required specifications and cell layouts were developed for both an automated and manual handling configuration of the cell.

3.1 EQUIPMENT SPECIFICATIONS

Specifications for new machinery to be included in the manufacturing cell were determined through evaluating the machinery currently used in manufacturing the reel drive shafts. As MacDon would typically use a competitive bidding system when determining a supplier for equipment in a capital project such as this, detailed specifications for the required cell equipment are provided without specific reference to a brand or model. Suppliers were contacted and additional feedback was received, which was used to create specifications for the equipment.

Certain specifications of the required lathe were kept the same as the current lathe to ensure that the driveshaft could be made. Milling capabilities, an automatic door, external coolant, chip collection bins and a 12-inch chuck are all features that were kept. The milling and turning capabilities of the machine are both required to manufacture the drive shaft. The machine must perform turning operations for the threads and thickness of the drive shaft as well as perform milling operations to machine the holes in the disc. A robot interface and an automatic door are required for the automated handling option. This will allow the lathe process to be integrated with the loading and unloading of parts by a handling robot. The coolant, chip collection and chuck size were all kept the same as the current lathe. These options are all compatible with the current process and with an automated or manual handling cell.

The only difference between requirements for the new lathe and the existing one used in the current process was that the bed length was shortened to 500mm, which is compatible with the largest reel drive shaft. This could be done since the new lathe in the manufacturing cell will be strictly dedicated to manufacturing reel drive shafts and will not need to accommodate larger parts. This results in a smaller overall lathe footprint, which saves space in the manufacturing cell. The specifications from the new lathe compared to the current lathe can be seen in TABLE IX. The motor that meets the mechanical power requirements for the proposed lathe is a 3-phase 220V 50/60 Hz motor [6].

TABLE IX: NEW AND CURRENT LATHE PROPERTIES COMPARISON

CNC Lathe Properties		
Current Lathe	**New Lathe**	**Benefits**
Milling Capabilities	Milling Capabilities	Capability maintained
Automatic Door	Automatic Door	Capability maintained
12-inch Chuck	12-inch Chuck	Capability maintained
800mm bed	500mm bed	Overall footprint of lathe reduced
External Coolant	External Coolant	Capability maintained
Chip Collection Bin	Chip Collection Bin	Capability maintained
No Robot Interface	Robot Interface	Compatible with Automation

The design also calls for a custom welding solution. This solution features 2 degrees of freedom including a part fixture capable of rotation. This will allow the welding arm to weld around the circumference of the driveshaft. The welding solution features three fixtures, allowing driveshafts to cool while others are being worked on. Since a custom welding solution such as this is not an off the shelf product, discussions were held with a local supplier capable of engineering a suitable solution. A cost was estimated based off a previous project that MacDon had completed with said supplier.

The handling robot requires 6 degrees of freedom to ensure it can perform the manipulation of parts required for loading and unloading into equipment. A vision system would be required to perform loading of discs, pre-cut shaft lengths, as well as weldments. This ensures discs and shaft lengths can continue to be transported in the carts currently used. A payload of 12kg is required to ensure it is capable of loading/unloading the heaviest shaft which is 6.76kg, with still approximately 5kg remaining for the robot's end effector. A robot with these specifications requires a 380-575V 50/60Hz 3 phase electrical connection [7].

The protective barrier around the cell will completely enclose the process and have an automatic stop at entry points of the cell which are triggered if an operator were to enter while the process is active. Entry ways to the barrier will need to provide enough space to allow for easy maneuverability of materials carts in and out of the cell. Additionally, they will be large enough to provide access for a standard sized forklift should this be necessary for moving carts.

A transportation cart is required to move parts to the cell and from the cell to either the paint line or assembly area. The cart must be maneuverable by hand and forklift compatible if necessary. The drive shafts are placed in removable racks in the cart, so that the parts can be removed from the cart and loaded onto the paint line. In addition, the cart should prevent contact between units, preventing damage from occurring during transport. A quantity of 6 carts is required. This ensures there are 3 available for the current days manufacturing, and 3 for holding the previous daily demand in the assembly area.

All the equipment required in the manufacturing cell along with their specifications can be seen in TABLE X. A full bill of materials with pricing can be seen in APPENDIX A.

TABLE X: REQUIRED MANUFACTURING CELL EQUIPMENT SPECS

Equipment Type	Required Specifications
CNC Lathe	• 18.12” turning length • 12” chuck • Robot interface (automation option only) • Automatic door (automation option only) • 500mm bed length • Milling capabilities • External Coolant
Custom Welding Solution	• 2 degrees of freedom • <1 m reach • Welding fixture capable of rotation, must perform circular welds on shafts
Material Handling Robot (Automated option only)	• 6 degrees of freedom • 1.8 m reach • 12 kg payload • Part gripping fixture • Vision system for loading/unloading parts
Protective Barrier (Automated option only)	• Emergency stops at entry points • Gate sensors to stop machinery if a gate is opened while the process is running, also to prevent machinery from starting if gate is currently open.
Transport Cart (Designed by MacDon)	• Compatible with forklift transportation • Can be pushed by hand • Removable sections to allow loading of multiple units on paint line at one time • Can carry up to 20 units • Quantity of 6 required

3.2 MANUFACTURING CELL LAYOUT

Layouts for both automated and manual handling configurations of the cell were created. The automated cell layout was designed first, as it required additional features such as a protective barrier and additional safety features to mitigate risks introduced by a handling robot. The automated layout was then modified for the use of a manual operator in the cell.

3.2.1 Automated Handling Cell Layout

The automated manufacturing cell utilizes a protective barrier which encompasses the work area of the automated robot. The maximum width of the barrier is 12ft (144in) to meet the space constraint in the paint line location. The length of the cell does not have a specific constraint, however, was kept as short as possible at 24ft (188in).

The footprint from a CNC lathe (Okuma LB3000 EXIIM [6]) matching the required specifications was used to create the layout. The rear chip dispensary option was selected instead of a side chip dispensary to allow for the CNC lathe to be positioned closer to the bottom barrier shown in Figure 6. This ensures there is an access path 3 feet wide along the left side of the machine, where the coolant tank access point is located. It also allows enough space for operators to walk to the back of the machine during maintenance if necessary. The work area of the 1.8m reach handling robot is marked in red. As shown in Figure 6, the robot has enough reach to access all required equipment and material loading areas without full extension.

Designated areas for material carts are marked in orange, these areas are 40in x 36in to allow for positioning of the concept transport cart shown in Figure 5 as well as the carts used for storing discs and pre-cut shaft lengths. Extra cart storage is provided outside the cell entrance for WIP that arrives at the cell while operations are ongoing. The main entrance to the cell is 6ft wide, allowing space for carts to maneuver in and out of the cell either manually or via the use of a standard sized forklift. The rear entrance to the cell is 5 feet wide, allowing suitable space for a standard sized forklift to remove the chip dispensary bin. A location for storing coolant required for the CNC lathe is also shown directly outside the right cell barrier. The programmable logic controller (PLC) station is located to the left of the main cell entrance. This allows the cell operator clear vision of all processes occurring in the cell during operation.

The manufacturing cell layout for the automated handling solution is shown in Figure 6. To ensure visual clarity, dimensions are not shown in this cell layout. A drawing providing critical dimensions of the cell is provided in APPENDIX B.

