2024

Comparative Study of Robotic And Manual Welding In A Low Volume-High Mix Manufacturing Environment: Case Study Of Tail Gate

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Comparative Study of Robotic And Manual Welding In A Low Volume-High Mix Manufacturing Environment: Case Study Of Tail Gate

By

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A Thesis Submitted in Partial Fulfillment of the

Requirements for the Degree of

Master of Science

In

Manufacturing Engineering Technology

Minnesota State University, Mankato

Mankato, Minnesota

(April, 2024)

April 2024

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This Thesis has been examined and approved by the following members of the student's committee.

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Acknowledgments

I extend my deepest gratitude to my advisor, Dr. Kuldeep Agarwal, for her invaluable guidance and support. My thanks also go to Dr. Shaheen Ahmed, Dr. Pawan Bhandari and Professor John Ruprecht for their insights and assistance. A special thank you to Truck Bodies and Equipment International, and their fabrication team, for their crucial contributions and collaboration.

I appreciate the collective wisdom and encouragement from my peers and the Department of Manufacturing Engineering Technology faculty.

Disclaimer

This thesis paper represents the collaborative efforts of five students, Aditya Suggula, Mayank Srinivasa Murthy, Niloufer Sarah, Poorna Pragna Mysore and Sai Sasank Pothamsetti, each investigating different segments of the subject matter. While the theoretical framework and foundational concepts may appear identical, underscoring our unified approach and understanding, specific portions of our work, notably the MTM1 analysis and MOST analysis, were undertaken as joint efforts. These sections were collaboratively developed to leverage our collective expertise, ensuring a rigorous and comprehensive examination. Beyond these shared analyses, the calculations and subsequent analyses within our individual papers are distinct, reflecting the unique contributions and insights of each student. This dual approach—combining collaborative and individual efforts—ensures a cohesive theoretical foundation while embracing diversity in analytical perspectives and conclusions across our varied parts.

ABSTRACT

Our study rigorously compared the efficacy of Methods-Time Measurement (MTM 1) and Maynard Operation Sequence Technique (MOST) against actual production times to identify the most accurate and efficient time management frameworks for manufacturing processes. We aimed to discern which method better predicts job completion times in a real-world setting, using a case study that included both manual and robotic welding in the assembly of a truck body part, the tipper tailgate. We discovered notable discrepancies between the predetermined time systems and actual observations, particularly in manual welding tasks. These differences highlighted the complexity of manual tasks, which involve intricate movements not fully accounted for by the predetermined systems. MOST emerged as more effective than MTM 1 in providing a detailed understanding of task execution times, especially in tasks that involve complex positioning. The study also delved into the comparison between the performance of skilled human welders and automated robotic systems. Our findings revealed that while robots can significantly enhance efficiency for simpler, repetitive tasks, the complex assembly work still requires the dexterity and expertise of skilled human welders. Surprisingly, in certain cases, human welders outperformed robots, underscoring the unique strengths and weaknesses of both. The analysis further demonstrated that robotic welding offers superior time efficiency and cost-effectiveness compared to manual welding, particularly as production volume increases. This efficiency translates into significant cost savings and increased production rates, making the case for integrating robotic technology into manufacturing processes compelling. Crucially, the coexistence of skilled welders with collaborative robots (cobots) brings immense benefits, merging human expertise with robotic precision and efficiency. This synergy not only optimizes production quality and speed but also mitigates the impact of skilled labor shortages. By embracing a hybrid approach to welding, manufacturers can achieve a balance between the adaptability

and problem-solving skills of human welders and the consistency and productivity of robotic systems, leading to enhanced operational excellence and competitive advantage in the manufacturing sector.

Introduction:

In the manufacturing sector, several components go through labor-intensive fabrication procedures like welding, stamping, and machining, particularly in businesses like TBEI that specialize in truck bodies and equipment. These parts are essential to heavy-duty vehicle tailgate assemblies because they provide secure and effective cargo handling. The manual welding method for tailgate assembly, especially in smaller firms catering to diverse standards and designs, mainly relies on skilled human labor, even with the developments in automation in manufacturing processes.

The goal of this study is to close the automation gap in the tailgate assembly process by thoroughly analyzing the time-motion of skilled welders. The specifics of hand welding in tailgate fabrication will be the main focus of the investigation of potential automation or robotization in low-volume, high-mix production scenarios. Using the tailgate assembly as the primary research target, this study attempts to identify challenges, opportunities, and viable strategies for enhancing productivity and precision using automated technology.

This research examines the interconnected bond between robots and human employees in the factory setting, acknowledging the opportunity for teamwork and cohabitation to improve manufacturing processes. Its goal is to explore how automation can enhance human welders' abilities and knowledge, aiming to facilitate the seamless incorporation of robotics alongside skilled labor. This integration is intended to optimize productivity and quality in tailgate assembly and other areas.

Welding

Welding involves the joining of materials and can be classified into three main groups: fusion welding, pressure welding, and brazing/soldering. Each group includes different welding methods, selected according to factors such as the materials being joined and the intended functionality of the product. (Giachino, (1973).)

Types of Welding.

Types of Welding:

1. Fusion Welding:

   Fusion welding involves melting the base materials or combining them with a welding rod. This category includes methods like arc welding, electron beam, gas, and laser welding. These methods use different energy sources, such as electrical, chemical, or light, to create the necessary heat for melting and joining.

2. Brazing/Soldering:

   In brazing/soldering, a filler material (brazing paste) is applied to the joining sections. This category includes induction heating brazing, torch brazing (flame brazing), light beam, and laser brazing. The energy sources for these methods can be electrical, chemical, or light.

Fusion Welding:

Fusion welding, a term frequently used but not universally understood, entails heating two or more objects and joining them without external pressure. (Giachino, (1973).) Depending on the job requirements, filler materials may be incorporated during fusion welding. This distinguishes fusion welding from non-fusion welding, which utilizes lower heat levels, ensuring the base metal does not melt. Examples of non-fusion welding include soldering, pressure welding, and brazing.

Before delving into fusion welding, it is essential to understand welding as a manufacturing process (KEYENCE America, n.d.). Recent research by the American

Welding Society highlights the substantial impact of welding, which contributes to 50% of the gross domestic product in the United States. Welding involves utilizing heat to attach two or more similar or non-identical items, with the use of a filler optional based on the nature of the work.

Types of Fusion Welding. Fusion welding, by definition, involves joining heat to connect two edges of either the same or different materials. The heated portions melt and, upon cooling, fuse. In cases of a significant gap between the two pieces, filler material may be employed. The heating process introduces a heat-affected zone within the materials, subjecting the base material to various stages.

Fusion welding occurs when the molten components of the base material mix with the molten filler. This process employs heat to produce an exterior junction at the weld point or melt the material in the joining zone. The FC-120 Gasless Flux Cored Wire Inverter Welding Machine is recognized as a top tool for executing various forms of fusion welding.

Fusion welding is Categorized based on the heat source. Common fusion welding styles include ACR welding and various forms of fusion arc welding (Shielded Metal Arc Welding, Tungsten Inert Gas Welding, Metal Gas Arc Welding, Submerged Arc Welding, Plasma Arc Welding, and Flux Cored Arc Welding). Gas welding, high-energy welding (Electron Beam Welding and Laser Welding), resistance welding (for seams and spot resistance welding), and friction welding (rotary, spot, linear, and stir friction welding) are also prevalent.

Arc Welding.

- Overview: Arc welding stands out as the most popular and widely used type of fusion welding. It relies on an electric arc to join two or more objects of the same or similar materials.

- Process: The electric arc generated in arc welding can reach temperatures of up to 6,000 degrees Fahrenheit, making it capable of melting even the toughest metals. This process involves creating a molten pool at the welding point, allowing the objects to fuse seamlessly.

- Special Features: Arc welding is not confined to conventional settings; it can be performed underwater, making it particularly advantageous for offshore welding projects where traditional welding methods might face challenges.

Laser Welding.

- Laser welding is a technique that employs a lens to focus light with high directivity and convergence, creating a high-energy density beam utilized as the primary heat source.
- By manipulating the laser beam output, penetration welding with a narrow width compared to the depth becomes feasible. Additionally, brazing and soldering can be achieved by melting and joining an alloy with a lower melting point than the base material.
- Notable advancements in laser output efficiency underscore the significance of laser welding in the future of manufacturing. This segment provides an overview of the common technologies employed in laser welding.

Principles of laser welding.

- Modulating the intensity and spot size of the laser beam emitted by a laser processing machine facilitates the welding and engraving of letters and patterns on the surface of base materials and cutting operations.
- In laser welding, a significantly stronger laser beam than those used in other processes is the heat source for melting and joining base materials. Employing a high-power output laser necessitates precise control over the beam convergence properties, including wavelength and energy density, and laser beam qualities, such as intensity and beam mode. Despite these requirements, laser welding proves versatile, accommodating delicate applications while excelling in joining both thick and thin plates.

Induction Welding.

- Overview: Induction welding distinguishes itself by relying on a unique principle that does not involve direct contact between an object's surface and the heat source.
- Process: Instead of direct contact, a wrapped coil is employed to create a magnetic field, which, in turn, induces heat in the metal. The magnetic field rapidly heats the metal surfaces, causing them to melt and fuse.
- Advantages: Induction welding offers rapid heating and minimal distortion, making it suitable for specific applications with critical precision and efficiency.

Oxyfuel Welding.

- Overview: Oxyfuel welding is a chemical-based fusion welding process that utilizes a flame to heat and join surfaces, with oxygen as the primary fuel source.

- Process: The fundamental principle is the reliance on oxygen to fuel the fire, creating a hot flame exceeding 4,500 degrees Fahrenheit. This intense heat is applied to the surfaces, allowing them to reach the molten state and fuse.
- Versatility: Oxyfuel welding is versatile and finds application in various industries, particularly where a portable and easily controllable heat source is required.

Solid Reactant Welding.

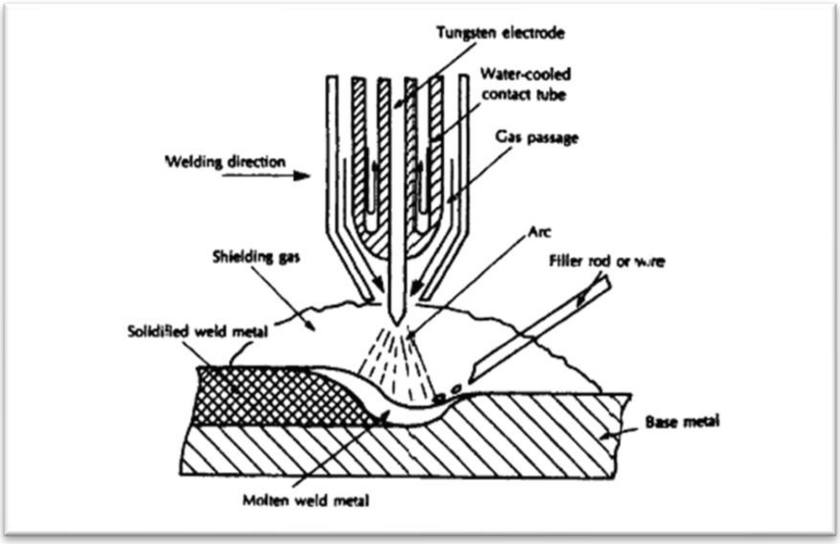
- Overview: Solid reactant welding is a fusion welding type that leverages chemical reactions with specific materials to achieve the joining process.
- Process: Certain compounds can generate heat when mixed. Solid reactant welding utilizes this principle, initiating chemical reactions that produce the required heat to join two or more objects.
- Applications: This type of fusion welding is applied in scenarios where chemical reactions can be harnessed for welding purposes, offering a unique approach to joining materials.

Non-Consumable (Non-Fusible) Electrode Type.

TIG Welding (Tungsten Inert Gas Welding). TIG welding, also known as Gas Tungsten Arc Welding (GTAW), falls under the non-consumable electrode category. TIG (Tungsten Inert Gas) welding employs an inert gas in the welding process. This particular arc welding method is characterized by its spark-free nature and is suitable for welding various metals, including stainless steel, aluminum, and iron. Non-consumable tungsten is the discharge electrode, while an inert gas such as argon or helium acts as the shielding gas. The process initiates an arc within the inert gas, utilizing the generated arc heat to melt and weld the base material. Despite the use of filler material, instances of spatter are minimal due to the inert gas's comprehensive coverage of the weld area, ensuring a stable arc.

Figure 1:

TIG welding (Messler, 1999)



A semi-automatic TIG welding machine comprises essential components, including the welding power supply, welding torch, and a gas cylinder with a gas flow controller. Additional instruments may be incorporated, especially when using a water-cooled torch or filler material in wire form.

The choice of electric current polarity (positive or negative) depends on the base material, necessitating a controller in the welding power supply to select the appropriate polarity accordingly. (Messler, 1999)

The welding process in TIG welding involves various classifications based on factors such as AC or DC power usage, the application of pulse or non-pulse current, and whether a filler wire is utilized.

The choice of AC or DC is contingent upon the base material being used. Additionally, the option of pulse or non-pulse current is available. Pulse TIG welding, for instance, involves the alternating change of welding current at a constant frequency between pulse current and base current. This results in periodic melting of the base material during the pulse current and subsequent cooling during the base current, creating weld spots resembling a string of beads. Furthermore, TIG welding can be categorized into two types based on a filler wire: cold and hot. Cold wire welding utilizes a standard filler wire, while hot wire welding preheats the wire by passing a current through it. Hotwire welding offers the advantage of increasing the deposition rate per unit time, allowing for quicker completion of the welding process. This addresses the time-consuming aspect of TIG welding, where high-quality welds are achieved but may take longer due to the gradual melting of the required filler material.

Table 1

Weld parameters for TIG welding

Output current	**Pulse**	**Frequency**
	Yes	Low frequency (0.5 Hz to 20 Hz)

Output current	**Pulse**	**Frequency**
Direct current (DC)		Medium frequency (20 Hz to 500 Hz)
		High frequency (20 kHz or higher)
	No	-
Alternate current (AC)	Yes	Low frequency (0.5 Hz to 20 Hz)
		Medium frequency (20 Hz to 500 Hz)
	No	

Key Features of TIG Welding include:

- Precision Welding: TIG welding allows for precise and intricate welds, making it suitable for applications where accuracy is crucial.
- Clean Welds: Using inert gas prevents atmospheric contamination, producing clean and high-quality welds.
- Versatility: TIG welding applies to various materials, including exotic metals and thin sheets.

Plasma Welding.

- Plasma welding is another non-consumable electrode type that shares similarities with TIG welding but utilizes a more focused plasma arc. Characteristics of plasma welding include:
- Increased Energy Density: The focused plasma arc increases energy density, allowing deeper penetration into the material.
- Enhanced Welding Speed: Plasma welding is known for its increased welding speed, contributing to efficiency in various applications.
- Narrower Heat-Affected Zone: The concentrated heat minimizes the size of the heat-affected zone, reducing potential distortions.