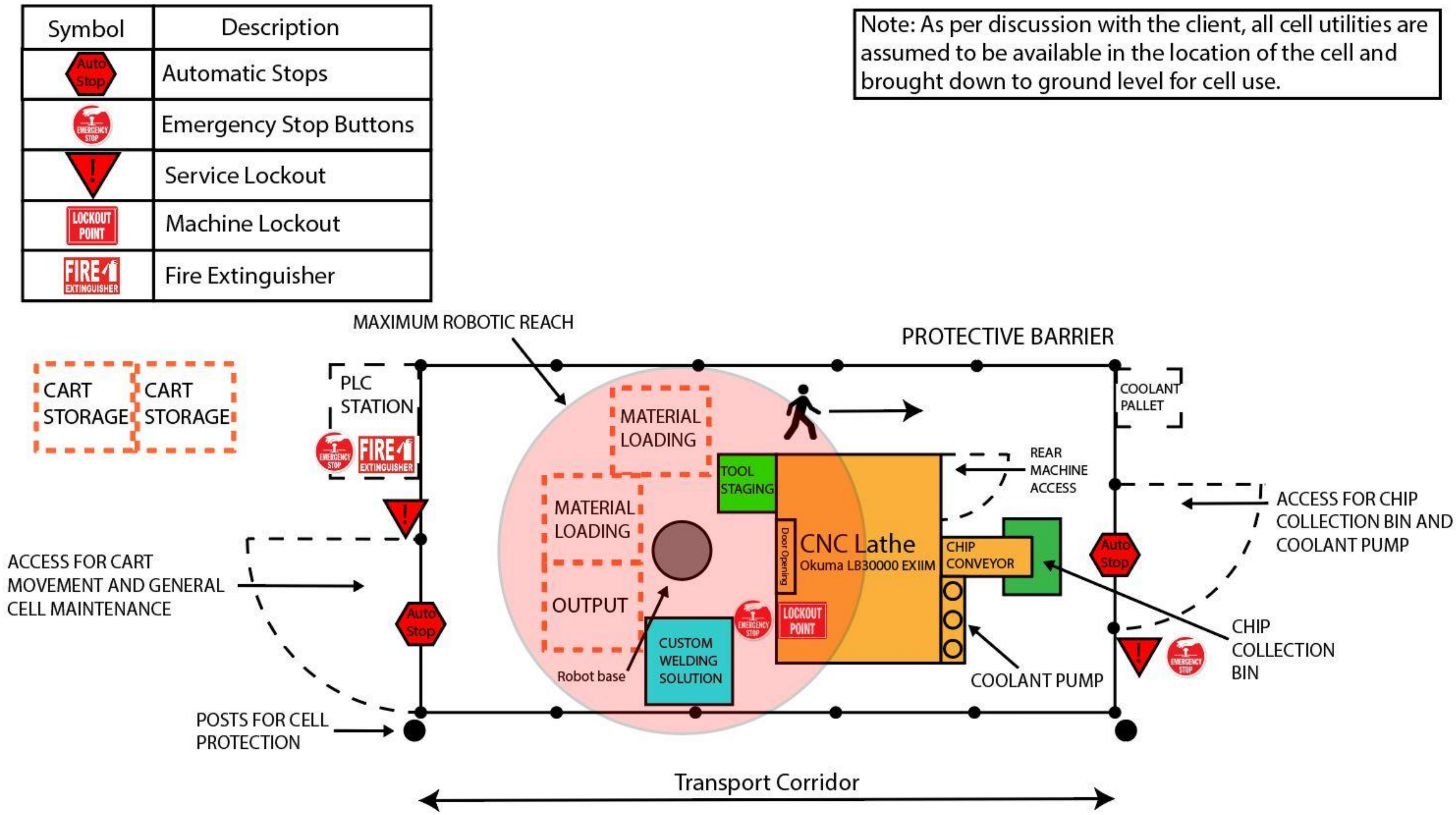

Figure 6. Automated handling cell layout

Safety features were added to the automated cell layout to mitigate risks introduced by the automated handling robot. In addition to the protective barrier, each entrance to the cell features automatic stop triggers, so that if barrier doors are opened during operation, all cell processes immediately stop. Manual stop buttons are located at each entrance to the cell, allowing operators outside the cell to stop cell operations if necessary. Service lock out points are provided at each cell entrance to allow for operators to electronically lockout the cell during maintenance. A fire extinguisher is also located at the PLC station, readily accessible to the managing operator in the case of fire. Steel posts are installed at each corner of the cell facing the transport corridor directly beside it. This provides additional protection for the cell from any traffic passing through this corridor.

3.2.2 Manual Handling Cell Layout

The manual cell features certain key differences from the automated cell to create a layout for a cell that would use a single manual operator as shown in Figure 7. Because the cell would not use a robot, the protective barrier surrounding the cell and automatic stop features were not necessary. Protection posts were left in place to protect any personnel and equipment from traffic passing through the transportation corridor beside the cell.

The CNC lathe was left in the same location as the automated cell, maintaining access to the side and rear of the machine for maintenance and chip bin removal. Locations for material carts were moved along the side of the cell as shown in Figure 7, creating a corridor for the operator to access the workspace where the CNC lathe and welding solution are easily accessible. Additional space for material carts is located outside the cell. Dimensions are not included on the layout in Figure 7 to ensure visual clarity. A dimensioned drawing of the manual handling cell layout is provided in APPENDIX B.

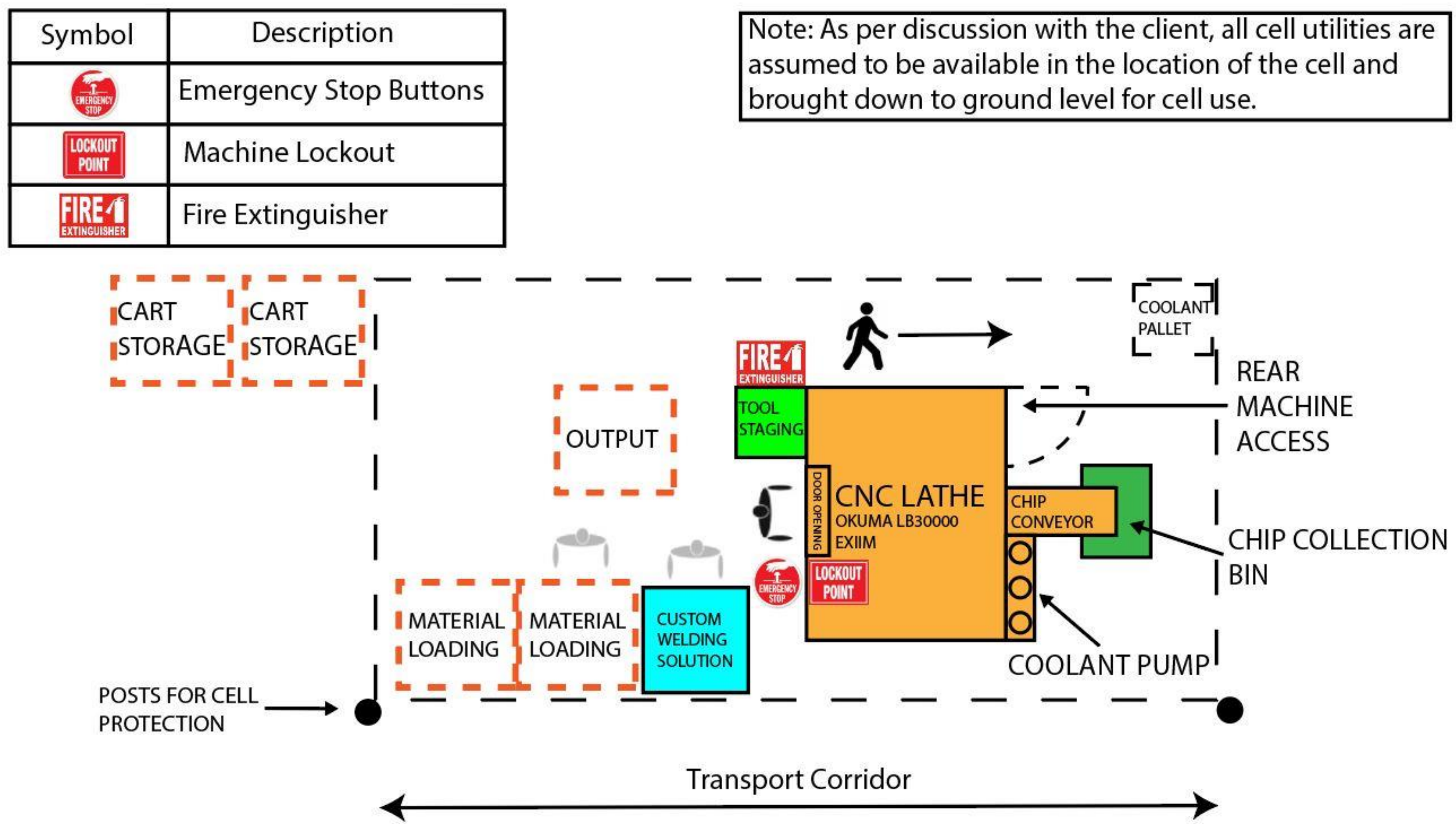

Figure 7. Manual handling cell layout

3.3 DESIGN IMPLEMENTATION AND NEW PROCESS PATH

The cell would encompass machining processes for the discs and shafts, as well as the welding operation. This still leaves three required processes for the shafts outside of the cell, all of which precede processes inside the cell. These include laser cutting, pressing and painting. To determine the distance reduction provided by the dedicated manufacturing cell and how it would be implemented into the current process path, a new process path was developed as shown in Figure 8. Process stations are summarized in TABLE XI.

TABLE XI: NEW PROCESS STATIONS

Station #	Description
1	Laser Cut
2	Press
3	Manufacturing Cell
4	Paint
5	Assembly
6	Inventory

[redacted]

Figure 8. New process path [5]

Production of the shafts still begins with a laser cutting process (station 1) to create the blank discs. These discs are then pressed at station 2. At this point in the process, the pressed discs are brought to the dedicated manufacturing cell (station 3), along with the pre-cut shaft lengths which MacDon purchases out of house. Machining of discs and the welding process which mounts the discs onto pre-cut shaft lengths is then carried out in the cell, the completed weldments are then sent to the paint line (station 4) for powder coat. Once this process is complete, they return to the manufacturing cell (station 3) for the final shaft machining process.

In the new process, the finished shafts would then be sent directly to assembly at station 5 as shown in Figure 8, as only the daily demand is manufactured, and the inventory area is not required. However, since the current process sends finished drive shafts to inventory, the path to inventory (station 6) has still been shown in Figure 8 for the purpose of comparison. Distances for each individual movement are summarized in TABLE XII.

TABLE XII: NEW PROCESS MOVEMENT DISTANCES

Movement #	Distance [m]
1 (Blue)	19.7
2 (Green)	298.0
3 (Yellow)	34.4
4 (Beige)	34.4
5 (Red)	98.9 (to inventory) 161.5 (to assembly)
Total	**485.8 (to inventory) 548.1 (to assembly)**

The total distance travelled by units in the new process is approximately 486m when units are brought to inventory, and approximately 548m when units are brought directly to assembly. This is a 51% and 45% reduction in total distance travelled during production respectively when compared to the current process path.

3.4 PRODUCTION SCHEDULE AND ANALYSIS

Analysis was performed to determine the capability of the manufacturing cell when performing all necessary processes to meet the daily demand of reel drive shafts. To perform the production analysis, a production schedule for the cell was developed. The schedule would run processes in parallel when possible to ensure maximum utilization of equipment, as well as maximum utilization of a handling robot or operator.

Process times were provided by the client for each of the current processes based on a fixed quantity. For example, the standard run labor for machining a batch of 100 discs is 3.3 hours as shown in TABLE XIII. This value was divided by the quantity to determine the run time per unit for each process.

TABLE XIII: SUMMARY OF PROCESS TIMES

Process	Quantity	Standard Run Labor [hours]	Run Labor per unit [hours]	Run Labor per unit [minutes]
Disc Machining	100	3.3	0.033	1.98
Shaft Machining (105364)	100	7.8	0.078	4.68
Shaft Machining (137291)	100	18.9	0.189	11.34
Shaft Machining (137451)	100	14.8	0.148	8.88
Welding	40	3.52	0.088	5.28

In performing the production analysis, the following assumptions were used:

- The manufacturing cell would be operational for two 8-hour shifts per day
- Manufacturing processes which precede processes located in the cell would be offset by one day and delivered to the cell by shift start, meaning production could begin in the cell immediately at the start of each day
- Process times for all equipment in the cell would be the same as the current process, therefore, process time data from the current process which was provided to the team by MacDon would be used in the analysis
- Process times per unit obtained from data provided by MacDon include loading/unloading time for that unit
- Loading/unloading time for an automated robot and human would remain the same, as data was not available to prove otherwise

The first shift of the day would begin at 8am. As per assumptions stated, processes preceding the cell would be complete by shift start, meaning a quantity of 54 laser cut and pressed discs as well as pre-cut shafts lengths would be readily available at the cell. The shift would begin with a machine setup to prepare the CNC lathe for processing the discs. This would require a duration of 0.75 hours (45 min) as provided in data from the current process. Cell operations would then begin by processing the first disc. This would require 1.98 minutes as shown in TABLE XIII. After the first disc is processed, it would be unloaded from the CNC lathe and loaded into the custom welding fixture along with the required pre-cut shaft lengths. The welding operation would then take place, requiring a duration of 5.28 minutes. During these 5.28 minutes, it would be possible for the robot/operator to run an additional disc through the CNC lathe at 1.98 minutes. After which, the welding operation will have completed, and the finished weldment would be unloaded. The next disc which has already been machined would then be loaded into the welding solution. Three iterations of this sequence are shown in TABLE XIV and represent a portion of the full schedule.

TABLE XIV: DISC MACHINING AND WELDING SEQUENCE

Cell Schedule			
Task	**Required Time [mins]**	**Simulataneous Task**	**Required Time [mins]**
Machine setup for Discs	45		
Load Disc	1.98		
Machine Disc			
Unload Disc			
Load Parts (137291)	5.28	(Robot in use)	1.65
Weld Disc (137291)		Load Disc	1.98
		Machine Disc	
		Unload Disc	
Unload Weldment (137291)		(Robot in use)	1.65
Load Parts (137291)	5.28	(Robot in use)	1.65
Weld Disc (137291)		Load Disc	1.98
		Machine Disc	
		Unload Disc	
Unload Weldment (137291)		(Robot in use)	1.65
Load Parts (137291)	5.28	(Robot in use)	1.65
Weld Disc (137291)		Load Disc	1.98
		Machine Disc	
		Unload Disc	
Unload Weldment (137291)		(Robot in use)	1.65

The sequence shown in TABLE XIV would repeat for 18 cycles until 18 weldments for that specific shaft type were complete. At this point, the batch of 18 weldments would be removed from the cell and sent to the paint line. The process would then continue in the same format with the next type of weldment being completed. A detailed manufacturing schedule is provided in APPENDIX C.

As shown in the schedule in APPENDIX C, 54 weldments are complete (18 for each shaft type) after approximately 5.5 hours of cell operation (1:30pm). A CNC lathe changeover is then performed to prepare for the final machining on the weldments after they are painted. This takes approximately 0.75 hours (45 minutes) as provided in the current process data. Utilizing a paint line lead time of 4 hours, the first batch of weldments arrives back at the cell at approximately 2:22pm, leaving a suitable amount of time for the CNC lathe changeover. When the first batch of painted weldments arrives back at the cell, the shaft machining process begins.

During the shaft machining stage, the CNC lathe is the only process running in the cell, along with the loading and unloading of shafts performed by the robot/operator. Three cycles of the sequence for shaft machining are show in TABLE XV. The entire sequence is shown in the detailed manufacturing schedule provided in APPENDIX C.

TABLE XV: SHAFT MACHINING SEQUENCE

Load weldment (137291)	11.34		
Machine (137291)			
Unload shaft (137291)			
Load weldment (137291)	11.34		
Machine (137291)			
Unload shaft (137291)			
Load weldment (137291)	11.34		
Machine (137291)			
Unload shaft (137291)			

TABLE XV shows the sequence for machining the 137291-drive shaft, which requires a process time of 11.34 minutes as shown in TABLE XIII. After this sequence has repeated 18 cycles, the batch of 137291-drive shafts is complete and would be removed from the cell and sent to assembly. The machining process for the next type of shaft would then begin. This process would continue until all 54 shafts (18 of each type) have been completed and sent to inventory, at which point the cell is finished operations for the day. As shown in APPENDIX C, shaft machining is completed after 13.8 hours of cell operation (9:50pm).

In developing the cell manufacturing schedule, it was determined that the order in which each type of weldment was produced was crucial. For example, if the 105364 weldments were to be completed first and sent to the paint line. They would then be the first set of weldments to return to the cell for shaft machining. However, the 105364 shafts have the lowest machining time by a substantial margin at 4.68 minutes as shown in TABLE XIII. Completion of these shafts would occur before the next batch of painted weldments has arrived at the cell, meaning there would be a period of cell inactivity. To avoid this, weldments for the 137291 shafts which have the highest machining time at 11.34 minutes are completed first and sent to the paint line. Therefore, machining for the 137291 shafts will occur first with the highest duration of overall machining time. This allows ample time for the next two batches of painted weldments to arrive at the cell, meaning as soon as machining of the 137291 shafts is complete, the next batch of weldments is waiting at the cell. This ensures the cell is constantly active. Critical times from the manufacturing schedule are shown in TABLE XVI.

TABLE XVI: SUMMARY OF CRITICAL MANUFACTURING TIMES

Time of Day	Description
8:00	Setup for disc machining on CNC lathe begins
8:45	Setup for disc machining on CNC lathe finishes
8:45	Machining of first disc begins
8:47	Welding for 137291 shafts begins
10:22	137291 weldments complete and sent to paint line (QTY 18)
10:22	Welding for 137451 shafts begins
11:57	137451 weldments complete and sent to paint line (QTY 18)
11:57	Welding for 105364 shafts begins
13:32	105364 weldments complete and sent to paint line (QTY 18)
13:32	Setup for shaft machining on CNC lathe begins
14:17	Setup for shaft machining on CNC lathe finishes
14:22	137291 painted weldments return to cell (QTY 18)
14:22	137291 shaft machining begins
15:57	137451 painted weldments return to cell (QTY 18)
16:00	Day shift ends, evening shift begins
17:32	105364 painted weldments return to cell (QTY 18)
17:46	Machining of 137291 shafts complete, finished batch sent to assembly (QTY 18)
17:46	137451 shaft machining begins
20:26	Machining of 137451 shafts complete, finished batch sent to assembly (QTY 18)
20:26	105364 shaft machining begins
21:50	Machining of 105364 shafts complete, finished batch sent to assembly (QTY 18)

As shown in the table, cell operation finishes at approximately 9:50 pm (13.8 hours of cell operation), leaving just over 2 extra hours at the end of the second 8-hour shift. The result of this analysis was that the manufacturing cell provides enough capacity to manufacture the daily demand of drive shafts required in MacDon's facility. Approximately two extra hours are left at the end of the second 8-hour shift, this extra capacity is available should MacDon decide to increase production to include a safety stock, or if daily demand increases over time.

When compared to the current process, the new manufacturing cell reduces the work in progress from 120 units to 54 units, a 55% reduction.

3.5 TRANSPORT COST

To obtain a cost for the transportation of the drive shafts, the distances calculated in the current and new processes were converted to time. This was done using the average forklift speed in MacDon's facility of 5km/h. The distance traveled from the start of the process to the end was divided by the forklift speed, which gives an estimate for the time the driveshaft spends in transport. It was then multiplied by MacDon's hourly forklift rate of $169 to give the cost of the time spent in transport.

To quantify distance travelled in the current process, provided production data for the past year was analyzed to determine the number of batches run per day for each process. This was then used to determine distance. The new production schedule was then analyzed to determine the required distance travelled for the new process.

The cost of time for the current process and the new proposed process can be seen in TABLE XVII. As shown in TABLE XVII, the new process provides a yearly transport savings of $14,699.86.

TABLE XVII: TRANSPORT COST

	Current Process	Designed Process	Difference
Distance Traveled (m)	2322	833	1489
Time in Transport (hrs/day)	0.6104	0.2666	0.3438
Cost of transportation/year	$26,098.87	$11,399.02	$14,699.86

3.6 COST AND ECONOMIC ANALYSIS

Economic analyses were completed to show the benefits of implementing this project's design. In addition to showing the monetary benefits of the design, another objective for the economic analyses is to show which version of the manufacturing cell (automated or manual handling) would provide the greatest benefit over an extended period of time. As one of the metrics for this project, payback period was one of the analyses that were completed. Since a payback period calculation is limited in how it represents an investment after the break-even point, the team also completed a net present value (NPV) analysis.

Prior to completing the analyses, a list of economic assumptions was created to ensure what factors would stay the same and which would change. Each of the analyses utilized data that was as accurate as could be collected within the scope of the project. The team attempted to obtain quotations for equipment but were unable to receive quotations from various suppliers. In these cases where the team was unable to achieve quotations, estimates from industry experts as well as estimations from previous projects that the client had received were used. Each of the analyses compared the automated handling and manual handling cells against the current process, analyzing the initial outlay costs (N/A for current process), recurring annual costs, as well as additional cash inflow that would be expected should one of the designs be implemented. The additional cash inflow between each of the designs and the current process is represented by the difference between the expected annual costs and the current annual costs.