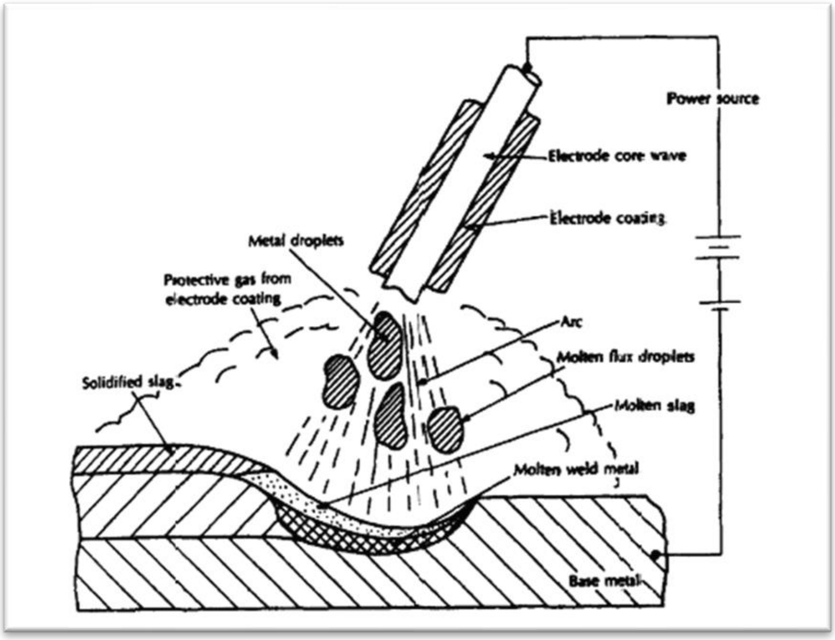
Consumable (Fusible) Electrode Type.

Shielded Metal Arc Welding (SMAW). Shielded Metal Arc Welding, commonly known as stick welding, is a consumable electrode type where a coated electrode is used. Shielded metal arc welding (SMAW) illustrates consumable (fusible) electrode-type arc welding. It employs a metal rod (known as a shielded metal arc welding rod) crafted from the same material as the base material, serving as the electrode. The arc between the electrode's core wire and the base material functions as the heat source.

The resulting molten metal is enveloped by the gas and glass-like slag produced from the shield of the core wire. This process boasts the advantage of being less susceptible to interference from wind or other external disturbances at the worksite due to the shielding provided by the gas and slag. Additionally, a shielding tube forms at the tip of the welding rod. SMAW has a rich history. It is often performed manually and earned the moniker manual arc welding. While its prevalence has diminished with the proliferation of automatic or semi-automatic MAG welding machines utilizing carbon dioxide (CO2), SMAW continues to find applications owing to its merits of facilitating quick and straightforward welding indoors and outdoors, coupled with relatively inexpensive equipment. (Messler, 1999)

Figure 2

Shielded Metal Arc Welding (SMAW) (Messler, 1999)



Features of SMAW include:

- Versatility: SMAW is versatile and can be applied to various materials and joint configurations.
- Portability: It is suitable for outdoor and remote applications, offering portability and ease of use.
- Cost-Effective: SMAW equipment is generally more affordable, making it a cost-effective choice for specific applications.

MAG Welding (Metal Active Gas Welding). Metal Active Gas Welding, or MAG welding, is a consumable electrode type that employs a continuously fed wire and a shielding gas with active components. MAG (Metal Active Gas) welding, or CO2 arc welding or CO2 welding, is a form of arc welding that employs an active gas, typically carbon dioxide (CO2) or a gas mixture of argon and CO_2. Primarily utilized for automatic or semi-automatic welding of ferrous metals, MAG welding is unsuitable for nonferrous metals like aluminum due to the chemical reactions involving CO_2.

In automatic or semi-automatic MAG welding, a coiled welding wire is an electrode, replacing the welding rod used in manual shielded metal arc welding. The coiled wire is connected to the wire feed unit and automatically directed to the torch tip by a feed roller driven by an electric motor. Upon passing through the contact tip, the wire is energized.

The welding process involves striking an arc between the wire and the base material. This simultaneous melting of the wire and base material creates a weld. Throughout this process, shielding gas is introduced through a nozzle into the weld area and its surroundings, forming a protective shield around the arc and weld pool, preventing exposure to the atmosphere. CO_2 gas, a gas mix of argon and CO_2, or a mix of argon with a small percentage of oxygen can be used as the shielding gas. Compared to shielded metal arc welding, MAG welding boasts a faster deposition rate, where the electrode transforms into weld metal. This results in increased work efficiency, which is attributed to deep penetration into the base material. Other notable advantages include high-quality weld metal and the ability to achieve automatic welding by installing the welding torch on a robot.

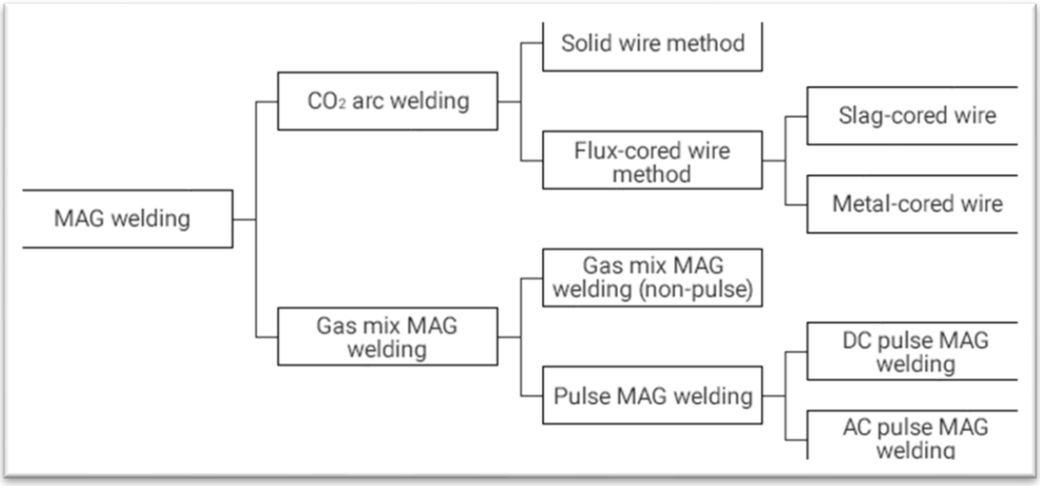
A semi-automatic MAG welding machine mainly consists of the following:

- Welding power supply
- Wire feed unit
- Welding torch
- Gas cylinder

The feed unit must feed the wire at a constant speed. Consequently, a constant-voltage characteristic power supply is generally used for the welding power supply. The wire feed unit is a continuous speed feeding type.

Figure 3

Flow chart on the different MAG welding techniques.



Key attributes include:

- High Productivity: MAG welding offers high deposition rates, making it suitable for rapid welding applications.
- Automated Processes: MAG welding is commonly used in automated systems, enhancing efficiency and precision.
- Adaptability: It is suitable for various materials and thicknesses, providing versatility in welding processes.

MIG Welding (Metal Inert Gas Welding). MIG welding, or Gas Metal Arc Welding (GMAW), is similar to MAG welding but typically uses inert gases for shielding. MIG (Metal Inert Gas) welding is another arc welding method. Similar to TIG welding, it utilizes an inert gas as a shielding gas. MIG welding belongs to the consumable electrode type, involving a discharge electrode that melts during welding. (Understanding the Fusion Welding Process - Arc Machines, n.d.)

This welding technique is commonly employed for joining stainless steel or aluminum alloy workpieces, and the choice of shielding gas depends on the specific metal to be welded. The electrode in MIG welding is a coiled welding wire, connected to the wire feed unit, which automatically moves to the torch tip through a feed roller powered by an electric motor. The wire is energized upon passing through the contact tip, initiating an arc between the wire and the base material. Simultaneously melting the wire and base material, this process forms the weld. Throughout the operation, shielding gas is delivered through a nozzle into the weld area and its surroundings to create a protective shield around the arc and weld pool, preventing exposure to the atmosphere.

Figure 4

MIG Welding. (Messler, 1999)

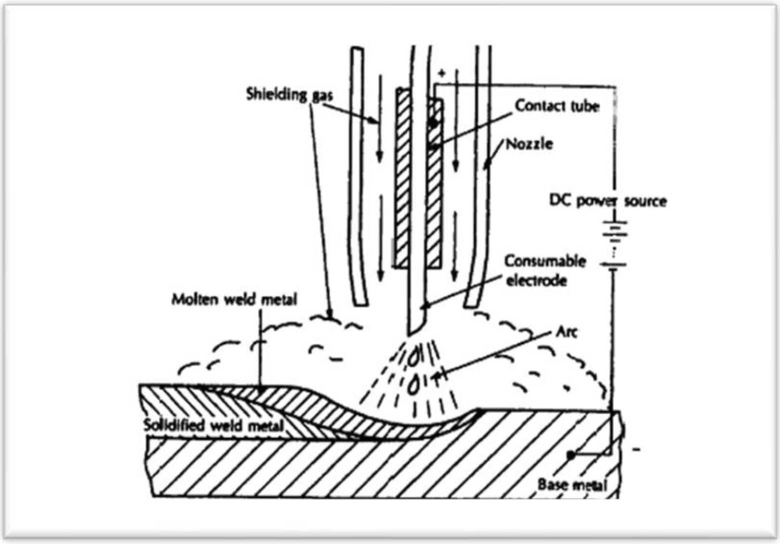


Table 2

Classification of MIG Welding

Classification of MIG welding	Pulse	Welding method
Direct current (DC)	No	Short-arc MIG welding
		Spray MIG welding
		Large-current MIG welding
	Yes	Pulse MIG welding
		Low-frequency superimposed pulse MIG welding.
Alternate current (AC)	Yes	AC pulse MIG welding
		Low-frequency superimposed AC pulse MIG welding.
DC + AC	Yes	AC/DC composite pulse MIG welding

Notable features of MIG welding include

- Ease of Use: MIG welding is known for its user-friendly nature, making it suitable for beginners and manual applications.
- High Productivity: The continuous wire feeding mechanism contributes to high productivity in various welding processes.
- Reduced Cleanup: MIG welding minimizes spatter and fumes, reducing the need for extensive post-weld cleanup.

Electro gas Arc Welding (EGW). Electro-gas Arc Welding is a consumable electrode type that involves welding in a vertical position with a continuously fed consumable electrode and a gas shield. The Electro gas arc welding (EGW)technique was developed to facilitate efficient vertical position welding of thick plates with stable penetration. The primary shielding gas employed in EGW is commonly CO2, although variations using argon gas, gas mixes of argon and CO2, oxygen, or helium are also prevalent. Flux-cored wires, which generate slag to form a clean bead, are predominantly utilized for welding wire, although solid wires find application in specific cases. The welding power supply is typically a DC constant-voltage or constant-current (drooping) characteristic power supply.

During the process, the weld pool is enclosed by the end of the base material, a copper shoe, and a fire-resistant backing. Vertical position welding is executed upwards, preventing the dripping of molten metal and enabling the welding of a thick plate in a single pass (one operation). Noteworthy advantages include a rapid deposition rate facilitated by a large current, high efficiency, and a relatively substantial margin for groove accuracy due to minimal angular distortion.

EGW finds application in welding vertical butt joints of various products, including ship's shell plates, bridges, storage tanks, and pressure vessels.

Characteristics of EGW include:

- Vertical Welding: EGW is particularly effective for vertical welding of thick plates, providing high-quality welds.
- High Deposition Rates: The process allows for high deposition rates, improving efficiency in specific applications.
- Reduced Distortion: Electro-gas arc welding reduces distortion due to its vertical welding orientation.

Applications of Fusion Welding:

Fusion welding finds extensive applications in constructing significant structures like airplanes, bridges, ships, pressure tanks, and welded pipes. Its versatility allows the merging of various materials, regardless of thickness, owing to the substantial heat levels generated during the process.

Fusion Welding in Different Materials:

- Metal Joining: Fusion welding involves intense heat to unite two or more metal pieces. Unlike soldering, fusion welding melts the base metal and may require a filler material to create a junction. As the molten components cool, they come together to produce a weld bead, resulting in a final product more durable than the starting material.
- Plastics Joining: Fusion welding is applicable in joining polymers, whereas solvent welding employs adhesives. The process involves washing and drying surfaces, applying pressure and heat to the molten component, and finally cooling the molten components to solidify the link between the two polymers.
- Wood Materials Joining: Fusion welding for wood components requires heat production through mechanical friction. This involves subjecting materials to high pressure, followed by linear friction, generating heat to fuse two wooden components. The process is simple,

eliminating the need for nails or adhesive, and results in a more robust finished product while preserving the original design.

Pros and Cons of Fusion Welding.

Pros:

- Use of Filler Material: Fusion welding allows the use of filler material when joining two wide sections.
- No External Pressure: The absence of external pressure preserves the initial shape of the welded components.
- Minimal Edge Design and Preparation: Fusion welding does not necessarily require intricate edge design and preparation, simplifying the process.
- Durable Welded Joints: Fusion welding produces robust joints between parent materials.
- Suitable for Industrial Processes: Fusion welding's speed and simplicity make it well-suited for various industrial applications.

Cons:

- Challenges with Dissimilar Materials: Joining two materials with different melting points can be challenging.
- Stress and Damage: Fusion welding may induce stress and damage on the welded component due to the need for fusion and solidification.
- Alteration of Parent Material: The original structure of the parent material changes the heating process.

- Heat-Affected Zone Weakness: The linked parts create a heat-affected zone, generally considered the weakest point in the entire structure.

Other Unique forms of welding.

- Electron Beam (light beam) Welding:
- Pressure Welding
- Friction welding

Electron Beam Welding. Electron beam (EB) welding relies on the emission of electrons in a vacuum tube or Braun tube. This welding method is primarily executed in a vacuum, known as high-vacuum welding. It stands out for its ability to minimize distortion across various applications, accommodating thick to thin plates and intricate welding requirements. In recent advancements, electron beam welding machines have been designed to operate effectively without a perfect vacuum (low-vacuum welding machines) or by incorporating a moving electron gun (moving electron gun welding machines), broadening the scope of potential applications.

Applications for electron beam welding include ship's shell plates, bridges, storage tanks, aircraft parts, and electronic components. In the realm of electronic components, a process known as electron beam sealing is employed to seal crystal oscillators that require joining in a vacuum. This involves vacuum brazing sealing, achieved by melting the filler material between a metal lid and a ceramic package through heat conduction induced by the electron beam. (Sterkenburg, 2021)

Pressure Welding: Pressure welding is a fundamental technique in metal joining processes. Unlike fusion welding, where heat is the primary agent, pressure welding requires force to create a solid and durable bond between materials. This process is extensively used in various industries due to its efficiency, precision, and versatility.

Types of Pressure Welding:

- Cold Welding
    1. Cold welding occurs at or near room temperature without applying external heat. This technique is particularly suitable for materials with high ductility.
    2. Commonly used in joining similar metals, cold welding relies on clean surfaces and high pressure to create a strong bond.
- Explosion Welding
    1. Explosion welding utilizes explosive forces to create a high-velocity collision between two materials, leading to their metallurgical bonding.
    2. This technique is effective for joining dissimilar metals, offering advantages in terms of versatility and compatibility.
- Ultrasonic Welding
    1. Ultrasonic welding employs high-frequency ultrasonic vibrations to generate localized heat and pressure, facilitating welding.
    2. Ultrasonic welding offers rapid and precise bonding, commonly used to assemble plastics and non-ferrous metals.

Friction Welding:

- Friction welding involves rotating one component against another, generating heat through friction. Once the materials reach a plastic state, pressure is applied to achieve a solid weld.
- This technique is versatile, applicable to similar and dissimilar materials, and particularly effective in joining cylindrical components.
- This technique induces high-speed friction between the base materials, be it metal or resin, causing them to soften through the generated heat. Subsequently, pressure is applied to facilitate their joining.

- Notably considered an environmentally friendly joining method, it eliminates the need for an external heat source beyond friction heat. Additionally, it removes the necessity for welding rods or flux, and unlike arc welding or gas welding, it produces no spatter or gas.
- Friction welding can be precisely controlled based on friction thrust (pushing force), rotation speed, and time. With these parameters numerically controlled, friction welding can be automated without human intervention, making it widely utilized in factory automation (FA).
- A notable variant of friction welding is Friction Stir Welding (FSW), which has garnered significant attention. In this process, a cylindrical tool with a probe (protrusion) rotates at high speed, and the tool is moved so that the probe digs along the joining section with high pressure.
- The tool's rotational motion softens the base materials, stirring the area around the weld to induce plastic deformation and atomic bonding between the materials.