Prior to discussing the analyses and their results, these are the economic assumptions that were utilized to complete the analyses.

3.6.1 Economic Assumptions

The team determined the economic assumptions that were used to complete the analysis. The assumptions are as follows:

- The number of operators that should be used to operate an automated handling cell is between 0.5 and 1. Both limits will be calculated.
- The number of operators that would be used to operate a manual handling cell is 1.5.
- The number of operators that would be used to operate the current process was 2.
- Transport costs as determined in section 3.5 were utilized within the analyses as variable costs.
- Integrator cost when not provided as a quote or estimation was included at a rate of an additional 75% of equipment cost as per industry experts' recommendation.

- Work hours for the designed process were calculated to be 13.84 hours per day to produce 54 units. For the other portions of time within a day, each operator will be completing other tasks that are not “billed” to the process.
- Work hours for the current process were calculated to be 12.3 hours per day.
- The annual number of workdays is assumed at 253 days.
- Welding will be completed using additional equipment and not using the material handling robot. Additional studies are required to determine the full schedule capacity of the material handling robot. A custom welding solution will be required for both the manual and automated handling cell.
- Maintenance amongst the lathes is assumed to be similar or the same, maintenance for the current process is assumed to be higher due to the additional lathe.
- For the NPV analysis, a default rate of return of 5% was used.
- For the NPV analysis, a lifecycle of 10 years was used for machine life.
- For the NPV analysis, an increase in annual variable costs of 2% was assumed.
- Due to the shorter length of time, increases in expenses (labour and maintenance) were not considered for the payback period analysis.

3.6.2 Payback Period Analysis

The team completed a payback period analysis as it was a one of the metrics that the design had to be measured against. A payback period analysis determines the length of time a company must wait for an investment to pay back the initial outlay cost.

The annual variable costs of the current process are summarized in TABLE XVIII.

TABLE XVIII: CURRENT PROCESS VARIABLE COSTS

MacDon		*Current Process*
Current Variable Costs	Daily	Annually
Operators (2x12.3 hours)	$1,353	$342,309
Lathe Maintenance		$10,000
Transport Costs		$26,099
Sum of annual cost		$378,408
Hourly Labour Rate	$55	

The payback period was calculated using the initial outlay costs (investment) divided by the difference between current annual outflow costs and the new annual outflow cost which signifies the additional cash inflow that would be created as a result of the investment. This is shown in the following calculation:

$$Payback\ Period = \frac{Initial\ Outlay\ Cost}{Current\ Annual\ Cash\ Outflow - New\ Annual\ Cash\ Outflow}$$

The payback period for the automated handling cell was calculated under half operator operation which resulted in a payback period of 2.15 years and was also calculated for single operator operation which resulted in a payback of 3.42 years. The results of the payback period analysis are shown in TABLE XIX along with the initial outlay costs associated with installing an automated handling cell. The approximated annual costs for the automated are summarized as well.

TABLE XIX: INITIAL OUTLAY COSTS AND PAYBACK PERIOD FOR AUTOMATED HANDLING CELL

MacDon		*Automated Handling Cell*
Initial Outlay Cost Description		Cost
Lathe		$252,647
Material Handling Robot with Vision System		$130,000
Custom Welding Solution		$34,231
PLC (software and HMI)		$6,000
Integration (Lathe, Welding Solution)		$29,470
Integration (Robot, PLC)		$102,000
Transport Carts		$5,694
Misc		$1,546
Total		$561,588
Automated Cell Variable Costs	Daily	Annually
Robot Maintenance		$10,000
Operator (1x13.84 hours)	$761	$192,584
Transport Costs		$11,399
Sum of Variable Costs (Annually)		$213,983
Payback Period		
Using 1 full time operator	**3.42**	**Years**
Using 0.5 full time operator	**2.15**	**Years**

The associated costs with the manual handling cell along with its payback period are summarized in TABLE XX. The payback period for the manual handling cell was 4.26 years.

TABLE XX: INITIAL OUTLAY COSTS AND PAYBACK PERIOD FOR MANUAL HANDLING CELL

MacDon		*Manual Handling Cell*
Initial Outlay Cost Description		Cost
Lathe		$240,437
Custom Welding Solution		$34,231
Integrator		$29,470
Transport carts		$5,694
Misc		$1,546
Total		$311,378
Manual Cell Variable Costs	Daily	Annually
Operator (1.5x13.84 hours)	$1,142	$288,875
Lathe Maintenance		$5,000
Transport Costs		$11,399
Sum of Variable Costs (Annually)		$305,274
Payback Period		
New Lathe (Purchaser's Option)	**4.26**	**Years**

This type of analysis does not always indicate the full value of an investment because it stops showing value after the break-even point and therefore, tends to favor lower cost, shorter term solutions and opposes higher cost solutions that may be better over a longer period. For this reason, the team decided to complement the payback period analysis with a Net Present Value (NPV) analysis which is discussed in the following section.

3.6.3 Net Present Value (NPV) Analysis

As discussed in Section 3.6.2, payback period does not always indicate the best valued investment for the entire life of the investment. For this reason, the team completed a net present value analysis to determine which version of the manufacturing cell (automated or manual handling) truly provides the best value over the life of the investment.

The same initial cash outlay costs, and annual variable costs were used as shown in TABLE XIX and TABLE XX were used for this analysis. The purpose of a net present value calculation is to show the present value of future cash inflows which are affected by the "time value of money". For the NPV calculations a discount rate of return of 5% was used. This value of 5% was suggested by the team and was also accepted by the client. The discount rate of return is the rate at which the initial cash outlay would be invested to provide return on investment if this project was not implemented. A positive net present value represents an investment that returns a greater rate than the specified discount rate of return and a higher net present value represents a better investment. As described in Section 3.6.1, annual variable costs were indexed at 2% for labour and maintenance increases. The full calculations for the NPV analysis are included in APPENDIX D.

TABLE XXI depicts the results for the NPV analysis. The NPV for the automated handling cell was calculated using half of an operator where the net present value was $1,669,075 as well as using one operator where the net present value was $845,215. These calculations represent that reasonable bounds for labour while using the automated cell. In this case, half of an operator is a more realistic number for operating a cell of this complexity, however a calculation using one operator was also given as a conservative estimate. Both options have a higher net present value than the manual cell which received an NPV of $314,344.

TABLE XXI: NET PRESENT VALUE ANALYSIS RESULTS

MacDon	Net Present Value (NPV)
Automated Cell (1 operator)	$845,215
Automated Cell (0.5 operators)	$1,669,075
Manual Cell	$314,344

Our team recommends that MacDon implements an automated handling cell using half an operator for operation due this option having the highest net present value.

4 CONCLUSION

The final design features a dedicated manufacturing cell to produce reel drive shafts, located beside the paint line in MacDon's facility. The cell is capable of performing all necessary machining for the discs and shaft features, as well as the required welding operation for reel drive shafts. Required equipment specifications have been determined for both an automated and manual handling configuration of the manufacturing cell. In combination with the dedicated cell, a transport cart designed by MacDon is used to transport weldments and completed drive shaft units during production. This cart incorporates fixtures required to hang drive shafts on the paint line, reducing handling. The cart also prevents drive shafts from contacting each other which prevents any damage during transport.

A production analysis was performed to evaluate the capabilities of the cell, based on the created manufacturing schedule in APPENDIX C, the cell is able to complete production for the daily demand of 54 reel drive shafts (18 of each type) after approximately 13.8 hours of operation. Based on two 8-hour shifts, this leaves approximately two extra hours of potential cell operation per day. This extra capacity may be utilized if MacDon were to decide to manufacture a safety stock, or if daily demand of the reel drive shafts increases over time.

A cost analysis was performed to establish payback periods for both automated and manual configurations of the manufacturing cell. The automated cell proved to provide a shorter payback period at 2.15 years, when compared to the manual cell's payback period of 4.26 years. Based on the cost analysis performed, the team proposes MacDon implement the automated handling manufacturing cell.

4.1 REVIEW OF PROJECT METRICS

Evaluated against the established benchmark metrics outlined in Section 1.4, the design proved to be successful. It met the ideal improvement targets for five out of the seven metrics, with two metrics meeting the marginal improvement target for the final design. The results of the metrics for the final design can be seen in TABLE XXII.

TABLE XXII: EVALUATION OF PROJECT METRICS

Metric	Units	Marginal Improvement	Ideal Improvement	Final Design	Evaluation of Metric
Number of movements the part makes between processing	Quantity	6	4	5	Marginal Improvement Target Met
Part distance travelled	Meters	598	498	486	Ideal Improvement Target Met
Operators have positive feedback regarding the process	Yes/No	Yes	Yes	Yes	Ideal Improvement Target Met
Units damaged	Qty/8 hrs. shift	2	0	0	Ideal Improvement Target Met
Work in progress	Quantity/shaft Type	100	54	54	Ideal Improvement Target Met
Payback period	Years	3	2	2.15	Marginal Improvement Target Met
Introduction of new hazards	Yes/No	No	No	No	Ideal Improvement Target Met

The final design was able to cut down the part movements to 5 which is a marginal improvement over the current process. This was achieved by grouping the welding and machining processes into a single manufacturing cell. Additional part movement was also removed as the result of a production schedule that sends the parts directly to assembly instead of to inventory then assembly.

The part distance traveled was reduced from 966m to 486m, a 50% reduction in distance traveled. For the purposes of comparison, the distance considered was the total distance traveled by the work in progress from the laser cutter to inventory, as that’s where the current process ends. Most of the shafts will be sent straight to assembly as a way of reducing the work in progress, which results in a total distance of 548m. When applying an average forklift speed of 5km/h to the distance traveled, the client will save $14,699.86 annually.

The metric for evaluating the operator’s feedback required subjective evaluation. The team had discussions with the operators on the paint line as well as operators in assembly. The feedback received in these discussions was positive towards reducing distance and handling of the process. It was these discussions with employees which led to the team receiving a different transportation cart design which was included in the final design.

The team anticipates that no units would be damaged in the new process. The new transportation cart in the design prevents the drive shafts from physically interacting with each other and the reduction in distance traveled will further lead to less damaged parts.

Currently, the drive shafts are manufactured in batches of 40 and a buffer is created at each process station. As outlined in Section 3.4, the new process will manufacture the daily requirement of 54 units. This means at a maximum, 18 units of each type of each drive shaft will be in progress at any given time, which meets the ideal value for WIP. This also marks a 55% reduction of WIP when compared to the current process's 120 units of WIP at any given time.

The team has determined that the implementation of an automated handling cell would result in a payback period of 3.42 years if the cell was operated using one operator compared to the marginal improvement value of 3 years. However, if the cell was operated using a more realistic value of half an operator, this would result in a payback period 2.15 years, compared to the ideal improvement value of 2 years.

New safety risks introduced by the automated robot are mitigated through safety features designed into the cell such as a protective barrier and entry ways which trigger automatic stops. Automating the process removes the operator completely from the process while the lathe and welding operations are in progress behind the barrier, ensuring no new safety risks are introduced to operations.

4.2 FUTURE CONSIDERATIONS

The implementation of the proposed final design is contingent on some aspects that were identified, however due to lack of resources and proper expertise were left to be considered later if the design is implemented. These include:

- Supply of utilities
- Load bearing capabilities of floor

- Price estimations
- Process simulation

The manufacturing cell was designed with the assumptions that the required utilities such as electricity, ventilation and exhaust would be readily available. These utilities must be routed to the cell which requires additional consideration.

The floor capacity depends on the thickness of concrete, concrete type, and reinforcement. Another determining factor is the substrate that is the compressed by the concrete slab. Adequate testing needs to be carried out to ensure that the floor underneath the proposed cell location can withstand the weight of the equipment.

The team had to rely on industry experts to obtain price estimations for certain aspects of the proposed design, such as a custom end effector for the handling robot, acquiring and programming plc's and a custom welding solution for the manufacturing cell. As MacDon would use a competitive bidding process to obtain a supplier to implement a project like this, equipment prices may vary.

Equipment suppliers can often provide simulation software to accurately determine the benefits of incorporating automation into a manufacturing process. This would allow for a more realistic production analysis than the one outlined in this report.

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APPENDICES

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APPENDIX A: BILL OF MATERIALS

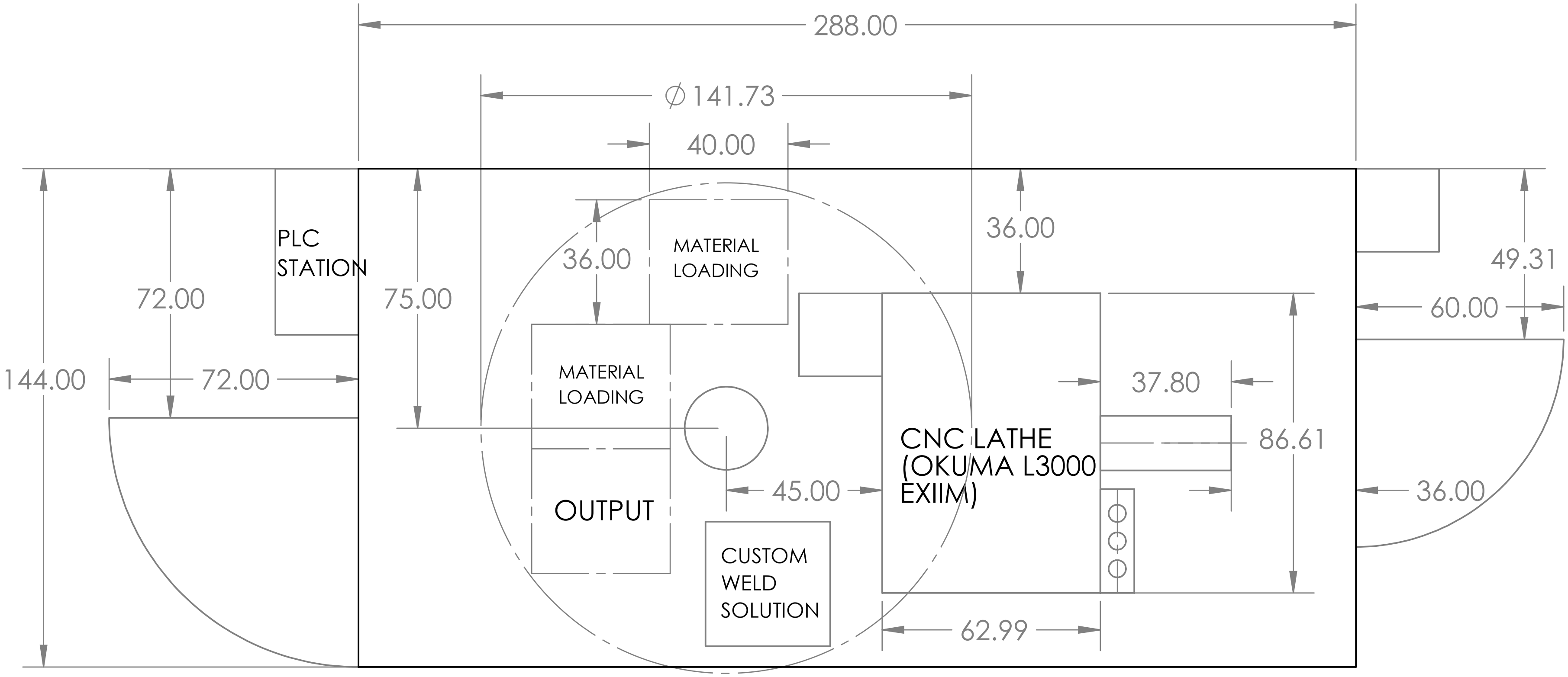
TABLE I: BILL OF MATERIALS FOR MANUAL CELL OPTION

MacDon	Specifications	QTY	Unit Price (CAD)	Total Price	Source
LATHE	Okuma LB3000EX-II/500-M (18.12 STD) with Big Bore (LB lathe with Milling Capacity, 500mm bed length, tail stock)	1	$203,889.00	$203,889.00	Okuma Quote
	M3205 CHUCK 12" BB212-A11	1	$7,900.20	$7,900.20	Okuma Quote
	P4906 STANDARD TOOLING PACKAGE, BMT TURRET (STATIC BASES ONLY)	1	$6,889.40	$6,889.40	Okuma Quote
	KUP-0936-00 VELOCITY - LIVE TOOL KIT - EXTERNAL COOLANT	1	$14,523.60	$14,523.60	Okuma Quote
	KMM-2396-00 Rear Discharge Chip Conv LB2000/3000, REAR DISC., HINGE (500 BED)(MAYFRAN)	1	$7,235.20	$7,235.20	Okuma Quote
Subtotal				**$240,437.40**	
WELDING SOLUTION	Custom Welding Solution	1	$34,231.05	$34,231.05	Eascan Quote
Subtotal				**$34,231.05**	
TRANSPORT CART	Tranportation Cart w/removeable paint line rack	6	$949.00	$5,694.00	Macdon Quote
Subtotal (6 carts)				**$5,694.00**	
INTEGRATION	Est. for Delivery, transformer and hydro approval of Lathe	1	$15,295.00	$15,295.00	Okuma Quote
	Integration and installation of Custom Welding Robot	1	$14,174.65	$14,174.65	Eascan Quote
Subtotal				**$29,469.65**	
MISC	Work Table	1	$175.00	$175.00	Zanduco.com[1]
	Fire extinguisher	1	$91.00	$91.00	Uline.ca[2]
	Chip Collection Bin	1	$1,280.00	$1,280.00	Uline.ca[2]
Subtotal				**$1,546.00**	
GRAND TOTAL				**$311,378.10**	