Brazing/Soldering Welding (Messler, 1999)***:***

Brazing. Brazing, a welding method utilizing filler materials with high melting points, encompasses various techniques. Torch brazing utilizes a conventional gas welding torch for heat, while induction heating brazing employs high-frequency induction heating. Controlled atmosphere brazing inside a vacuum furnace without flux involves heating and cooling the base and filler materials. These methods find applications in the non-oxidizing brazing of stainless steel and the automated joining of titanium and ceramic workpieces.

In recent times, laser brazing has emerged as a noteworthy brazing technique. Laser brazing utilizes light energy (laser) to melt a wire-shaped filler material supplied between base materials for joining. This process minimizes the melting of the base materials, resulting in reduced thermal deformation. Consequently, lightweight, and highly rigid joining can be achieved without compromising product design.

Resistance spot welding was traditionally employed for joining automobile roofs, side panels, and trunk lids. This involved additional processes like creating a groove for resistance spot welding and covering the part with molding to conceal the groove and weld spots. Laser brazing, on the other hand, preserves the appearance of the base material, eliminating the need for processes such as working the groove and preparing molding. Moreover, laser brazing significantly enhances joint strength and joining speed compared to resistance spot welding, making it a preferred choice in the automotive and other industries, particularly in Europe and Japan.

Soldering. In brazing and soldering, soldering is a joining method employing filler materials with low melting points. In contrast to brazing, soldering harnesses a light beam as its heat source. This section delves into the intricacies of soldering, a technique frequently employed for detailed joining work. Traditional soldering relies on heat generated by an electric current, often facilitated by a soldering iron. Variants of soldering methods encompass dip and reflow soldering, where components are united by immersing them in molten solder.

Light beam soldering has gained prominence in recent years, particularly in producing electronic components within the realm of factory automation. In this process, light emanating from a high-power source is collected by a reflector and precisely focused on the welding point. Soldering is then executed utilizing the energy derived from the light. Leveraging solders with low melting temperatures (soft filler materials) and enabling the utilization of robots for meticulous joining proves invaluable for assembly automation and the mass production of heat-sensitive electronic components.

Welding Automation:

The realm of welding has undergone a transformative shift, propelled by the widespread adoption and decreasing costs of factory automation (FA) equipment due to advancements in digital technology. This evolution has seen welding methods progress from manual to semi-automatic to fully automatic welding. Simultaneously, the integration of robot welding has witnessed substantial growth, particularly in industries like automotive, where it has become an indispensable component for optimizing welding processes. This surge in robot usage is bolstered by cutting-edge instruments such as sensors, displacement meters, controllers, and programmable logic controllers (PLCs), which enable swift, precise detection, and feedback control. The incorporation of robots into welding procedures is on a steady rise.

Robotic Welding:

Robotic welding entails employing a robotic arm to grasp and maneuver the welding torch, with the robot programmed to execute a specific torch movement pattern to achieve the desired weld. Equipped with sensors, the robot continually monitors the welding process, making adjustments as required (Chen, 2014) (Wang, 2020) (Zheng, 2022) (Pedersen, 2016) (Lopes, 2017).

Controlled by a specialized computer program tailored for welding, the robot receives torch movement and manipulation instructions. It also integrates feedback from monitoring sensors to adapt during the welding process. A typical robotic welding system comprises various essential components harmonizing to automate welding tasks:

- Robot: This is primarily responsible for physically executing the welding, typically realized through a multi-axis robotic arm under computer control.

- Welding Equipment: Encompasses the welding power source, torch, and additional equipment like wire feeders, gas supplies, and control panels.
- Control System: This involves the computer orchestrating robot movements, the power supply for welding equipment, and other peripherals such as sensors and cameras.
- Programming: This involves utilizing specialized software that enables users to define robot movements, power supply parameters, and other necessary settings for the welding process.

The operation of the robotic welding system:

1. The robot is instructed to follow a specific pattern tailored to the shape of the workpiece.

2. Activating the welding equipment, the welding torch is brought into contact with the workpiece.

3. Utilizing feedback from sensors, cameras, or other peripherals, the robot's control system adjusts its position and movement to ensure a consistent weld along the workpiece edges.

4. The robot progresses along the programmed path, executing the welding process as it advances.

5. Upon completion of welding, the robot and welding equipment are deactivated, and the workpiece is removed.

Notably, the robotic welding system can incorporate advanced technologies such as machine vision, sensor-based feedback control, and artificial intelligence to enhance its performance, precision, and flexibility.

List of sensors & systems necessary for the robots to function:

Systems:

- Control Systems
- Programming
- Machine Vision
- 2D machine vision
- Open CV

Sensors:

- Camera-based sensors
- Force Based Sensors
- Position Sensors
- Temperature Sensors
- Current Sensors
- Gas Sensors
- Proximity Sensors

Features of the robot for welding purposes. Several essential characteristics are necessary for a robot to engage in welding which includes (Lei, 2020) (Pires J. N., 2006) (Xu, 2017):

1. Substantial payload capacity: Welding robots need to support the weight of welding equipment and execute welding tasks effectively.

2. Precise and consistent performance: Achieving consistent, high-quality welds demands robots with precise movements and repeatability.

3. Sturdy construction: Maintaining rigidity and stiffness is crucial for welding robots to ensure accurate welding.

4. Swift motion and acceleration: Efficient welding requires robots capable of swift movement and rapid acceleration.

5. Resistance to high temperatures: Welding robots should endure high temperatures and harsh conditions inherent in welding processes.

6. Management of welding torch: Robots must manage the welding torch adeptly, maintaining a steady distance and angle relative to the workpiece.

7. Versatility in welding processes: Welding robots must accommodate various welding techniques such as MIG, TIG, and Stick welding.

8. Incorporation of safety measures: Robots should include safety features like emergency stop buttons, light curtains, and fire suppression systems to safeguard operators from welding hazards.

9. Adaptability: Flexibility is essential for welding robots to operate effectively across diverse environments and tasks.

Robots for welding:
Various types of robots are commonly employed for welding purposes (Herath, 2022) (Siciliano, 2016) (Kurfess, 2018) (Tsai, 1999):

1. Articulated Robots: Equipped with multiple rotary joints allowing movement in various directions, articulated robots are capable of handling heavy loads and performing precise tasks, making them well-suited for welding. Their flexibility and adaptability in welding applications have been extensively studied (Yoshikawa, 1985) (Tomei, 1990).

2. SCARA Robots: With two parallel rotary joints enabling movement in the X-Y plane, SCARA robots are known for their precision and repeatability, making them a suitable option for welding tasks (de Luca, 2005) (Pires J. N., 2007).

3. Delta Robots: Featuring three parallel rotary joints for movement in the X-Y-Z plane, delta robots offer high precision and repeatability, particularly beneficial for welding tasks that require high speed and acceleration (Isla, 2013) (Craig, 2018).

4. Cartesian Robots: Equipped with three linear joints allowing movement in the X-Y-Z plane, Cartesian robots demonstrate high precision and repeatability, making them well-suited for welding tasks that demand utmost accuracy and precision (Tomei, 1990) (de Luca, 2005).

5. Collaborative Robots (Co-bots): Designed for safe interaction with humans, collaborative robots are useful in welding applications. Lightweight and easy to use, they can be programmed for a wide range of tasks. (Groover, 2008) (Dhillon, 2002).

Table 3:

Types of robots used in welding.

Type of Robot	**Advantages**	**Disadvantages**	**Examples**
Articulated Robots	High payload capacity, high flexibility, and versatility are widely used in welding applications.	High cost, high maintenance requirements, high complexity	Fanuc Robotics' Arc Mate series, ABB Robotics' IRB series, KUKA Robotics' KR series
SCARA Robots	High precision and repeatability, well-suited for welding applications	Limited work envelope, high cost	Epson Robots' LS series, Adept Technology's Quattro series, Denso Robotics' VS series

Delta Robots	High precision and repeatability, high speed and acceleration well-suited for welding applications	Limited work envelope, high cost	Staubli Robotics' TX series, KUKA Robotics' KR AGILUS series, ABB Robotics' IRB 120 series
Cartesian Robots	High precision and repeatability, well-suited for applications that require high accuracy and precision	Limited work envelope, high cost	Yaskawa Motoman's MH series, FANUC Robotics' LR Mate series, ABB Robotics' IRB 120 series
Collaborative Robots (Co-bots)	Lightweight and easy to use, can be programmed to perform a wide range of tasks, safe to work alongside humans	Limited payload capacity, lower precision, and repeatability compared to traditional robots, not suitable for heavy-duty welding tasks	Universal Robots' UR series, KUKA Robotics' LBR iiwa series, ABB Robotics' YuMi series

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Co-bots – Collaborative Robots in Welding:

Co-bots, or collaborative robots, represent a robotic system engineered to collaborate with humans within a shared workspace. They typically possess smaller frames and greater flexibility compared to traditional industrial robots, incorporating sensors and safety features to ensure safe operation in close proximity to humans. Co-bots find various applications in robotic welding in reconfigurable systems. One key advantage is their flexibility and adaptability. Due to their compact size and flexibility, co-bots can seamlessly integrate into reconfigurable systems and transition between workstations as required.

Another benefit of employing co-bots for robotic welding within reconfigurable systems is their capacity to operate safely alongside humans. This fosters a more efficient and flexible workflow, with co-bots assuming tasks deemed hazardous or monotonous for human workers. Furthermore, co-bots can be outfitted with machine vision systems, enabling real-time monitoring of the welding process to identify defects or deviations from desired weld specifications. This capability facilitates prompt adjustments to enhance weld precision and quality. Moreover, co-bots often have sensors and safety features to detect and respond to environmental changes or obstacles. This capability proves invaluable in reconfigurable systems where co-bots must adapt to varying workstations and tasks.

In summary, leveraging co-bots for robotic welding in reconfigurable systems offers numerous advantages, including enhanced flexibility, adaptability, safety, and superior quality control. Their ease of integration and mobility between workstations are particularly beneficial in environments where system layouts and functions undergo constant modifications.

Examples of Co-bots. Numerous instances exist where co-bots are employed for welding tasks within low-volume production settings. Some illustrations encompass:

- The Universal Robots UR10 co-bot is frequently utilized for arc welding, resistance welding, and spot welding in low-volume production scenarios. Renowned for its ease of programming and adaptability, it seamlessly integrates with diverse welding tools like torch holders, wire feeders, and fume extractors.
- The Fanuc CR-35iA co-bot is explicitly engineered for MIG welding in low-volume production environments. Its compact design and substantial payload capacity make it suitable for various welding applications.

- The KUKA LBR iiwa co-bot, characterized by its lightweight and compact structure, ideally suited for effortless integration into low-volume production settings. It commonly undertakes spot welding, tack welding, and other precision welding duties.
- The ABB IRB 1200 co-bot is tailored for spot, seam, and precision welding tasks. Compact and adaptable, it seamlessly integrates into low-volume production environments.
- The Yaskawa Motoman MH50 co-bot is a versatile option capable of undertaking MIG welding, TIG welding, and other welding assignments. It is specifically designed for low-volume production settings and interfaces with a variety of welding tools.

These examples underscore just a fraction of the co-bots utilized for welding within low-volume production environments. Optimal co-bot selection hinges on factors such as the specific welding techniques employed, the layout and dimensions of the production area, and the precise demands of the task at hand.

Time and motion study:

Time and motion analysis is a systematic strategy for analyzing labor procedures, identifying inefficiencies, and increasing efficiency in industrial settings. This methodology is built on various time study methodologies, each with its own advantages and uses. It is used to minimize unnecessary work, organize the remaining work in the best possible sequence, standardize suitable work procedures, and define precise time standards for the task. In Time and motion study, fundamental motions or sets of motions that are challenging to assess using traditional stopwatch time study procedures accurately are assigned primary motion times, synthetic timings, or predefined times. Instead, timing devices like motion picture cameras or videotape machines can measure extremely short parts, and these times are calculated by analyzing a large sample of diverse actions. The synthetic results combine logical groupings of basic motions (therbligs) and are predefined to forecast standard times for newly created activities arising from modifications to the methods.

History of time study:

Industrial engineering and management methods have developed around time and motion analysis to improve productivity and efficiency at work. This method examines and quantifies the amount of time and fundamental movements required to complete activities to determine standard labor durations. The development of time and motion studies over a century ago is reflected in its history, significantly impacting contemporary engineering and management techniques.

The Genesis: Frederick W. Taylors scientific management. In the late 19th century, Frederick W. Taylor, who is frequently hailed as the father of scientific management, laid the groundwork for the study of time and motion. Through his groundbreaking research, Taylor (1911) popularized the idea of breaking down tasks into their fundamental motions and timing these to determine the most productive ways to do a task. His groundbreaking book "The Principles of Scientific Management," which promoted a scientific method of examining work processes, set the foundation for later research (Taylor, 1911).

The Gilbreths innovations. Frank B. and Lillian M. Gilbreth developed the methodology by adding the notion of therbligs, or the fundamental movements needed to do work, building on Taylor's concepts. Motion picture cameras were a breakthrough that the Gilbreths used to examine workers' movements. This allowed for extensive motion analysis and the creation of better work procedures (Gilbreth & Gilbreth, 1917).

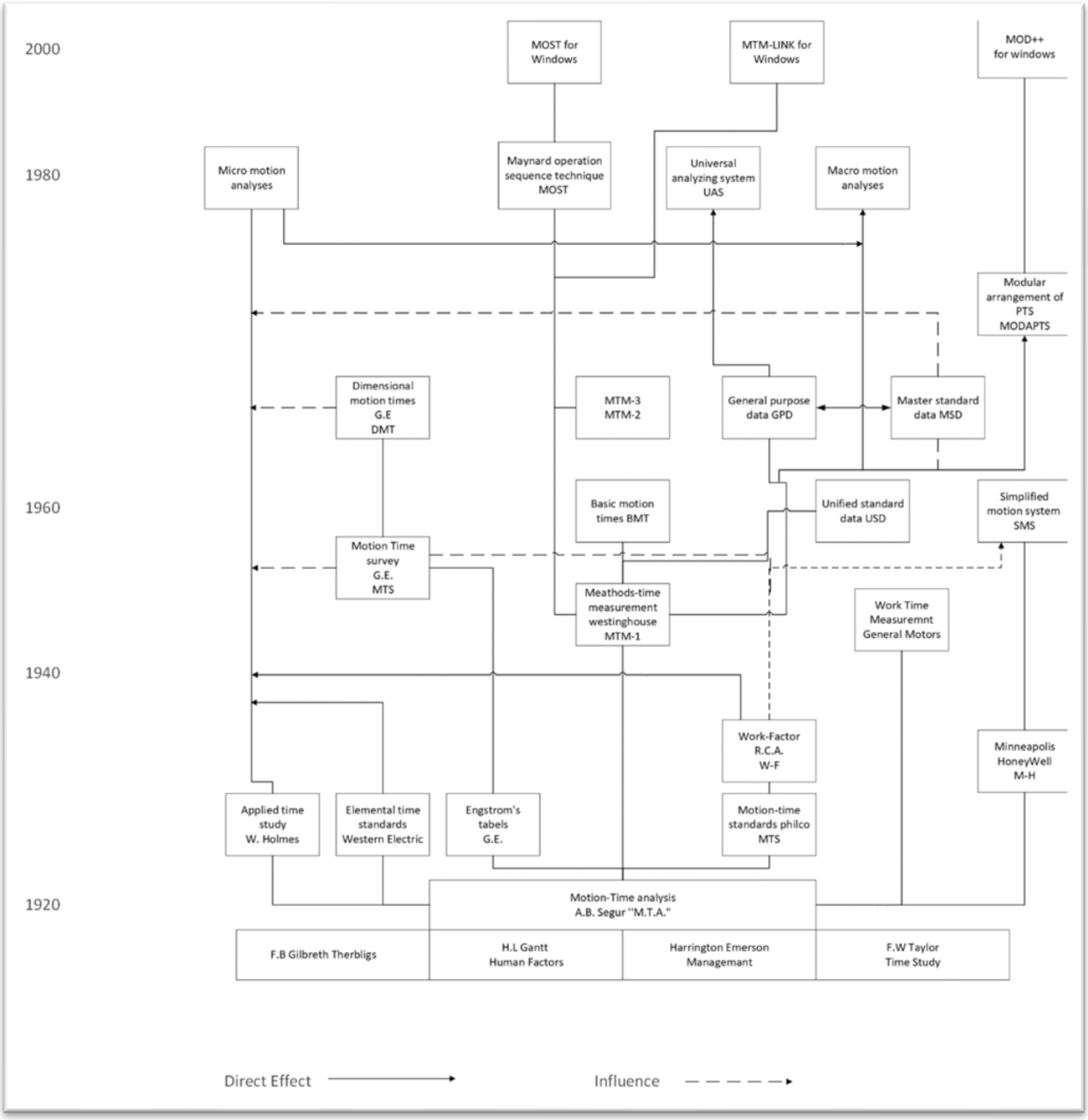
Mid-20th-century development. Time and motion studies became widely accepted in various sectors during the 1920s and 1940s. Under the influence of Gilbreths and others, the approaches changed to consider worker weariness and ergonomics (Barnes, 1980). In order to swiftly and precisely calculate work rates following World War II, there was a trend toward the use of fundamental motion times and preset time systems, such as Work Factor, Methods-Time Measurement (MTM), and the Maynard Operation Sequence Technique (MOST) (Maynard, 1948).