TABLE II: BILL OF MATERIALS FOR AUTOMATED CELL OPTION

MacDon	Specifications	QTY	Unit Price (CAD)	Total Price	Source
LATHE	Okuma LB3000EX-II/500-M (18.12 STD) with Big Bore (LB lathe with Milling Capacity, 500mm bed length, tail stock)	1	$203,889.00	$203,889.00	Okuma Quote
	M3205 CHUCK 12" BB212-A11	1	$7,900.20	$7,900.20	Okuma Quote
	P4906 STANDARD TOOLING PACKAGE, BMT TURRET (STATIC BASES ONLY)	1	$6,889.40	$6,889.40	Okuma Quote
	KUP-0936-00 VELOCITY - LIVE TOOL KIT - EXTERNAL COOLANT	1	$14,523.60	$14,523.60	Okuma Quote
	M8281 AUTO DOOR WITH DUAL CYCLE START, INTERFACE	1	$2,606.80	$2,606.80	Okuma Quote
	M2105 AUTO DOOR (SINGLE) WITH DUAL CYCLE START	1	$9,602.60	$9,602.60	Okuma Quote
	KMM-2396-00 Rear Discharge Chip Conv LB2000/3000, REAR DISC., HINGE (500 BED)(MAYFRAN)	1	$7,235.20	$7,235.20	Okuma Quote
Subtotal				**$252,646.80**	
WELDING SOLUTION	Custom Welding Solution	1	$34,231.05	$34,231.05	Eascan Quote
Subtotal				**$34,231.05**	
MATERIAL HANDING	Material Handling Robot, Fanuc M-20iA, with Vision System	1	$130,000.00	$130,000.00	cisco-eagle.com[3]
	Programmable Logic Controller	1	$6,000.00	$6,000.00	Industry Expert Estimate
Subtotal				**$136,000.00**	
TRANSPORT CART	Tranportation Cart w/removeable paint line rack	6	$949.00	$5,694.00	Macdon Quote
Subtotal (6 carts)				**$5,694.00**	
INTEGRATION	Est. for Delivery, transformer and hydro approval of Lathe	1	$15,295.00	$15,295.00	Okuma Quote
	Integration and installation of Custom Welding Robot and Material Handling Robot	1	$14,174.65	$14,174.65	Eascan Quote
	Integration and installation for Material Handling Robot and PLC system	1	$87,000.00	$102,000.00	Industry Expert Estimate
Subtotal				**$131,469.65**	
MISC	Work Table	1	$175.00	$175.00	Zanduco.com[1]
	Fire extinguisher	1	$91.00	$91.00	Uline.ca[2]
	Chip Collection Bin	1	$1,280.00	$1,280.00	Uline.ca[2]
Subtotal				**$1,546.00**	
GRAND TOTAL				**$561,587.50**	

APPENDIX B: CRITICAL CELL DIMENSION DRAWINGS

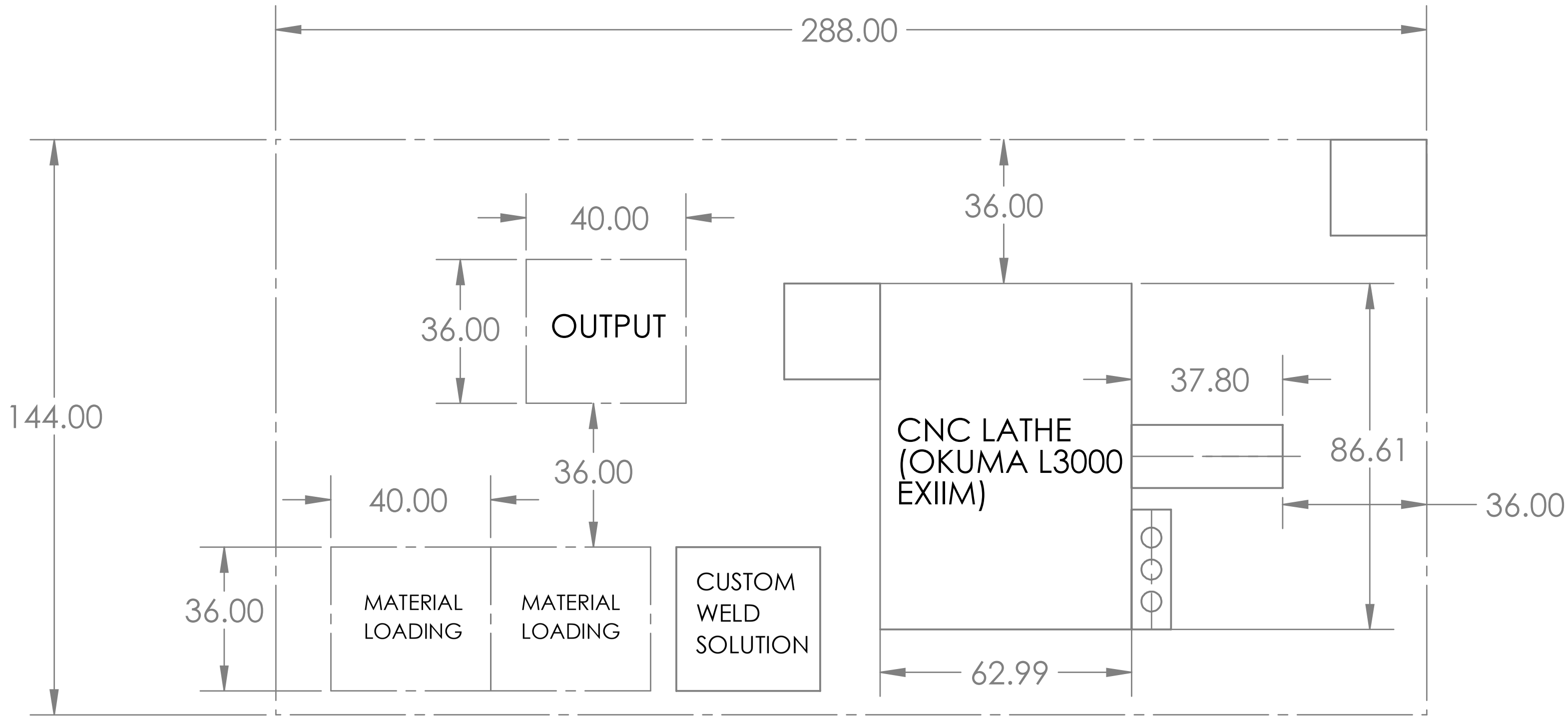


NOTE: ONLY CRITICAL CELL DIMENSIONS SHOWN.
DIMENSIONS ARE SUBJECT TO CHANGE
DEPENDING ON SELECTED EQUIPMENT SUPPLIER.

UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN	Team 16	2019/11/23
	CHECKED		
	ENG APPR.		
	MFG APPR.		
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
MATERIAL	Prepared for: MacDon Industries Ltd.		
FINISH			
DO NOT SCALE DRAWING			

TITLE: Cell Geometry - Automated

SIZE	DWG. NO.	REV
A	1	0
SCALE: 1:48	WEIGHT:	SHEET 1 OF 1



NOTE: ONLY CRITICAL CELL DIMENSIONS SHOWN.
DIMENSIONS ARE SUBJECT TO CHANGE
DEPENDING ON SELECTED EQUIPMENT SUPPLIER.

UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN	Team 16	2019/11/23
	CHECKED		
	ENG APPR.		
	MFG APPR.		
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
MATERIAL	Prepared for: MacDon Industries Ltd.		
FINISH			
DO NOT SCALE DRAWING			

TITLE:

Cell Geometry - Manual

SIZE	DWG. NO.	REV
A	2	0
SCALE: 1:48	WEIGHT:	SHEET 1 OF 1

APPENDIX C: MANUFACTURING SCHEDULE

TABLE III: PROCESS TIMES

Process Times		
Machine Times (QTY 1)	**hrs**	**min**
Discs	0.033	1.98
105364	0.078	4.68
137291	0.189	11.34
137451	0.148	8.88
Welding (QTY 1)	0.088	5.28

Note: In the following schedule shown in TABLE IV, “Robot” refers to either an automated handling robot, or human labor. The schedule is applicable to both cases as data was not available to prove the increase in efficiency of the automated handling robot.

TABLE IV: CELL PRODUCTION SCHEDULE

Cell Schedule			
Task	**Required Time [mins]**	**Simulataneous Task**	**Required Time [mins]**
Machine setup for Discs	45		
Load Disc	1.98		
Machine Disc			
Unload Disc			
Load Parts (137291)	5.28	(Robot in use)	1.65
Weld Disc (137291)		Load Disc	1.98
		Machine Disc	
		Unload Disc	
Unload Weldment (137291)		(Robot in use)	1.65
Load Parts (137291)	5.28	(Robot in use)	1.65
Weld Disc (137291)		Load Disc	1.98
		Machine Disc	
		Unload Disc	
Unload Weldment (137291)		(Robot in use)	1.65
Load Parts (137291)	5.28	(Robot in use)	1.65
Weld Disc (137291)		Load Disc	1.98
		Machine Disc	
		Unload Disc	
Unload Weldment (137291)		(Robot in use)	1.65
Load Parts (137291)	5.28	(Robot in use)	1.65
Weld Disc (137291)		Load Disc	1.98
		Machine Disc	
		Unload Disc	
Unload Weldment (137291)		(Robot in use)	1.65

Load Parts (137291)		(Robot in use)	1.65
		Load Disc	
Weld Disc (137291)	5.28	Machine Disc	1.98
		Unload Disc	
Unload Weldment (137291)		(Robot in use)	1.65
Load Parts (137291)		(Robot in use)	1.65
		Load Disc	
Weld Disc (137291)	5.28	Machine Disc	1.98
		Unload Disc	
Unload Weldment (137291)		(Robot in use)	1.65
Load Parts (137291)		(Robot in use)	1.65
		Load Disc	
Weld Disc (137291)	5.28	Machine Disc	1.98
		Unload Disc	
Unload Weldment (137291)		(Robot in use)	1.65
Load Parts (137291)		(Robot in use)	1.65
		Load Disc	
Weld Disc (137291)	5.28	Machine Disc	1.98
		Unload Disc	
Unload Weldment (137291)		(Robot in use)	1.65
Load Parts (137291)		(Robot in use)	1.65
		Load Disc	
Weld Disc (137291)	5.28	Machine Disc	1.98
		Unload Disc	
Unload Weldment (137291)		(Robot in use)	1.65
Load Parts (137291)		(Robot in use)	1.65
		Load Disc	
Weld Disc (137291)	5.28	Machine Disc	1.98
		Unload Disc	
Unload Weldment (137291)		(Robot in use)	1.65
Load Parts (137291)		(Robot in use)	1.65
		Load Disc	
Weld Disc (137291)	5.28	Machine Disc	1.98
		Unload Disc	
Unload Weldment (137291)		(Robot in use)	1.65
Load Parts (137291)		(Robot in use)	1.65
		Load Disc	
Weld Disc (137291)	5.28	Machine Disc	1.98
		Unload Disc	
Unload Weldment (137291)		(Robot in use)	1.65
Load Parts (137291)		(Robot in use)	1.65
		Load Disc	
Weld Disc (137291)	5.28	Machine Disc	1.98
		Unload Disc	
Unload Weldment (137291)		(Robot in use)	1.65

Load Parts (137291)		(Robot in use)	1.65
		Load Disc	
Weld Disc (137291)	5.28	Machine Disc	1.98
		Unload Disc	
Unload Weldment (137291)		(Robot in use)	1.65
Load Parts (137291)		(Robot in use)	1.65
		Load Disc	
Weld Disc (137291)	5.28	Machine Disc	1.98
		Unload Disc	
Unload Weldment (137291)		(Robot in use)	1.65
Load Parts (137291)		(Robot in use)	1.65
		Load Disc	
Weld Disc (137291)	5.28	Machine Disc	1.98
		Unload Disc	
Unload Weldment (137291)		(Robot in use)	1.65
Load Parts (137291)		(Robot in use)	1.65
		Load Disc	
Weld Disc (137291)	5.28	Machine Disc	1.98
		(Robot in use)	
Unload Weldment (137291)		(Robot in use)	1.65
Batch of 18 weldments (137291) complete and sent to paint. Elapsed Time: 2.367 hrs.			
Load Parts (137451)		(Robot in use)	1.65
		Load Disc	
Weld Disc (137451)	5.28	Machine Disc	1.98
		Unload Disc	
Unload Weldment (137451)		(Robot in use)	1.65
Load Parts (137451)		(Robot in use)	1.65
		Load Disc	
Weld Disc (137451)	5.28	Machine Disc	1.98
		Unload Disc	
Unload Weldment (137451)		(Robot in use)	1.65
Load Parts (137451)		(Robot in use)	1.65
		Load Disc	
Weld Disc (137451)	5.28	Machine Disc	1.98
		Unload Disc	
Unload Weldment (137451)		(Robot in use)	1.65
Load Parts (137451)		(Robot in use)	1.65
		Load Disc	
Weld Disc (137451)	5.28	Machine Disc	1.98
		Unload Disc	
Unload Weldment (137451)		(Robot in use)	1.65

Load Parts (137451)	5.28	(Robot in use)	1.65
Weld Disc (137451)		Load Disc	1.98
		Machine Disc	
		Unload Disc	
Unload Weldment (137451)		(Robot in use)	1.65
Load Parts (137451)	5.28	(Robot in use)	1.65
Weld Disc (137451)		Load Disc	1.98
		Machine Disc	
		Unload Disc	
Unload Weldment (137451)		(Robot in use)	1.65
Load Parts (137451)	5.28	(Robot in use)	1.65
Weld Disc (137451)		Load Disc	1.98
		Machine Disc	
		Unload Disc	
Unload Weldment (137451)		(Robot in use)	1.65
Load Parts (137451)	5.28	(Robot in use)	1.65
Weld Disc (137451)		Load Disc	1.98
		Machine Disc	
		Unload Disc	
Unload Weldment (137451)		(Robot in use)	1.65
Load Parts (137451)	5.28	(Robot in use)	1.65
Weld Disc (137451)		Load Disc	1.98
		Machine Disc	
		Unload Disc	
Unload Weldment (137451)		(Robot in use)	1.65
Load Parts (137451)	5.28	(Robot in use)	1.65
Weld Disc (137451)		Load Disc	1.98
		Machine Disc	
		Unload Disc	
Unload Weldment (137451)		(Robot in use)	1.65
Load Parts (137451)	5.28	(Robot in use)	1.65
Weld Disc (137451)		Load Disc	1.98
		Machine Disc	
		Unload Disc	
Unload Weldment (137451)		(Robot in use)	1.65
Load Parts (137451)	5.28	(Robot in use)	1.65
Weld Disc (137451)		Load Disc	1.98
		Machine Disc	
		Unload Disc	
Unload Weldment (137451)		(Robot in use)	1.65

Load Parts (137451)	5.28	(Robot in use)	1.65
Weld Disc (137451)		Load Disc	1.98
		Machine Disc	
		Unload Disc	
Unload Weldment (137451)		(Robot in use)	1.65
Load Parts (137451)	5.28	(Robot in use)	1.65
Weld Disc (137451)		Load Disc	1.98
		Machine Disc	
		Unload Disc	
Unload Weldment (137451)		(Robot in use)	1.65
Load Parts (137451)	5.28	(Robot in use)	1.65
Weld Disc (137451)		Load Disc	1.98
		Machine Disc	
		Unload Disc	
Unload Weldment (137451)		(Robot in use)	1.65
Load Parts (137451)	5.28	(Robot in use)	1.65
Weld Disc (137451)		Load Disc	1.98
		Machine Disc	
		Unload Disc	
Unload Weldment (137451)		(Robot in use)	1.65
Load Parts (137451)	5.28	(Robot in use)	1.65
Weld Disc (137451)		Load Disc	1.98
		Machine Disc	
		Unload Disc	
Unload Weldment (137451)		(Robot in use)	1.65
Batch of 18 weldments (137451) complete and sent to paint. Elapsed Time: 3.159 hrs.			
Load Parts (105364)	5.28	(Robot in use)	1.65
Weld Disc (105364)		Load Disc	1.98
		Machine Disc	
		Unload Disc	
Unload Weldment (105364)		(Robot in use)	1.65
Load Parts (105364)	5.28	(Robot in use)	1.65
Weld Disc (105364)		Load Disc	1.98
		Machine Disc	
		Unload Disc	
Unload Weldment (105364)		(Robot in use)	1.65
Load Parts (105364)	5.28	(Robot in use)	1.65
Weld Disc (105364)		Load Disc	1.98
		Machine Disc	
		Unload Disc	
Unload Weldment (105364)		(Robot in use)	1.65

Load Parts (105364)	5.28	(Robot in use)	1.65
Weld Disc (105364)		Load Disc	1.98
		Machine Disc	
		Unload Disc	
Unload Weldment (105364)		(Robot in use)	1.65
Load Parts (105364)	5.28	(Robot in use)	1.65
Weld Disc (105364)		Load Disc	1.98
		Machine Disc	
		Unload Disc	
Unload Weldment (105364)		(Robot in use)	1.65
Load Parts (105364)	5.28	(Robot in use)	1.65
Weld Disc (105364)		Load Disc	1.98
		Machine Disc	
		Unload Disc	
Unload Weldment (105364)		(Robot in use)	1.65
Load Parts (105364)	5.28	(Robot in use)	1.65
Weld Disc (105364)		Load Disc	1.98
		Machine Disc	
		Unload Disc	
Unload Weldment (105364)		(Robot in use)	1.65
Load Parts (105364)	5.28	(Robot in use)	1.65
Weld Disc (105364)		Load Disc	1.98
		Machine Disc	
		Unload Disc	
Unload Weldment (105364)		(Robot in use)	1.65
Load Parts (105364)	5.28	(Robot in use)	1.65
Weld Disc (105364)		Load Disc	1.98
		Machine Disc	
		Unload Disc	
Unload Weldment (105364)		(Robot in use)	1.65
Load Parts (105364)	5.28	(Robot in use)	1.65
Weld Disc (105364)		Load Disc	1.98
		Machine Disc	
		Unload Disc	
Unload Weldment (105364)		(Robot in use)	1.65
Load Parts (105364)	5.28	(Robot in use)	1.65
Weld Disc (105364)		Load Disc	1.98
		Machine Disc	
		Unload Disc	
Unload Weldment (105364)		(Robot in use)	1.65

Load Parts (105364)	5.28	(Robot in use)	1.65
Weld Disc (105364)		Load Disc	1.98
		Machine Disc	
		Unload Disc	
Unload Weldment (105364)		(Robot in use)	1.65
Load Parts (105364)	5.28	(Robot in use)	1.65
Weld Disc (105364)		Load Disc	1.98
		Machine Disc	
		Unload Disc	
Unload Weldment (105364)		(Robot in use)	1.65
Load Parts (105364)	5.28	(Robot in use)	1.65
Weld Disc (105364)		Load Disc	1.98
		Machine Disc	
		Unload Disc	
Unload Weldment (105364)		(Robot in use)	1.65
Load Parts (105364)	5.28	(Robot in use)	1.65
Weld Disc (105364)		Load Disc	1.98
		Machine Disc	
		Unload Disc	
Unload Weldment (105364)		(Robot in use)	1.65
Load Parts (105364)	5.28	(Robot in use)	1.65
Weld Disc (105364)		Load Disc	1.98
		Machine Disc	
		Unload Disc	
Unload Weldment (105364)		(Robot in use)	1.65
Load Parts (105364)	5.28		
Weld Disc (105364)			
Unload Weldment (105364)			
Batch of 18 weldments (137451) complete and sent to paint. Elapsed Time: 5.535 hrs.			

Note: At this point, all disc machining and welding processes are complete. The first batch of 18 painted weldments (137291) return to the cell approximately 6.367 hours into the first shift.

Each successive batch of painted weldments returns from paint to the cell prior to completion of the previous batch of painted weldments being machined, allowing the cell to constantly be working.