Modern Applications. Modern time and motion studies have incorporated cutting-edge technologies since the late 20th century. Computer simulations, software, and recording technologies have expedited the process, making it suitable for a variety of industries outside of traditional manufacturing, such as healthcare and services. The goal is to balance ergonomics, worker satisfaction, and production (Sullivan, 2002).

Predetermined time systems: MTM and MOST. Methods-Time Measurement (MTM) and the Maynard Operation Sequence Technique (MOST) are notable developments in time and motion studies approaches. MTM, created in the 1940s, offers a methodical way to examine jobs and establish time requirements using predetermined motion timings. This method is further improved by MOST, a derivation of MTM, which provides effective methods for determining work rates (Maynard, 1948) (Zandin, 2001).

Figure 5:

History of Time and Motion Study.



Types of Time and Motion study methodologies:

The techniques that supported time and motion studies changed dramatically as technology advanced. These studies were initially mainly manual in nature, requiring each move to be meticulously recorded and examined by hand. Although efficient, this method required much time and was prone to human mistakes. The development of electronic technology as we entered the digital era completely changed how time and motion investigations are carried out. These contemporary approaches use computing capacity to group motions together according to their similarities, improving analytical accuracy and efficiency. This change improved productivity and operational performance by streamlining the process and enabling a more sophisticated and nuanced understanding of workflows. The many time and motion study types are listed below.

MTM-1(Methods - Time Measurement-1). By providing time values for the seven basic motions—reach, move, turn, grip, position, disengage, and release—MTM-1 establishes the foundation. Its methodology involves examining motion picture videos frame by frame across a variety of work areas, then rating and tabulating the results to ascertain how different attributes, like weight and distance, affect the motion times. With the introduction of MTM-1, manual operations were systematically broken down into their component motions, and time criteria were assigned in advance that considered the specifics of each motion. This system is the foundation for further MTM tiers and specialized systems that concentrate on intricate and particular motion analysis.

MTM-2(Methods - Time Measurement-2). Designed to extend the application of MTM to places where the level of information in MTM-1 could be too costly, MTM-2 breaks down data into less complex, synthesized groups that are appropriate for most motion sequences. The major focus of MTM analysis is still on single and combined fundamental motions, but it is expanded to cover a broader range of tasks. MTM-2 offers a compromise between detail and practicality, and it excels in tasks where the manual phase of the work cycle requires fewer intricate or simultaneous hand movements.

MTM-3(Methods - Time Measurement-3). MTM-3 is a further simplification that aims to reduce time at the expense of some accuracy. It is most appropriate for activities where the main goal is to achieve moderately accurate and relatively quick time standards. MTM-3 simplifies analysis for tasks that do not require the fine detail of MTM-1 or MTM-2 by narrowing the system down to only four categories of manual motions. This is a practical option where speed is of the essence.

Specialized Systems: MTM-V, MTM-C, and MTM-M. Beyond the general-purpose systems of MTM-1, MTM-2, and MTM-3, the MTM family includes specialized systems tailored to specific industry needs. MTM-V addresses the unique requirements of metal-cutting operations, which are particularly beneficial in short-run machine shops. MTM-C caters to the banking and insurance industries, providing standards for clerical-related tasks. Lastly, MTM-M offers a solution for evaluating operator work in microminiature manufacturing, a growing field where traditional time study methods fall short.

MOST (Maynard Operation Sequence Technique). The MOST system originated from the MTM system and was created to meet the demand for faster analysis without compromising accuracy. Maxi-MOST, Mini-MOST, and Basic-MOST are the three stages of analysis that make up the structured approach, each of which is designed to accommodate varying operation lengths and frequencies. These vary from very short and frequent jobs that are best studied by Mini-MOST to long, uncommon operations that are best analyzed by Maxi-MOST. For operations of moderate length and frequency, Basic-MOST acts as an intermediary.

The time study analysis of the welding processes in this work was conducted using the MTM-1 and MOST methodologies. MTM-1 provides a comprehensive and detailed version of the time and motion study, while MOST is the most recent and extensively utilized technique among all time and motion studies. We aimed to determine which of the two approaches worked better for a comparable procedure.

Applications of Time and Motion Study.

1. Improving Work Methods:

   Time and motion studies are utilized to evaluate current work practices and pinpoint opportunities for improvement. By dissecting tasks into their individual acts, inefficiencies or pointless motions can be removed, resulting in more productive and efficient work processes.

2. Labor Cost Reduction:

   Streamlining operations can shorten task completion times. Because workers can accomplish more activities in the same period, this time reduction can result in significant labor cost reductions.

3. Productivity Enhancement:

   Time and motion studies can result in notable increases in productivity by carefully analyzing and optimizing each motion and step in a process. To do this, duties are streamlined, unnecessary effort is decreased, and elimination unnecessary steps.

4. Ergonomic Improvements:

   Time and motion studies also examine employees' physical movements to create workflows that lessen fatigue and injury risk. This may promote a better work environment and lower the risk of musculoskeletal problems at work.

5. Quality Improvement:

   Standardizing the most effective work practices identified by time and motion studies can minimize variability in task execution. As procedures become more standardized, quality may increase.

6. Workforce Allocation and Capacity Planning:

   These studies assist firms in comprehending the amount of time needed for various jobs and procedures, which is essential for capacity planning. Comprehending the actual duration of jobs aids in more precise workload estimation and efficient workforce distribution.

7. Performance Measurement and Benchmarking:

   Time and motion studies offer a benchmark for measuring performance by creating standards based on the most productive work practices. These benchmarks can compare employee performance and pinpoint areas needing development.

Methods - Time Measurement (MTM-1):

A foundational method in the time and motion study field, the Methods-Time Measurement (MTM) system, specifically MTM-1, is designed to optimize productivity through the analysis of manual work processes. MTM-1 is distinguished by its precise and methodical approach, which deconstructs manual tasks into basic motions that are each given a preset time standard. This section explores MTM-1's operational mechanics and offers information on its methodology and use in industrial engineering.

Core Ideas of MTM-1. The core concept of MTM-1 is that every manual labor can be broken down into a set of fundamental movements. These movements include, but are not limited to, reach, move, turn, grasp, position, disengage, and release. The process is based on a thorough analysis of tasks to identify these constituent motions and the application of specified time values to each based on empirical data collecting and considerable research.

The MTM-1 Methodology *(Maynard, 1948)***.**

- Manual Operation Analysis:

The first stage in the MTM-1 process involves thoroughly examining the manual operation under study. This means breaking down the operation into its individual movements. For this kind of study, it's frequently necessary to record and analyze the motions involved in the work using high-speed motion picture cameras or video analysis.

- Finding the Basic Motions:

After the operation has been recorded, the following stage is to find the basic motions that the task requires. The MTM system's standardized collection of fundamental motions is the foundation for this identification procedure. Depending on the type of task being carried out, each of these motions—known as therbligs—is categorized (e.g., reaching for an object, moving an object, rotating an object).

- Time Value Assignment:

Each recognized basic motion is assigned a preset time value. Time measurement units, or TMUs, are used to express these time values. One TMU is equal to 0.036 seconds. The time values are obtained by thoroughly examining the motion's characteristics and the environment in which it is performed, accounting for variables including distance traveled, object weight, and motion complexity.

- Calculation and Evaluation:

Several parameters that affect the duration of each motion are taken into consideration while rating and tabulating the motion picture analysis data. This involves examining motion properties, like reach and item weight, when moving an object. Precise time standards calculation is aided by comprehensive tables and charts that offer time values for many scenarios.

- Calculation of Standard Times:

The overall time required for a task can be determined by adding up the times for each of the fundamental motions involved. The total indicates how long a worker would typically need to complete the assignment under typical working circumstances.

- Allowance Incorporation:

The tabulated numbers only take fundamental motions' direct times into consideration. To create a thorough time standard for the activity, extra time must be allotted for personal needs, exhaustion, and inevitable delays on top of the basic time.

Figure 6:

Normal Time Values for MTM Motion Element- Reach (Freivalds, 2014)

TABLE 4 (a) Normal Time Values for MTM-1 Motion Element: **Reach** (R)

Distance		Time in TMU				Hand in Motion		Case and Description
cm	inches	A	B	C or D	E	A	B	
< 2.0	< 0.75	2.0	2.0	2.0	2.0	1.6	1.6	**A** Reach to object in fixed location, or to object in other hand or on which other hand rests.
2.5	1	2.5	2.5	3.6	2.4	2.3	2.3	
5.1	2	4.0	4.0	5.9	3.8	3.5	2.7	
7.6	3	5.3	5.3	7.3	5.3	4.5	3.6	**B** Reach to single object in location that may vary slightly from cycle to cycle.
10.1	4	6.1	6.4	8.4	6.8	4.9	4.3	
12.5	5	6.5	7.8	9.4	7.4	5.3	5.0	
15.2	6	7.0	8.6	10.1	8.0	5.7	5.7	
17.8	7	7.4	9.3	10.8	8.7	6.1	6.5	**C** Reach to object jumbled with other objects in a group so that search and select occur.
20.3	8	7.9	10.1	11.5	9.3	6.5	7.2	
22.9	9	8.3	10.8	12.2	9.9	6.9	7.9	
25.4	10	8.7	11.5	12.9	10.5	7.3	8.6	
30.5	12	9.6	12.9	14.2	11.8	8.1	10.1	**D** Reach to a very small object or where accurate grasp is required.
35.6	14	10.5	14.4	15.6	13.0	8.9	11.5	
40.6	16	11.4	15.8	17.0	14.2	9.7	12.9	
45.7	18	12.3	17.2	18.4	15.5	10.5	14.4	
50.8	20	13.1	18.6	19.8	16.7	11.3	15.8	**E** Reach to indefinite location to get hand in position for body balance or next motion or out the way.
55.9	22	14.0	20.1	21.2	18.0	12.1	17.3	
61.0	24	14.9	21.5	22.5	19.2	12.9	18.8	
66.0	26	15.8	22.9	23.9	20.4	13.7	20.2	
71.1	28	16.7	24.4	25.3	21.7	14.5	21.7	
76.2	30	17.5	25.8	26.7	22.9	15.3	23.2	
Additional		0.4	0.7	0.7	0.6	TMU per 2.54 cm > 76 cm (per 1.0 in > 30 in.)		

Figure 7:

Normal Time Values for MTM motion element - Grasp (G) (Freivalds, 2014)

TABLE 4 (b) Normal Time Values for MTM-1 Motion Element: **Grasp** (G)

Type of Grasp	Case	Time, TMU	Description and Object Dimensions	
Pickup	1A	2.0	Any size object, by itself	
	1B	3.5	Object very small or lying close against a flat surface	
	1C1	7.3	Interference with grasp on bottom and one side of cylindrical object	Diameter > 1.3 cm (0.5 in.)
	1C2	8.7		Diameter 0.6 to 1.3 cm (0.25 to 0.5 in.)
	1C3	10.8		Diameter < 0.6 cm (0.25 in.)
Regrasp	2	5.6	Change grasp without relinquishing control	
Transfer	3	5.6	Control transferred from one hand to other	
Select	4A	7.3	Object jumbled with other objects so that search and select occur	Size larger than 2.5 × 2.5 × 2.5 cm (1 × 1 × 1 in.)
	4B	9.1		0.6 × .6 × .3 cm (.25 × .25 × .12 in) to 2.5 × 2.5 × 2.5 cm (1 × 1 × 1 in.)
	4C	12.9		Size smaller than .6 × .6 × .3 cm (.25 × .25 × .12 in.)
Contact	5	0	Contact, sliding, or hook grasp	

Figure 8:
Normal Time Values for MTM motion element - Move (M) (Freivalds, 2014)

TABLE 4 (c) Normal Time Values for MTM-1 Motion Element: **Move** (M)

Distance		Time in TMU			Hand in motion	Weight up to	Formula Parameters		Case and Description
cm	inches	A	B	C	B	kg (lb)	Constant	Factor	
< 2.0	< 0.75	2.0	2.0	2.0	1.7				**A** Move object to other hand or against stop.
2.5	1	2.5	2.9	3.4	2.3	1.1 (2.5)	0	1.00	
5.1	2	3.6	4.6	5.2	2.9				
7.6	3	4.9	5.7	6.7	3.6	3.4 (7.5)	2.2	1.06	
10.1	4	6.1	6.9	8.0	4.3				**B** Move object to approximate or indefinite location.
12.5	5	7.3	8.0	9.2	5.0	5.7 (12.5)	3.9	1.11	
15.2	6	8.1	8.9	10.3	5.7				
17.8	7	8.9	9.7	11.1	6.5	7.9 (17.5)	5.6	1.17	
20.3	8	9.7	10.6	11.8	7.2				
22.9	9	10.5	11.5	12.7	7.9	10.2 (22.5)	7.4	1.22	**C** Move object to exact location.
25.4	10	11.3	12.2	13.5	8.6				
30.5	12	12.9	13.4	15.2	10.0	12.5 (27.5)	9.1	1.28	
35.6	14	14.4	14.6	16.9	11.4				
40.6	16	16.0	15.8	18.7	12.8	14.7 (32.5)	10.8	1.33	
45.7	18	17.6	17.0	20.4	14.2				
50.8	20	19.2	18.2	22.1	15.6	17.0 (37.5)	12.5	1.39	
55.9	22	20.8	19.4	23.8	17.0				
61.0	24	22.4	20.6	25.5	18.4	19.3 (42.5)	14.3	1.44	
66.0	26	24.0	21.8	27.3	19.8				
71.1	28	25.5	23.1	29.0	21.2	21.5 (47.5)	16.0	1.50	
76.2	30	27.1	24.3	30.7	22.7				
Additional		0.8	0.6	0.85	TMU per 2.54 cm > 76 cm (per 1.0 in. > 30 in.)				

Figure 9:

Normal Time Values for MTM motion element - Position (P) (Freivalds, 2014)

TABLE 4 (d) Normal Time Values for MTM-1 Motion Element: **Position** (P)

			Time in TMU	
Class	Description of Fit	Symmetry	Easy to Handle	Difficult to Handle
1	Loose (no pressure required)	S SS NS	5.6 9.1 10.4	11.2 14.7 16.0
2	Close (light pressure required)	S SS NS	16.2 19.7 21.0	21.8 25.3 26.6
3	Exact (heavy pressure required)	S SS NS	43.0 46.5 47.8	48.6 52.1 53.4

Key: S = symmetrical, SS = semi-symmetrical, NS = nonsymmetrical.

Figure 10:

Normal Time Values for MTM motion element - Release (R) (Freivalds, 2014)

TABLE 4 (e) Normal Time Values for MTM-1 Motion Element: **Release** (RL)

Case	Time in TMU	Description
1	2.0	Normal release performed by opening fingers as an independent motion
2	0	Contact release with no finger motion

Figure 11:

Normal Time Values for MTM motion element - Apply Pressure (AP) (Freivalds, 2014)

TABLE 4 (h) Normal Time Values for MTM-1 Motion Element: **Apply Pressure** (AP)

Symbol	Time in TMU	Description
APA	10.6	Apply pressure alone
APB	16.2	Apply pressure preceded by regrasp

Figure 12:

Normal Time Values for MTM motion element- Body, Leg, and Foot motions (Freivalds, 2014)

TABLE 4 (j) Normal Time Values for MTM-1 Motion Element: **Body, leg,** and **foot motions** (various symbols given in table)

Motion	Symbol	Time in TMU	Description and Conditions
Sit	SIT	34.7	From standing position
Stand	STD	43.4	From seated position
Turn body	TBC1	18.6	Turn body 45° to 90°, Case 1 – Lagging foot not aligned with leading foot
Turn body	TBC2	37.2	Turn body 45° to 90°, Case 2 – Lagging foot aligned with leading foot
Bend	B	29.0	Bend body forward so hands can reach knees
Stoop	S	29.0	Stoop body forward so hands can reach floor
Arise	AB	31.9	Arise from bent position
Arise	AS	31.9	Arise from stooped position
Kneel	KOK	29.0	Kneel on one knee
Kneel	KBK	69.4	Kneel on both knees
Arise	AKOK	31.9	Arise from kneeling position on one knee
Arise	AKBK	76.7	Arise from kneeling position on both knees
Walk	W*X*FT	5.3 per ft	Walking in ft of distance, X = distance in ft
Walk	W*N*P	15.0/pace	Walking in number of paces, N = number of paces
Walk	W*N*PO	17.0/pace	Walking in number of paces with weight or obstruction, N = number of paces
Leg motion	LM6	7.1	Move leg up to 6 in. any direction
Leg motion	LM*X*	$7.1 + 1.2(X\text{-}6)$	Move leg more than 6 in. any direction, where X = distance of movement
Foot motion	FM	8.5	Foot moves up to 4 in. hinged at ankle
Foot motion	FMP	19.1	Foot moves up to 4 in. hinged at ankle, apply heavy pressure with leg muscles

MOST (Maynard Operation Sequence Technique):

The Maynard Operation Sequence Technique (MOST) is a highly structured, predetermined time measurement system designed to streamline the establishment of time standards for manual work tasks. Developed by Zandin in 1980 and initially applied at Saab-Scania in Sweden in 1967, MOST is an evolution of the Methods-Time Measurement (MTM) system, engineered to offer a faster yet equally precise alternative for time analysis. This methodology significantly reduces the time required to establish standards, performing analyses at least five times faster than MTM-1 without a notable sacrifice in accuracy. MOST is distinguished by its applicability across a wide spectrum of operations. It is categorized into three hierarchical levels based on the task's frequency and duration: Maxi-MOST, Basic-MOST, and Mini-MOST. (NIEBEL, 1988) (Freivalds, 2014).

MOST Structure. MOST is organized into three levels to accommodate various operation lengths and frequencies:

- Maxi-MOST: This level is tailored for long, infrequent operations ranging from 2 minutes to several hours that occur less than 150 times per week. It offers rapid analysis with a trade-off in precision, suitable for tasks with high variability.
- Basic-MOST: This is the intermediate level, optimized for tasks lasting 0.5 to 3 minutes. It is also the most commonly applied level, designed for operations that do not fit the criteria for Maxi-MOST or Mini-MOST.
- Mini-MOST: Applies to very short, highly repetitive tasks under 1.6 minutes in length, repeated more than 1500 times a week. Mini-MOST is characterized by its detailed and precise analysis, catering to operations with minimal variability.

MOST Sequence Models. MOST methodology revolves around three basic sequence models, each targeting specific types of movements or tool interactions. These are:

1. General Move: Focuses on the free spatial movement of an object through the air.
2. Controlled Move: Pertains to movements where the object either remains in contact with a surface or stays attached to another object.
3. Tool and Equipment Use: Deals with common hand tools and equipment.

Operational Phases and Sub activities. In MOST, tasks are analyzed through a sequence of operational phases and sub-activities:

- Get: Involves reaching for an object, possibly with body motion or steps, and gaining manual control. This phase uses sub-activities like Action Distance (A), Body Motion (B), and Gain Control (G).
- Put: Entails moving the object to a new location, potentially with body motion, and placing it at a specified location, utilizing sub-activities such as Placement (P).
- Return: Describes the action of returning to the workstation, mainly involving the Action Distance (A) sub-activity.

Each sub-activity is defined by index values correlating to the relative difficulty, which are subsequently converted into time values in TMUs by scaling.

Analysis and Application. In applying MOST, tasks are broken down into their constituent actions, identified with the appropriate sequence model, and analyzed using the defined sub-activities and index values. This breakdown enables the precise calculation of time standards for manual operations, incorporating considerations for body movements, control levels, and tool use.

For example, a task involving picking up an object, placing it elsewhere, and returning to the original position would be analyzed by breaking down the movements into A, B, G, A, B, P, and A sequences, assigning index values to each sub-activity, and calculating the total time in TMUs.

Advantages and Implementation. MOST's structured approach allows for rapid and accurate time standard establishment across a broad range of manual tasks. Its hierarchical system—spanning MaxiMOST, BasicMOST, and Mini-MOST—enables tailored analysis suited to the specific characteristics of each operation. Furthermore, the methodology's division into general move, controlled move, and tool use sequences ensures comprehensive coverage of manual work types. In practice, MOST facilitates the efficient design and optimization of work processes, contributing to productivity improvement and effective labor planning. Its capability for rapid analysis with minimal accuracy compromise makes it a preferred method for industrial engineers.

Figure 13:

MOST Time Values for General Move (Freivalds, 2014)

A B G A B P A (Get / Put / Return) — **General Move**

Index x 10	A Action Distance	B Body Motion	G Gain Control	P Placement	Index x 10
0	≤ 2 in. (5 cm)			Pickup Toss	0
1	Within Reach		GRASP: Light Object Light Objects Simo	PUT: Lay Aside Loose Fit	1
3	1 - 2 Steps	Sit or Stand Bend and Arise 50% occ.	GET: Light Objects Non-Simo Heavy or Bulky Blind or Obstructed Disengage Interlocked Collect	PLACE: Loose Fit Blind or Obstructed Adjustments Light Pressure Double Placement	3
6	3 - 4 Steps	Bend and Arise		POSITION: Care or Precision Heavy Pressure Blind or Obstructed Intermediate Moves	6
10	5 - 7 Steps	Sit or Stand with Adjustments			10
16	8 - 10 Steps	Stand and Bend Bend and Sit Climb On or Off Through Door			16

A — Action Distance, Extended Values

Index	Steps	Feet	Meters
24	11 - 15	38	12
32	16 - 20	50	15
42	21 - 26	65	20
54	27 - 33	83	25
67	34 - 40	100	30
81	41 - 49	123	38
96	50 - 57	143	44
113	58 - 67	168	51
131	68 - 78	195	59
152	79 - 90	225	69
173	91 - 102	255	78
196	103 - 115	288	88
220	116 - 128	320	98
245	129 - 142	355	108
270	143 - 158	395	120
300	159 - 174	435	133
330	175 - 191	478	146

Figure 14:

MOST Time Values for Controlled Move (Freivalds, 2014)

A B G M X I A (Get / Move/Actuate / Return) — **Controlled Move**

Index x 10	M Move Controlled		X Process Time			I Alignment	Index x 10
	Push/Pull/Turn	Crank	Seconds	Minutes	Hours		
1	≤ 12 in. (30 cm) Button Switch Knob		.5 Sec.	.01 Min.	.0001 Hr.	1 Point	1
3	> 12 in. (30 cm) Resistance Seat or Unseat High Control 2 Stages ≤ 24 in. (60 cm) Total	1 Rev.	1.5 Sec.	.02 Min.	.0004 Hr.	2 Points ≤ 4 in. (10 cm)	3
6	2 Stages > 24 in. (60 cm) Total 1 - 2 Steps	2 - 3 Rev.	2.5 Sec.	.04 Min.	.0007 Hr.	2 Points > 4 in. (10 cm)	6
10	3 - 4 Stages 3 - 5 Steps	4 - 6 Rev.	4.5 Sec.	.07 Min.	.0012 Hr.		10
16	6 - 9 Steps	7 - 11 Rev.	7.0 Sec.	.11 Min.	.0019 Hr.	Precision	16

M — Push or Pull, Extended Values

Index	Steps
24	10 - 13
32	14 - 17
42	18 - 22
54	23 - 28
67	29 - 34

Crank, Extended Values

Index	Revs.
24	12 - 16
32	17 - 21
42	22 - 28
54	29 - 36

I — Alignment of Machining Tools

Index	Align To
3	Workpiece
6	Scale Mark
10	Indicator Dial

Alignment of Non-typical Objects

Index	Positioning Method
0	Against Stop(s)
3	1 Adjustment to Stop
6	2 Adjustments to Stop(s) 1 Adjustment to 2 Stops
10	3 Adjustments to Stop(s) 2 - 3 Adjustments to Linemark

Non-typical Object Characteristics
Flat, Large, Flimsy, Sharp, Difficult to handle

Figure 15:

MOST Time Values for Tool Use (Fasten and Loosen) (Freivalds, 2014)

A B G A B P (Get Tool, Put Tool) * (Tool Action) A B P A (Aside Tool, Return) — **Tool Use**

F L — Fasten or Loosen

Index x 10	Finger Action	Wrist Action				Arm Action					Power Tool	Index x 10
	Spins	Turns	Strokes	Cranks	Taps	Turns		Strokes	Cranks	Strikes	Screw Diam.	
	Fingers, Screwdriver	Hand, Screwdriver, Ratchet, T-Wrench	Wrench	Wrench, Ratchet	Hand, Hammer	Ratchet	T-Wrench 2-Hands	Wrench	Wrench, Ratchet	Hammer	Power Wrench	
1	1	-	-	-	1	-	-	-	-	-	-	1
3	2	1	1	1	3	1	-	1	-	1	1/4 in. (6 mm)	3
6	3	3	2	3	6	2	1	-	1	3	1 in. (25 mm)	6
10	8	5	3	5	10	4	-	2	2	5		10
16	16	9	5	8	16	6	3	3	3	8		16
24	25	13	8	11	23	9	6	4	5	12		24
32	35	17	10	15	30	12	8	6	6	16		32
42	47	23	13	20	39	15	11	8	8	21		42
54	61	29	17	25	50	20	15	10	11	27		54

Figure 16:

MOST Time Values for Tool Use (Cut, Surface Treat, and Measure) (Freivalds, 2014)

A B G A B P (Get Tool, Put Tool) * (Tool Action) A B P A (Aside Tool, Return) — **Tool Use**

Index x 10	C Cut				S Surface Treat			M Measure	Index x 10
	Cutoff	Secure	Cut	Slice	Air-Clean	Brush-Clean	Wipe	Measure	
	Pliers		Scissors	Knife	Nozzle	Brush	Cloth	Measuring Tool	
	Wire		Cuts	Slices	sq. ft. (0.1 m²)	sq. ft. (0.1 m²)	sq. ft. (0.1 m²)		
1		Grip	1	-	-	-	-		1
3	Soft		2	1	-	-	1/2		3
6	Medium	Twist Form Loop	4	-	1 Spot Cavity	1	-		6
10	Hard		7	3	-	-	1	Profile Gauge	10
16		Secure Cotter Pin	11	4	3	2	2	Fixed Scale Caliper ≤ 12 in. (30 cm)	16
24			15	6	4	3	-	Feeler Gauge	24
32			20	9	7	5	5	Steel Tape ≤ 6 ft. (2 m) Depth Micrometer	32
42			27	11	10	7	7	OD-Micrometer ≤ 4 in. (10 cm)	42
54			33					ID-Micrometer ≤ 4 in. (10 cm)	54

P Tool Placement

Tool	Index	Tool	Index
Hammer	0 (1)	Measuring Tool	1
Fingers or Hand	1 (3) (6)	Screwdriver	3
Pliers	1 (3)	Ratchet	3
Scissors	1 (3)	T-Wrench	3
Knife	1 (3)	Wrench	3
Surface Treating Tool	1	Power Tool	3
		Adjustable Wrench	6 (3)

Figure 17:

MOST Time Values for Tool Use (Record and Think) (Freivalds, 2014)

A B G A B P (Get Tool, Put Tool) * (Tool Action) A B P A (Aside Tool, Return) — **Tool Use**

Index x 10	R Record				T Think				Index x 10
		Write		Mark	Inspect		Read		
		Pencil/Pen		Marker	Eyes/Fingers		Eyes		
	Digits	Words	Copy	Digits	Points	Digits, Single Words	Text of Words	Compare	
1	1	-	-	Check Mark	1	1	3	1	1
3	2	-	1	1 Scribe Line	3	3 Gauge	8	2	3
6	4	1	3	2	5 Feel for Heat	6 Scale Value Date or Time	15	4	6
10	6	-	5	3	9 Feel for Defect	12 Vernier Scale	24	8	10
16	9 Signature or Date	2	8	5	14	Table Value	38	13	16
24	13	3	10	7	19		54		24
32	18	4	14	10	26		72		32
42	23	5	18	13	34		94		42
54	29	7	22	16	42		119		54

P Tool Placement

Tool	Index
Writing Tool	1
Keyboard/Electric Typewriter	1
Keypad	1
Letter/Paper Handling	1

Figure 18:

MOST Time Values for Equipment Use (Freivalds, 2014)

A B (Get) G A B (Put) P * (Use Equipment) A B (Aside) P A (Return)

Equipment Use

Index x 10	W Keyboard/Electric Typewriter		K Keypad		H Letter/Paper Handling					Filing				Index x 10
	Set	Words	Digits	Data	Operations	Jog or Tap	Staple	Stamp	Leaf Through Paper	Select	Open/Close Select	File	Open/Close File	
1	Tab	Click Mouse	2	2		1	Electric		1					1
3		1	6	6	Open Envelope	3	Hole Punch Hand Remove		4					3
6	Set Tab	2 Date	11	12	Interleaf	6		1 Ink	7	1				6
10	Set Margin	4	18	20	Seal Envelope	10		2	12	3		1		10
16		6	28	32	Fold and Crease	16		3	20	6	2	4	1	16
24	Insert and Remove	8	39	46				5	28	9	6	7	5	24
32		11	52	60				7	37	12	9	10	8	32
42		15 Address	68	79				9	47	17	12	15	11	42
54		19	85	100				11	61					54

Time Study Analysis:

This study examined a tipper truck tailgate with multiple essential parts. These consist of the sturdy outer shell body, which offers structural integrity, and the crucial hinges, which enable effortless opening and shutting movements. The tailgate also has a strong latch mechanism, guaranteeing stable closure during transport and dumping.