Task	Required Time [mins]	Simulataneous Task	Required Time [mins]
Machine setup for shaft machining	45		
Load weldment (137291)			
Machine (137291)	11.34		
Unload shaft (137291)			
Load weldment (137291)			
Machine (137291)	11.34		
Unload shaft (137291)			
Load weldment (137291)			
Machine (137291)	11.34		
Unload shaft (137291)			
Load weldment (137291)			
Machine (137291)	11.34		
Unload shaft (137291)			
Load weldment (137291)			
Machine (137291)	11.34		
Unload shaft (137291)			
Load weldment (137291)			
Machine (137291)	11.34		
Unload shaft (137291)			
Load weldment (137291)			
Machine (137291)	11.34		
Unload shaft (137291)			
Load weldment (137291)			
Machine (137291)	11.34		
Unload shaft (137291)			
Load weldment (137291)			
Machine (137291)	11.34		
Unload shaft (137291)			
Load weldment (137291)			
Machine (137291)	11.34		
Unload shaft (137291)			
Load weldment (137291)			
Machine (137291)	11.34		
Unload shaft (137291)			
Load weldment (137291)			
Machine (137291)	11.34		
Unload shaft (137291)			
Load weldment (137291)			
Machine (137291)	11.34		
Unload shaft (137291)			
Load weldment (137291)			
Machine (137291)	11.34		
Unload shaft (137291)			
Load weldment (137291)			
Machine (137291)	11.34		
Unload shaft (137291)			

Load weldment (137291)			
Machine (137291)	11.34		
Unload shaft (137291)			
Load weldment (137291)			
Machine (137291)	11.34		
Unload shaft (137291)			
Load weldment (137291)			
Machine (137291)	11.34		
Unload shaft (137291)			
Machining of 18 (137291) shafts complete. Elapsed Time: 9.769. Change over to 137451.			
Load weldment (137451)			
Machine (137451)	8.88		
Unload shaft (137451)			
Load weldment (137451)			
Machine (137451)	8.88		
Unload shaft (137451)			
Load weldment (137451)			
Machine (137451)	8.88		
Unload shaft (137451)			
Load weldment (137451)			
Machine (137451)	8.88		
Unload shaft (137451)			
Load weldment (137451)			
Machine (137451)	8.88		
Unload shaft (137451)			
Load weldment (137451)			
Machine (137451)	8.88		
Unload shaft (137451)			
Load weldment (137451)			
Machine (137451)	8.88		
Unload shaft (137451)			
Load weldment (137451)			
Machine (137451)	8.88		
Unload shaft (137451)			
Load weldment (137451)			
Machine (137451)	8.88		
Unload shaft (137451)			
Load weldment (137451)			
Machine (137451)	8.88		
Unload shaft (137451)			
Load weldment (137451)			
Machine (137451)	8.88		
Unload shaft (137451)			
Load weldment (137451)			
Machine (137451)	8.88		
Unload shaft (137451)			

Load weldment (137451)			
Machine (137451)	8.88		
Unload shaft (137451)			
Load weldment (137451)			
Machine (137451)	8.88		
Unload shaft (137451)			
Load weldment (137451)			
Machine (137451)	8.88		
Unload shaft (137451)			
Load weldment (137451)			
Machine (137451)	8.88		
Unload shaft (137451)			
Load weldment (137451)			
Machine (137451)	8.88		
Unload shaft (137451)			
Load weldment (137451)			
Machine (137451)	8.88		
Unload shaft (137451)			
Machining of 18 (137451) shafts complete. Elapsed Time: 12.433 hrs. Change over to 105364.			
Load weldment (105364)			
Machine (105364)	4.68		
Unload shaft (105364)			
Load weldment (105364)			
Machine (105364)	4.68		
Unload shaft (105364)			
Load weldment (105364)			
Machine (105364)	4.68		
Unload shaft (105364)			
Load weldment (105364)			
Machine (105364)	4.68		
Unload shaft (105364)			
Load weldment (105364)			
Machine (105364)	4.68		
Unload shaft (105364)			
Load weldment (105364)			
Machine (105364)	4.68		
Unload shaft (105364)			
Load weldment (105364)			
Machine (105364)	4.68		
Unload shaft (105364)			
Load weldment (105364)			
Machine (105364)	4.68		
Unload shaft (105364)			
Load weldment (105364)			
Machine (105364)	4.68		
Unload shaft (105364)			

Load weldment (105364)			
Machine (105364)	4.68		
Unload shaft (105364)			
Load weldment (105364)			
Machine (105364)	4.68		
Unload shaft (105364)			
Load weldment (105364)			
Machine (105364)	4.68		
Unload shaft (105364)			
Load weldment (105364)			
Machine (105364)	4.68		
Unload shaft (105364)			
Load weldment (105364)			
Machine (105364)	4.68		
Unload shaft (105364)			
Load weldment (105364)			
Machine (105364)	4.68		
Unload shaft (105364)			
Load weldment (105364)			
Machine (105364)	4.68		
Unload shaft (105364)			
Load weldment (105364)			
Machine (105364)	4.68		
Unload shaft (105364)			
Load weldment (105364)			
Machine (105364)	4.68		
Unload shaft (105364)			
Machining of 18 (105364) shafts complete. Elapsed Time: 13.837 hrs.			

APPENDIX D: ECONOMIC/COST ANALYSIS

The following tables are applicable for the Payback Period analysis. TABLE V includes the variable costs for the current process and the labour rate that was used for the operator cost calculation.

TABLE V: CURRENT PROCESS VARIABLE COSTS

MacDon		Current Process
Current Variable Costs	Daily	Annually
Operators (2x12.3 hours)	$1,353	$342,309
Lathe Maintenance		$10,000
Transport Costs		$26,099
Sum of annual cost		$378,408
Hourly Labour Rate	$55	

The initial outlay costs and payback periods for the automated and manual handling cell designs are shown in TABLE VI and TABLE VII.

TABLE VI: INITIAL OUTLAY COSTS AND PAYBACK PERIOD FOR AUTOMATED HANDLING CELL

MacDon		Automated Handling Cell
Initial Outlay Cost Description		Cost
Lathe		$252,647
Material Handling Robot with Vision System		$130,000
Custom Welding Solution		$34,231
PLC (software and HMI)		$6,000
Integration (Lathe, Welding Solution)		$29,470
Integration (Robot, PLC)		$102,000
Transport Carts		$5,694
Misc		$1,546
Total		$561,588
Automated Cell Variable Costs	Daily	Annually
Robot Maintenance		$10,000
Operator (1x13.84 hours)	$761	$192,584
Transport Costs		$11,399
Sum of Variable Costs (Annually)		$213,983
Payback Period		
Using 1 full time operator	**3.42**	**Years**
Using 0.5 full time operator	**2.15**	**Years**

TABLE VII: INITIAL OUTLAY COSTS AND PAYBACK PERIOD FOR MANUAL HANDLING CELL

MacDon		*Manual Handling Cell*
Initial Outlay Cost Description		Cost
Lathe		$240,437
Custom Welding Solution		$34,231
Integrator		$29,470
Transport carts		$5,694
Misc		$1,546
Total		$311,378
Manual Cell Variable Costs	Daily	Annually
Operator (1.5x13.84 hours)	$1,142	$288,875
Lathe Maintenance		$5,000
Transport Costs		$11,399
Sum of Variable Costs (Annually)		$305,274
Payback Period		
New Lathe (Purchaser's Option)	**4.26**	**Years**

The following tables are applicable for the net present value (NPV) analysis. The costs from TABLE VI and TABLE VII for the automated and manual handling cells were also used for the NPV analysis. TABLE VIII depicts the current process costs as well as the some assumed values that were used for the NPV analysis.

TABLE VIII: CURRENT PROCESS VARIABLE COSTS AND VARIOUS NPV ASSUMPTIONS

MacDon		*Current Process*
Current Costs	Daily	Annually
Operators (2x12.3 hours)	1353	$342,309
Lathe Maintenance		$10,000
Transport Costs		$26,099
Sum of annual cost		$378,408
Hourly Rate	$55	
Default Rate of Return	5%	
Annual Increase in Costs	2%	

The cash flows and results for the NPV analysis are shown in TABLE IX, TABLE X, and TABLE XI. NPV calculations were completed using the following formula:

$$NPV = \sum_{t=0}^{n} \frac{R_t}{(1+i)^t}$$

NPV is the sum from time period zero to n

Where: R_t is the number cash flow for a specified time period,

i is the discount rate of return, and

t is the specified time period

TABLE IX: NPV CASH FLOWS AND RESULTS FOR SINGLE OPERATOR AUTOMATED CELL

	Automated Cell 1 operator
Initial Cash Outlay	-$561,587
Period	Cash Flows
1	$167,714
2	$171,068
3	$174,490
4	$177,979
5	$181,539
6	$185,170
7	$188,873
8	$192,651
9	$196,504
10	$200,434
NVP	$845,215

TABLE X: NPV CASH FLOWS AND RESULTS FOR HALF OPERATOR AUTOMATED CELL

	Automated Cell 0.5 operators
Initial Cash Outlay	-$561,587
Period	Cash Flows
1	$265,932
2	$271,250
3	$276,675
4	$282,209
5	$287,853
6	$293,610
7	$299,482
8	$305,472
9	$311,581
10	$317,813
NVP	$1,669,075

TABLE XI: NPV CASH FLOWS AND RESULTS FOR MANUAL CELL

	Manual Cell
Initial Cash Outlay	-$311,377
Period	Cash Flows
1	$74,596
2	$76,088
3	$77,610
4	$79,162
5	$80,745
6	$82,360
7	$84,008
8	$85,688
9	$87,401
10	$89,149
NVP	$314,344

APPENDIX REFERENCES

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