Figure 19:

Tipper Tailgate

Figure 20:

Tipper Tailgate Robotic Setup

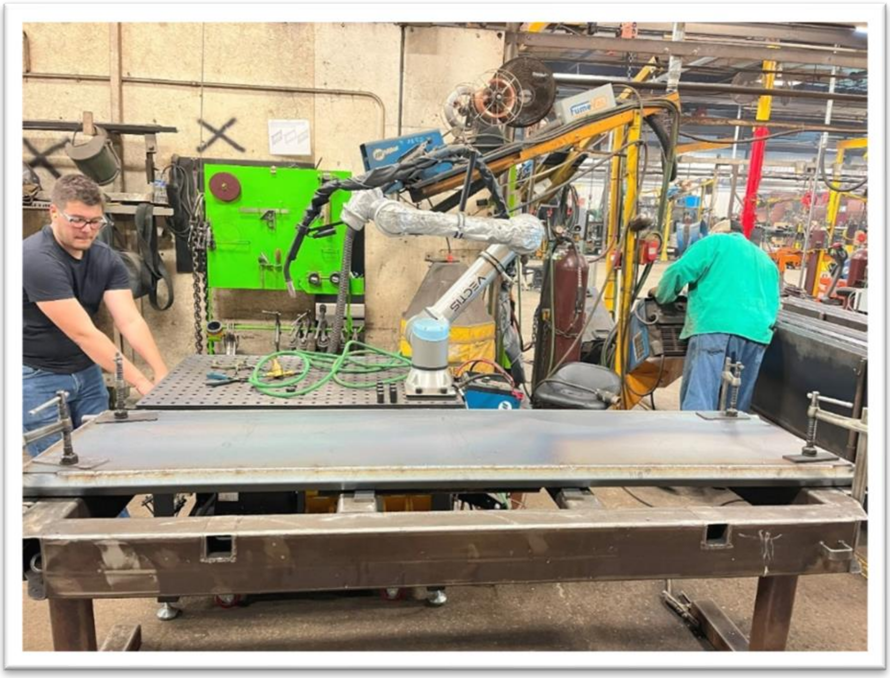


Figure 21:

Robotic Weld Finished piece.

Welding Time Study Engineering Analysis

We take several criteria into account when comparing the time efficiency of robotic and manual welding for these components:

- Complexity of the welds: The decision between robotic and manual welding may depend on the accessibility and intricacy of the welds needed to form tailgate assembly. Robotic welding may be more effective for simple, repeatable welds, but manual welding may be better for intricate, variable, or difficult-to-reach welds.
- Material Specifications: Welding parameters are affected by the materials specified for these components. Robotic welding systems can precisely maintain consistent welding settings for materials that need precision heat control.
- Considering the tolerances (. XX ±.06 or 1/16", XXX ±.031 or 1/32") and finish requirements, robotic welding may provide better consistency and quality control, particularly for components where surface finish or aesthetics are essential after welding.
- Production Volume: Due to its quicker changeover times and faster welding speeds, robotic welding can decrease cycle times and significantly boost throughput in high-volume production.

Figure 22:

Welding of Specialized Workpiece

Manual Welding Analysis for the part:

MTM-1 Analysis (Maynard, H. B., & Stegemerten, M):

The MTM-1 system was chosen for the manual welding operation analysis because it is the first and most comprehensive predetermined time system for time and motion studies. It is particularly well-suited for the in-depth analysis of labor-intensive manual occupations such as welding due to its comprehensive method of measuring human motions. The depth of MTM-1's analysis of fundamental motions allows for a sophisticated comprehension of the operation's time requirements, guaranteeing accurate temporal element measurement and analysis of the welding process. This decision demonstrates a dedication to using a strict process that accurately and carefully depicts the intricacy of manual welding.

A thorough observational study was used to document the intricate details of the process during a Methods-Time Measurement (MTM) analysis of a hand welding process. The welding process was recorded on camera, creating a visual dataset for more in-depth analysis afterward. This recorded footage was carefully examined using a stopwatch, allowing the welding procedure to be divided into distinct steps. To help with the measurement of time values for standardized motions, each identified step was then cross-referenced against established normal time value tables. This approach is an essential part of the MTM methodology. The actual time spent on the welding operations was precisely recorded because of the unique nature of welding operations and the absence of specified time values within the standard MTM tables for the welding process itself. This real-time measurement was essential since standard MTM time value tables do not address the welding process's particular needs and time requirements. To ensure compliance with the MTM framework, the actual welding time was converted into Time Measurement Units (TMU), a standardized unit of measure in MTM analysis.

A total MTM time value for the whole welding operation was created by combining these TMU-converted welding timings with the MTM values obtained from the standardized motions. This complete TMU value provided a comprehensive time profile of the manual welding process by summing the distinctive welding times and the standardized motion timings.

After calculating these MTM values, the welding processes' actual observed times were compared. The comparative examination showed that the values produced from the MTM Analysis were about 35% less than the real observed times due to the complexity of the tailgate assembly and its idiosyncrasies.

MOST Analysis (Niebel, B. W., & Freivalds, A):

We chose the Maynard Operation Sequence Technique (MOST) as our other technique for time and motion study analysis of a manual welding operation. This choice was made because MOST is one of the most advanced and effective work process analysis approaches available in industrial engineering. In this case, we applied the Basic MOST analysis option, which was thought to be most suitable considering the welding job took—roughly thirty-eight minutes per part.

MOST is well known for its effectiveness, providing a far quicker analytical procedure than the conventional MTM-1 system. This efficiency gain—which is projected to be around five times larger—is especially beneficial in situations where quick assessments and iterative process adjustments are essential. In addition, the simplified methodology of Basic MOST, which is distinguished by a smaller count of motion types, makes the analysis more straightforward to understand and less complicated. This simplicity is beneficial when doing tasks involving basic movements, like manual welding procedures.

Our analysis used index values for motions taken from the MOST data card to calculate Time Measurement Units (TMU). Using this card as a guide, the measurement of motion times may be standardized, and every step of the welding process can be assessed in relation to a reliable and consistent standard. The accurate and objective measurement of work aspects made possible using index values and the MOST data card structure enhances our time study's accuracy and dependability.

Robotic Welding analysis for the part:

Robotic welding at TBEI utilizes cutting-edge automation with the VECTIS Automation UR10E Co-bot. It combines human experience with robotic precision to enhance welding efficiency and quality and improve worker safety. The workflow must be meticulously structured to integrate human and robotic capabilities seamlessly.

Figure 23:

Welding Cobot in action.

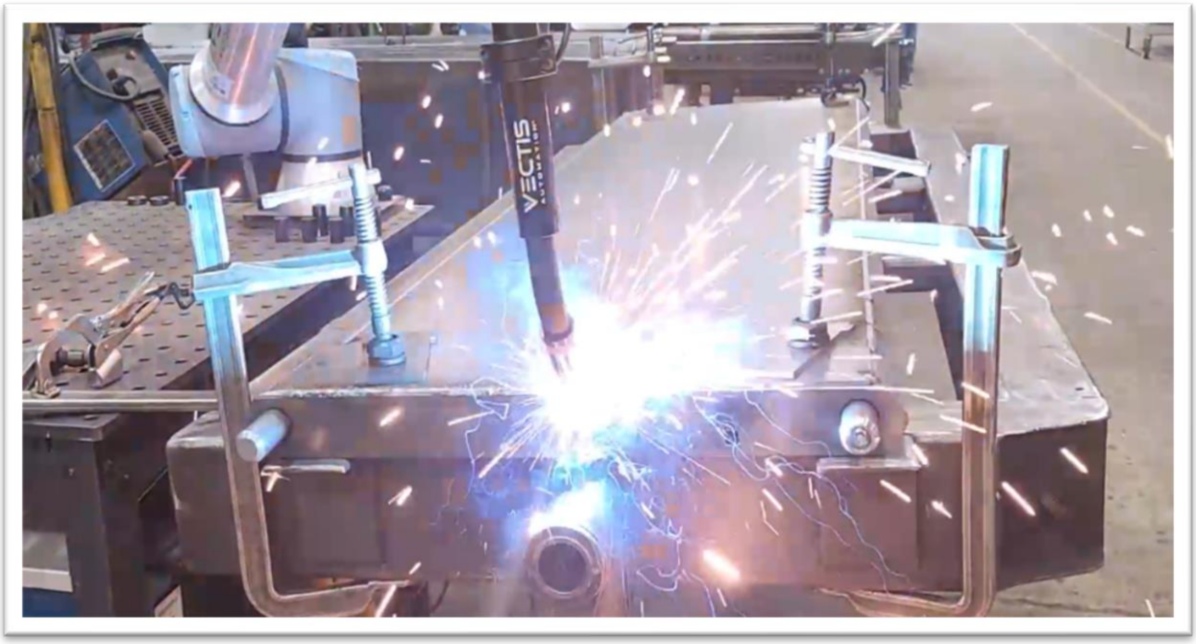
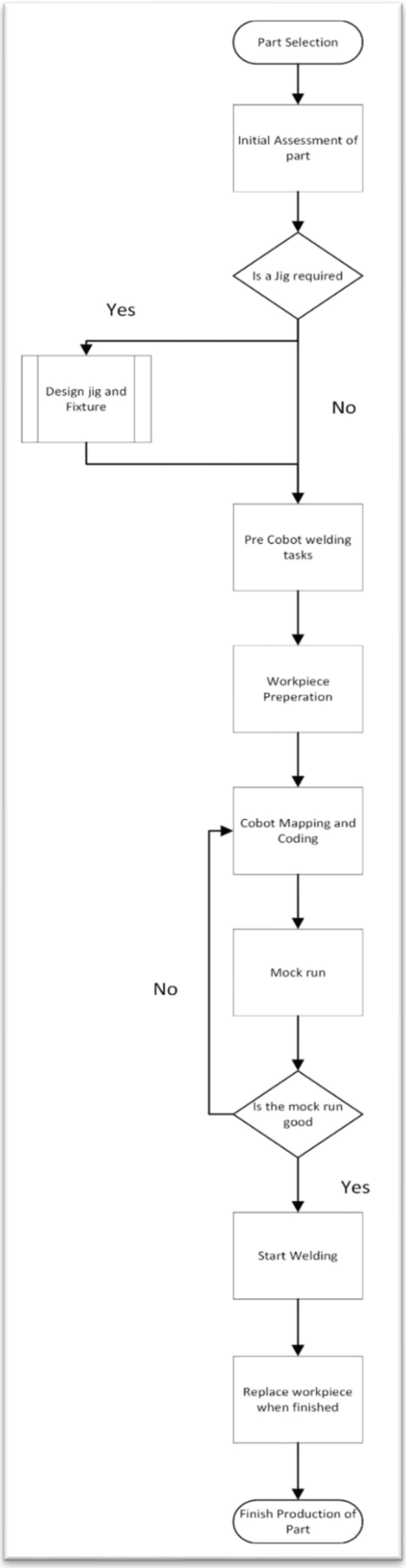


Figure 24

Robotic welding process.



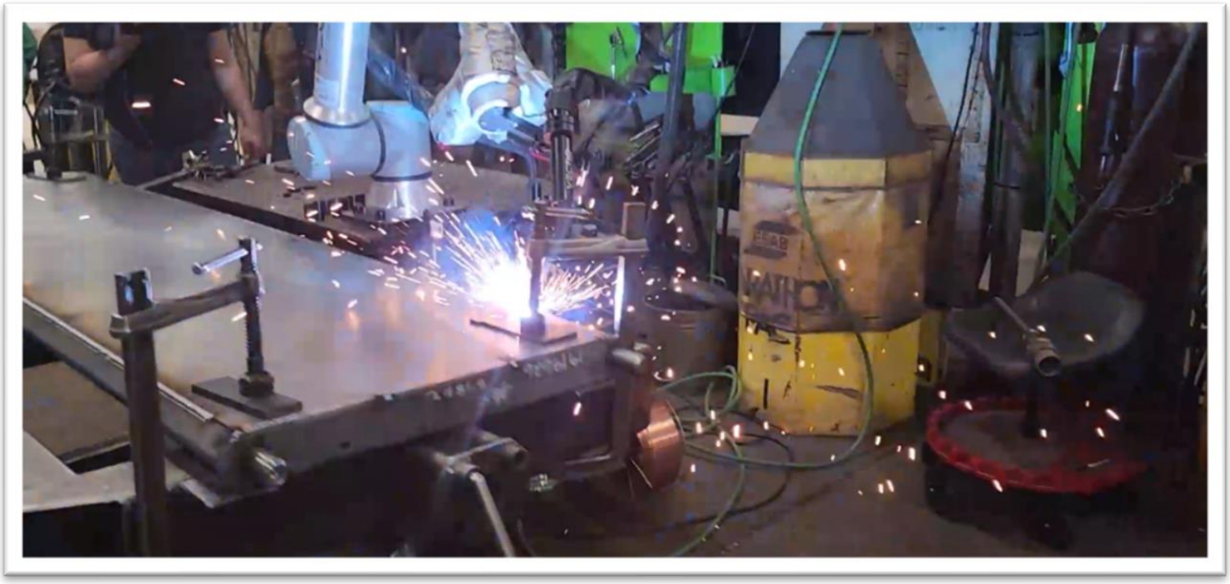
The process begins with a comprehensive evaluation of a part to determine its suitability for robotic welding. Subsequently, if necessary, the design and fabrication of fixtures and jigs are redesigned with precision to facilitate optimal positioning of the workpiece for both manual and co-bot welding ease.

Upon completion of the fixture preparation, if required, human operators perform initial welding tasks such as tack welds, particularly for intricate components beyond the cobot's current capabilities and to make a basic tailgate assembly shape. Once these steps are done, the workpiece is prepared for robotic welding.

The next crucial stage involves mapping and coding the welding path into the cobot's system. This is achieved through point-by-point instructions by moving the cobot’s welding arm through the start point of the weld multiple times between tracking points and the finishing point. A mock run is conducted to ascertain the coding accuracy and the anticipated welds' quality.

Figure 25:

Robotic Welding.



Should discrepancies arise during the mock run, the mapping and coding process is redone to revalidate, ensuring the precise execution of welding tasks. Only upon successful revalidation does the welding process start.

This systematic approach is replicated for subsequent welds, ensuring consistent quality throughout manufacturing.

MOST Analysis for Robotic Welding

We used both MTM and MOST predetermined time systems to calculate the theoretical time taken to weld the Tailgate. We wanted to compare the predetermined time system to see which was closest to the time to weld the part. It was determined that MOST was closer than MTM.

Figure 26:

Robotic Fixture.

Cost Analysis:

Cost plays a major role in every industry, and in this scenario, it does, too. Including cobots in the manufacturing process reduces the dependence on highly skilled operators; hence, the cost to employ a highly experienced operator can be optimized.

A few factors were considered while doing the cost analysis, such as the welding cost for both manual and robotic welding, fixture cost (if needed), design and material cost (if needed), and coding costs for the cobots.

The cost analysis was done in the following steps:

- Calculating the average times:
  - Using time study, we are calculating the average times for the tailgate's manual and robotic welding processes.
- Considering welding costs:
  - We are assuming $60/hr as a standard welding rate for our calculations.
- Establish price per part:
  - Divide the welding cost by the number of parts per hour.
- Optimization of robotic welding times:
  - Assume an improvement of robotic welding times by 5% &10% and calculate new costs.
- Creation of a price table:
  - Develop a table using the above calculations for quantities until we reach the breakeven point.
- Adding upfront costs of robot purchase design and programming:
  - Add the robot, fixtures, and coding costs to the equation to finally get the per-part price.

    In the case of tailgate, we are using the same worktable for robotic and manual welding. So, we eliminate the need for extra fixtures, saving on jig/fixture costs. Additionally, we need to consider the cost of programming the cobot, which we assume is $100 per hour.

Conclusion:

Time Study Results:

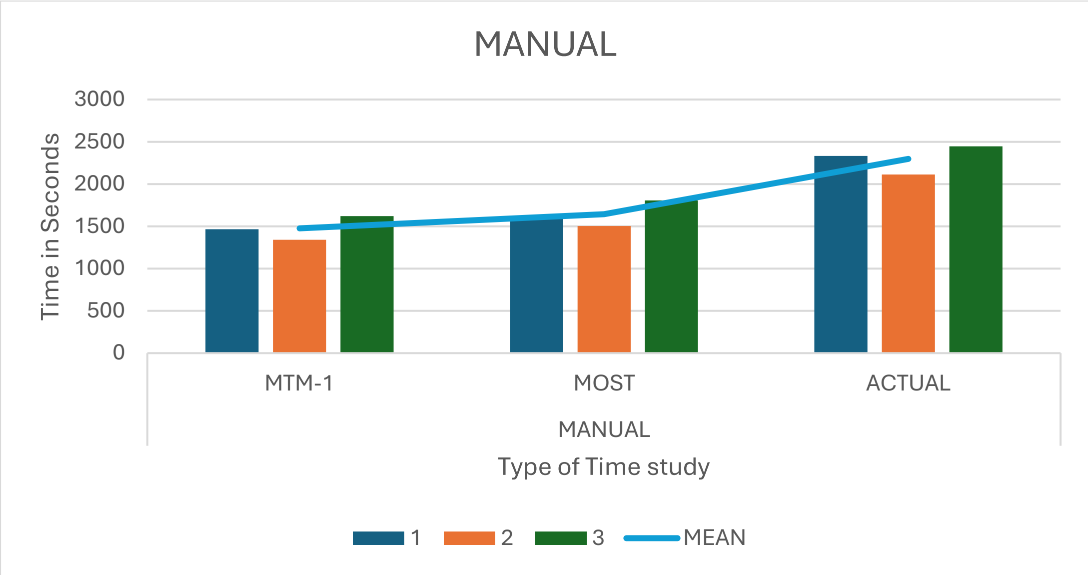
We executed three critical analyses with significant implications for manufacturing efficiency and labor dynamics during our study. First, we conducted a detailed comparative analysis between MTM 1 (Methods-Time Measurement) and MOST (Maynard Operation Sequence Technique). We aimed to understand these time management frameworks' relative advantages and application contexts in streamlining manufacturing processes. This comparison was essential for identifying the most effective technique for enhancing operational throughput.

To validate the accuracy of predetermined time standards against real-world times, these methods' reliability can be assessed in predicting job completion times in a live production environment by applying predetermined time study techniques and actual time tracking on a single part across three samples.

We also explored the performance differential between a professional human welder and an automated robotic unit, and their coexistence utilizing the above-mentioned time study methods.

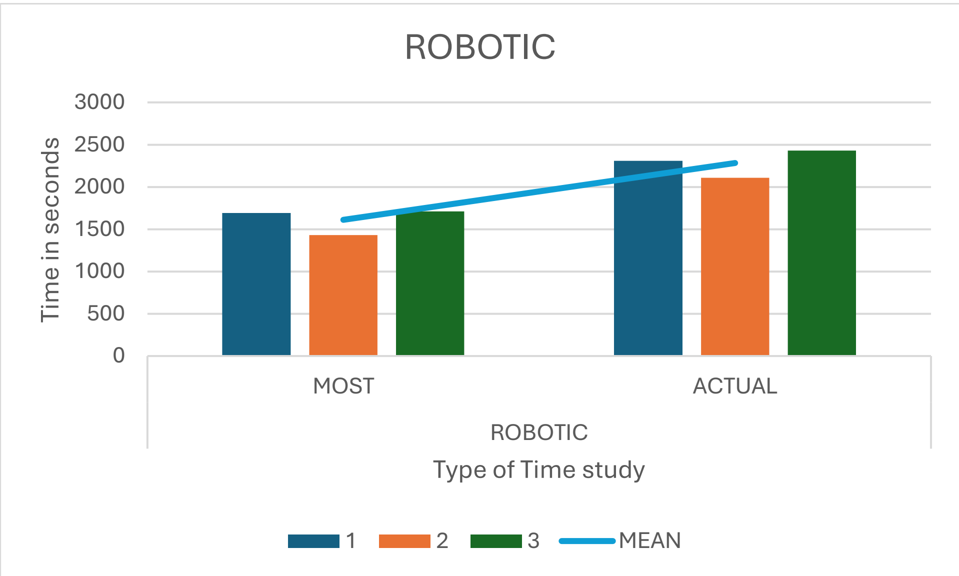
Graph 1:

Time Study Comparison (Manual)



Graph 2:

Time Study Comparison (Robotic)



From the predetermined time studies and time and motion studies of both manual and robotic welding, we can see that for manual welding, there is a significant difference in time between the predetermined time systems and normal time study. For manual welding, the MTM time is 35% lower than the actual time taken, and MOST is 28% lower than the actual; when it comes to robotic welding, the difference between the predetermined time and the actual time is 29% apart.

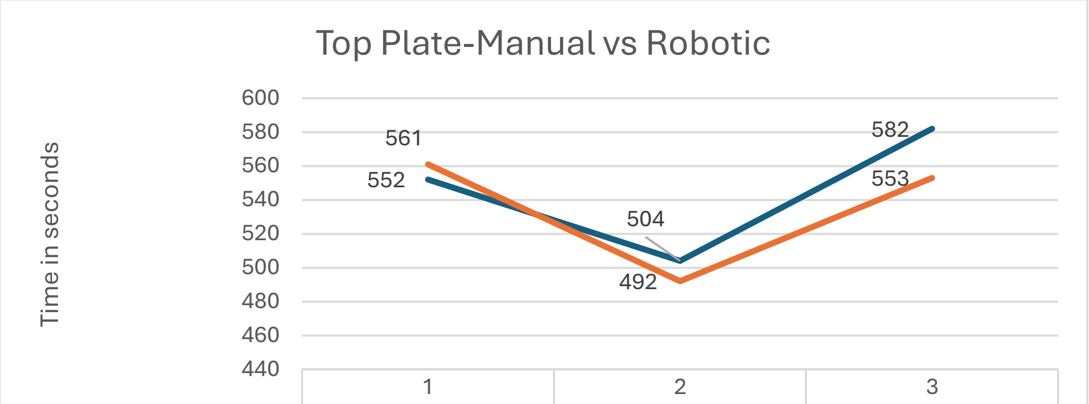
This is because when analyzing predetermined time studies of manual welding, there are many precise, intricate movements made by humans to get the part, prep it, and weld it. The predetermined time systems don't accurately measure the time taken for the action to be completed.

In MTM 1, they use very specific actions, while MOST techniques look at things more broadly. Regarding positioning, which is a big part of the time spent, MTM 1 only considers one way of doing it. Even if you take the longest time for positioning in MTM 1, it doesn't cover all the variations. But with MOST techniques, you can see how long it takes to get into position because they look at things in more detail.

The similarity in timings between manual and robotic welding can be attributed to the complexity of assembling the tailgate. This complexity arises from the numerous parts that require precise positioning and tack welding by humans to create the basic shape of the tailgate. While robots are utilized for welding long beads without human intervention, the intricate assembly process remains primarily reliant on human skill and judgment. Therefore, the overall time required for the assembly process ultimately depends on the skill and speed at which humans work.

Graph 3:

Top Plate - Manual VS Robotic



	1	2	3
Manual-Top Plate	552	504	582
Robotic-Top Plate	561	492	553

An intriguing finding surfaced when comparing three trials centered on welding the top plate, where the robot was employed. In one instance, the human completed the straight, long welding task for the top plate faster than the robot. This indicates that humans and robots each have their strengths and weaknesses. However, it's essential to note that while humans have idiosyncrasies and may experience fatigue, robots can be optimized to become faster and more efficient over time. Their coexistence in the welding process enhances efficiency, speed, and safety and allows for continual optimization and improvement.

Cost analysis results:

The extensive investigation conducted for this study has yielded significant insights into the comparison between robotic and manual welding processes. Firstly, robotic welding consistently demonstrates superior time efficiency compared to manual welding across various scenarios. The shorter average time required for robotic welding increases production rates, throughput, and subsequent cost savings. For instance, robotic welding averages 535 seconds per task, whereas manual welding averages 546 seconds. Even if the hourly welding cost remains the same for both methods, robotic welding proves advantageous due to its faster task completion, effectively managing costs. Additionally, robotic welding optimizes labor resource efficiency by reducing overall labor expenses per item produced, even when considering fixed labor costs.

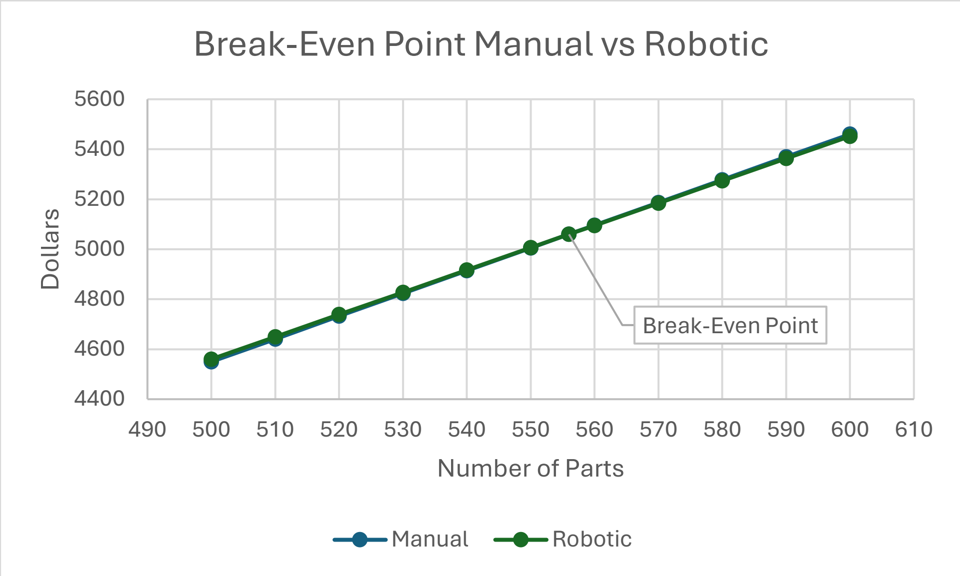
Furthermore, robotic welding shows better cost-effectiveness than hand welding when comparing welding cost per part. Robotic welding's cost per part drops as optimization levels rise, underscoring the system's financial benefits even more. For example, robotic welding reaches a cost per component as low as $8.03 at optimization levels of 10%, while the most significant cost per part for manual welding is $9.10. The thorough research concludes by highlighting the economic advantages of robotic welding over manual welding. Investing in robotic welding technology significantly reduces costs and increases productivity and throughput. Therefore, coexistence of robotic welding & manual welding is a wise financial and strategic move for companies looking to streamline their welding procedures and increase cost-effectiveness.

To calculate the breakeven points between robotic and manual welding procedures, we now need to find the point at which the total cost of each approach equals one. This happens when the total cost of employing robotic welding and manual welding adds up to the same amount. By scrutinizing the gathered data, we evaluated the breakeven points for varying quantities of manufactured parts.

Breakeven Analysis:

Graph 4:

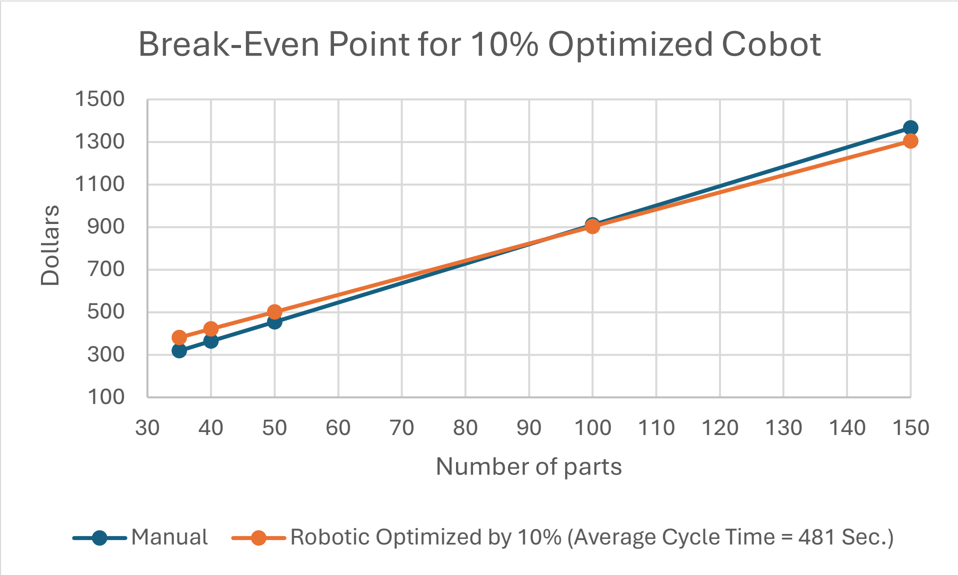
Breakeven Robotic



When a cost analysis is run, it is seen that robotic welding will break even with manual welding at 556 parts, at which point robotic welding will cost $5059.52 and manual welding will cost $5059.6.

Graph 5:

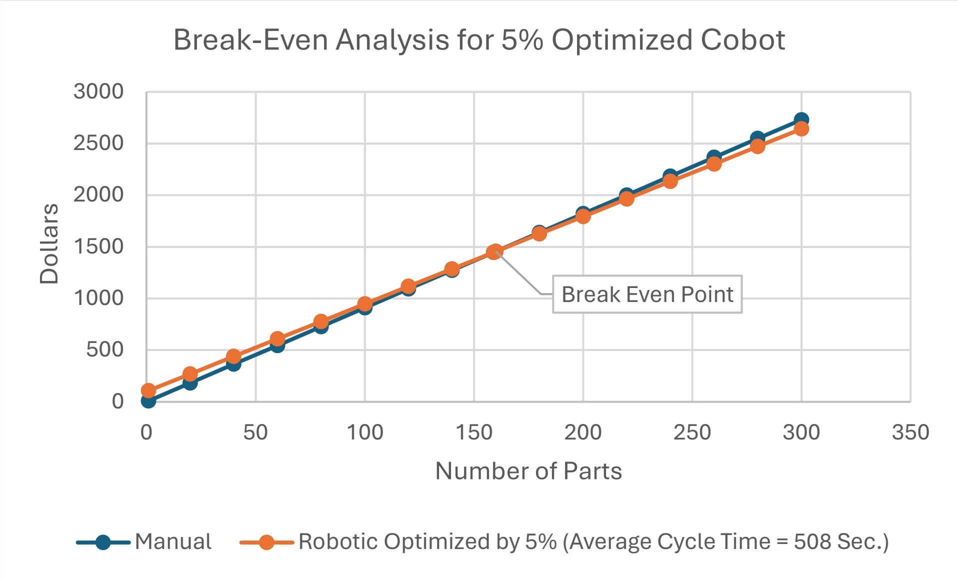
10% Optimization of Robotic



If the robotic welding is optimized by 10%, it will break even with the manual welding cost at 94 parts, at which the robotic welding will cost $854.82, and the manual welding will cost $855.4.

Graph 6:

5% Optimization of Robotic



If the robotic welding is optimized at 5%, it will break even with the manual welding cost at 159 parts, at which the robotic welding will cost $1446.73, and the manual will cost $1446.9.

Based on the break-even analysis, manual welding is more economical for lower quantities of parts. However, the advantages of robotic welding become increasingly apparent as the volume of parts rises, resulting in overall cost reduction. In our LVHM (Low Volume High Mix) scenario, employing robots alongside human workers accelerates task completion and efficiency. This integration addresses shortages in skilled labor and enhances production pace. Moreover, the efficiency and optimization offered by robotic welding play pivotal roles in achieving the desired quality of the final product, even without relying heavily on highly skilled labor.

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Appendix

MTM Manual (Trail-1)								
SL No	**Left hand description**	**LH motion**	**TMU**	**RH motion**	**Right hand description**	**Body Motion**	**Body Description**	**Actual time taken**
1			37.2			TBC2	Operator turned 90	20
2			53			W10FT	Operator moved to the Parts cart	
3	Grab the base	G1A	2	G1A	grab the base			
4	Move base to work area	M72B	60.39	M72B	Move base to work area			
5	Position the base on the work table	P2NS	26.6	P2NS	Position the base on the work table			
6			21.2			W4FT	Operator moved to the worktable	
7	Turn the base 160	TL180	28.2	TL180	Turn base 180			
8			37.2			TBC2	Operator turned 90	120
9			53			W10FT	Operator moved to the Parts cart	
10	Grasped the top with crane	G5	0	G5	Grasped the top with crane			
11	Move Top to work area	M48B	42.822	M48B	Move Top to work area			
12			10.6			W2FT	Operator moved to the toolbox	100
13	grab the toolbox	G1A	2	G1A	grab the toolbox			
14			10.6			W2FT	Operator moved the toolbox to the worktable	
15	grab 2 plates from toolbox	G1A	2	G1A	grab 2 plates from toolbox			

16	Release the plate	RL1	2	RL1	Release the plate			
17	grab the plate	G1A	2	G1A	grab the plate			
18	Position the plate on the jig	P3SS	46.5	P3SS	Position the plate on the jig			
19			19.8	R20C	Reach into the toolbox to get cylinder			
20			2	G1A	grab the cylinder			
21			22.1	M20C	Move cylinder to jig			
22			43	P3S	Position cylinder onto jig			
23	Reach into the toolbox to get cylinder	R20C	19.8					
24			19.8	R20C	Reach into the toolbox to get cylinder sleeve			
25	grab the cylinder	G1A	2					
26			2	G1A	grab the cylinder sleeve			
27	Move cylinder to jig	M20C	22.1					
28	Position cylinder onto jig	P3S	43					
29			22.1	M20C	Move cylinder to jig			
30			43	P3S	Position cylinder sleeve onto jig			
31			10.5	R18HA	Move hand to gun			40

32			2	G1A	Grab welding gun			
33			20.4	M18C	Move gun to part			
34			10.6	APA	Press the trigger			
35			27.8		Tack Weld			
36			2	RL1	Release trigger			
37			9.2	M2C	Move the gun to next position			
38			10.6	APA	Press the trigger			
39			55.6		Tack Weld			
40			2	RL1	Release trigger			
41			25.5	M24C	Move the gun to next position			
42			10.6	APA	Press the trigger			
43			27.8		Tack Weld			
44			2	RL1	Release trigger			
45			9.2	M2C	Move the gun to next position			
46			10.6	APA	Press the trigger			
47			55.6		Tack Weld			
48			2	RL1	Release trigger			
49			20.4	M18C	Move gun to holder			
50			2	RL1	Release gun into holder			
51	grab the plate assembly	G1A	2	G1A	grab the plate assembly			
52	Move plate assembly	M24B	20.6	M24B	Move plate assembly			20
53	grab the plate	G1A	2					
54	Position the plate on the jig	P3SS	46.5					

55			19.8	R20C	Reach into the toolbox to get cylinder sleeve			
56			2	G1A	grab the cylinder sleeve			
57			43	P3S	Position cylinder sleeve onto jig			
58	Reach into the toolbox to get cylinder	R20C	19.8					
59	grab the cylinder	G1A	2					
60	Position cylinder onto jig	P3S	43					
61			10.5	R18HA	Move hand to gun			
62			2	G1A	Grab welding gun			
63			20.4	M18C	Move gun to part			
64			10.6	APA	Press the trigger			
65			27.8		Tack Weld			
66			2	RL1	Release trigger			
67			9.2	M2C	Move the gun to next position			17
68			10.6	APA	Press the trigger			
69			55.6		Tack Weld			
70			2	RL1	Release trigger			
71			25.5	M24C	Move the gun to next position			
72			10.6	APA	Press the trigger			
73			27.8		Tack Weld			
74			2	RL1	Release trigger			

75			9.2	M2C	Move the gun to next position			
76			10.6	APA	Press the trigger			
77			55.6		Tack Weld			
78			2	RL1	Release trigger			
79			20.4	M18C	Move gun to holder			
80			2	RL1	Release gun into holder			
81	grab the plate assembly	G1A	2	G1A	grab the plate assembly			
82	Move plate assembly	M24B	20.6	M24B	Move plate assembly			
83	grab the cylinder from jig	G1A	2					
84	Remove the cylinder from jig	M20B	18.2					
85	Grasp Jig	G1A	2	G1A	Grasp Jig			
86	Move jig aside	M24B	20.6	M24B	Move jig aside			
87	Grasp Jig 2	G1A	2	G1A	Grasp Jig 2			
88	Move jig 2 to work table	M24B	20.6	M24B	Move jig 2 to work table			56
89			19.8	R20C	Reach into the toolbox to get small cylinder			
90			2	G1A	grab the small cylinder			
91			43	P3S	Position small cylinder onto jig			
92	Reach into the toolbox to get small plate	R20C	19.8					
93	grab the plate	G1A	2					
94	Position plate onto jig	P3S	43					

95	Reach into the toolbox to get small ring	R20C	19.8					
96	grab the small ring	G1A	2					
97	Position small ring onto jig	P3S	43					
98	Reach into the toolbox to get triangular plate	R20C	19.8					
99	grab the triangular plate	G1A	2					
100	Position triangular plate onto jig	P3S	43					
101	Reach into the toolbox to get S plate	R20C	19.8					
102	grab the S plate	G1A	2					
103	Position S plate onto jig	P3S	43					
104	Reach into the toolbox to get Square bend	R20C	19.8					
105	grab the Square bend	G1A	2					
106	Position Square bend onto jig	P3S	43					
107			10.5	R18HA	Move hand to gun			42
108			2	G1A	Grab welding gun			
109			20.4	M18C	Move gun to part			
110			10.6	APA	Press the trigger			
111			27.8		Tack Weld			
112			2	RL1	Release trigger			

113			5.2	M2C	Move the gun to next position			
114			10.6	APA	Press the trigger			
115			55.6		Tack Weld			
116			2	RL1	Release trigger			
117			11.1	M7C	Move the gun to next position			
118			10.6	APA	Press the trigger			
119			194.6		Weld 1 inch			
120			2	RL1	Release trigger			
121			11.1	M7C	Move the gun to next position			
122			10.6	APA	Press the trigger			
123			194.6		Weld 1 inch			
124			2	RL1	Release trigger			
125			3.4	M1C	Move the gun to next position			
126			10.6	APA	Press the trigger			
127			194.6		Weld 1 inch			
128			2	RL1	Release trigger			
129			13.5	M10C	Move gun to holder			67
130			2	RL1	Release gun into holder			
131			10.8	R7C	Reach to the S subassembly on jig			
132			2	G1A	grab the S subassembly			
133			9.4	TS180	Flip S subassembly			
134			8.4	R4C	Reach to the triangle subassembly on jig			

135			2	G1A	grab the triangle subassembly			
136			5.2	M2C	Move triangle subassembly			
137	Reach into the toolbox to get small plate with hole	R20C	19.8					
138	grab the small plate with hole	G1A	2					
139	Position small plate with hole onto triangle subassembly	P3S	43					
140	Reach into the toolbox to get bolts	R20C	19.8	R20C	Reach into the toolbox to get bolts			
141	grab the bolts	G1A	2	G1A	grab the bolts			
142	Position bolts onto triangle subassembly	P3S	43	P3S	Position bolts onto triangle subassembly			
143			7.3	R10HA	Move hand to gun			
144			2	G1A	Grab welding gun			
145			20.4	M18C	Move gun to part			25
146			10.6	APA	Press the trigger			
147			27.8		Tack Weld			
148			2	RL1	Release trigger			
149			3.4	M1C	Move the gun to next position			
150			10.6	APA	Press the trigger			
151			139		Weld 1 inch			
152			2	RL1	Release trigger			

153			3.4	M1C	Move the gun to next position			
154			10.6	APA	Press the trigger			
155			139		Weld 1 inch			
156			2	RL1	Release trigger			
157			13.5	M10C	Move gun to holder			
158			2	RL1	Release gun into holder			
159	grab the triangle subassembly	G1A	2	G1A	grab the subassembly 1			8
160	Move triangle subassembly	M24B	20.6	M24B	Move subassembly 1			
161			7.3	R10HA	Move hand to gun			
162			2	G1A	Grab welding gun			
163			20.4	M18C	Move gun to part			
164			10.6	APA	Press the trigger			
165			27.8		Tack Weld			
166			2	RL1	Release trigger			
167	Reach to the small plate subassembly on jig	R7C	10.8					26
168	grab the small plate subassembly	G1A	2					
169	Flip small plate subassembly	TS180	9.4					
170			9.2	M5C	Move the gun to next position			
171			10.6	APA	Press the trigger			
172			139		Weld 1 inch			
173			2	RL1	Release trigger			

174	Reach to the small plate subassembly on jig	R7C	10.8					
175	grab the small plate subassembly	G1A	2					
176	Flip small plate subassembly	TS180	9.4					
177			9.2	M5C	Move the gun to next position			
178			10.6	APA	Press the trigger			
179			139		Weld 1 inch			
180			2	RL1	Release trigger			
181	Reach to the small plate subassembly on jig	R7C	10.8					
182	grab the small plate subassembly	G1A	2					
183	Move small plate subassembly	M24B	20.6					
184	Reach into the toolbox to get L plate	R20C	19.8					14
185	grab the L plate	G1A	2					
186	Position L plate onto jig	P3S	43					
187	Reach into the toolbox to get cylinder	R20C	19.8					
188	grab the Cylinder	G1A	2					
189	Position Cylinder onto jig	P3S	43					
190			7.3	R10HA	Move hand to gun			20

191			2	G1A	Grab welding gun			
192			20.4	M18C	Move gun to part			
193			10.6	APA	Press the trigger			
194			27.8		Tack Weld			
195			2	RL1	Release trigger			
196	Reach to the L subassembly on jig	R7C	10.8					
197	grab the L subassembly	G1A	2					
198	Flip L subassembly	TS180	9.4					
199			9.2	M5C	Move the gun to next position			
200			10.6	APA	Press the trigger			
201			139		Weld 1 inch			
202			2	RL1	Release trigger			
203	Reach to the L subassembly on jig	R7C	10.8					
204	grab the L subassembly	G1A	2					
205	Flip L subassembly	TS180	9.4					
206			9.2	M5C	Move the gun to next position			
207			10.6	APA	Press the trigger			
208			139		Weld 1 inch			
209			2	RL1	Release trigger			
210	Reach to the L subassembly on jig	R7C	10.8					30
211	grab the L subassembly	G1A	2					

212	Move L subassembly	M24B	20.6					
213	Grasp Jig	G1A	2	G1A	Grasp Jig 2			
214	move jig aside	M24B	20.6	M24B	Move jig 2 aside			
215	Grasp plate assembly	G1A	2	G1A	Grasp plate assembly			
216	Grasp plate assembly	M24B	20.6	M24B	Grasp plate assembly			
217	Position plate assembly onto side of base	P3NS	47.8	P3NS	Position plate assembly onto side of base			
218	Reach to the clamp	R24C	22.5	R24C	Reach to the clamp			60
219	grab the clamp	G1A	2	G1A	grab the clamp			
220	Move clamp to base	M24C	25.5	M24C	Move clamp to base			
221	Position clamp onto side of base	P3NS	47.8	P3NS	Position clamp onto side of base			
222			15.3	R30HA	Move hand to gun			
223			2	G1A	Grab welding gun			
224			30.7	M30C	Move gun to part			
225			10.6	APA	Press the trigger			
226			27.8		Tack Weld			
227			2	RL1	Release trigger			
228			10.3	M6C	Move the gun to next position			22
229			10.6	APA	Press the trigger			
230			27.8		tack Weld			
231			2	RL1	Release trigger			
232			10.3	M6C	Move the gun to next position			
233			10.6	APA	Press the trigger			
234			27.8		tack Weld			

235			2	RL1	Release trigger			
236			10.3	M6C	Move the gun to next position			
237			10.6	APA	Press the trigger			
238			27.8		tack Weld			
239			2	RL1	Release trigger			
240			20.4	M18C	Move the gun to next position			
241			10.6	APA	Press the trigger			
242			27.8		tack Weld			
243			2	RL1	Release trigger			
244			13.5	M10C	Move gun to holder			
245			2	RL1	Release gun into holder			
246	Reach to the clamp	R24C	22.5	R24C	Reach to the clamp			
247	grab the clamp	G1A	2	G1A	grab the clamp			
248	move clamp to other side	M96C	86.8	M96C	move clamp to other side			
249	Grasp plate assembly	G1A	2	G1A	Grasp plate assembly			
250	move plate assembly	M24B	20.6	M24B	move plate assembly			
251	Position plate assembly onto side of base	P3NS	47.8	P3NS	Position plate assembly onto side of base			70
252	Reach to the clamp	R12C	14.2	R12C	Reach to the clamp			
253	grab the clamp	G1A	2	G1A	grab the clamp			
254	Move clamp to base	M24C	25.5	M24C	Move clamp to base			
255	Position clamp onto side of base	P3NS	47.8	P3NS	Position clamp onto side of base			
256			7.3	R10HA	Move hand to gun			25

257			2	G1A	Grab welding gun			
258			20.4	M18C	Move gun to part			
259			10.6	APA	Press the trigger			
260			27.8		Tack Weld			
261			2	RL1	Release trigger			
262			10.3	M6C	Move the gun to next position			
263			10.6	APA	Press the trigger			
264			27.8		tack Weld			
265			2	RL1	Release trigger			
266			10.3	M6C	Move the gun to next position			
267			10.6	APA	Press the trigger			
268			27.8		tack Weld			
269			2	RL1	Release trigger			
270			10.3	M6C	Move the gun to next position			
271			10.6	APA	Press the trigger			
272			27.8		tack Weld			
273			2	RL1	Release trigger			
274			20.4	M18C	Move the gun to next position			
275			10.6	APA	Press the trigger			
276			27.8		tack Weld			
277			2	RL1	Release trigger			
278			13.5	M10C	Move gun to holder			
279			2	RL1	Release gun into holder			120
280	Reach to the clamp	R24C	22.5	R24C	Reach to the clamp			

281	grab the clamp	G1A	2	G1A	grab the clamp			
282	Move clamp aside	M24C	25.5	M24C	Move clamp aside			
283	Reach to toolbox	R24C	22.5	R24C	Reach to the toolbox			
284	grab the toolbox	G1A	2	G1A	grab the toolbox			
285	Move clamp toolbox	M24C	25.5	M24C	Move clamp toolbox			
286	grab the base	G1A	2	G1A	grab the base			
287	Flip base	TL180	28.2	TL180	Flip base			
288	Reach into the toolbox to get triangle Subassembly	R20C	19.8					
289	grab the triangle Subassembly	G1A	2					
290	Position triangle Subassembly onto base	P3NS	53.4					
291	Reach into the toolbox to get L subassembly	R20C	19.8					
292	grab the L subassembly	G1A	2					
293	Move L subassembly	M24B	20.6					
294	Reach into the toolbox to get small subassembly	R20C	19.8					
295	grab the small subassembly	G1A	2					
296	Move small subassembly	M24B	20.6					
297	Reach into the toolbox to get medium plate	R20C	19.8					

298	grab the medium plate	G1A	2					
299	Move medium plate	M24B	20.6					
300	Reach into the toolbox to get small square plate	R20C	19.8					
301	grab the small square plate	G1A	2					
302	Move small square plate	M24B	20.6					
303	Position small square plate on base	P3SS	52.1					
304			7.3	R10HA	Move hand to gun			
305			2	G1A	Grab welding gun			
306			20.4	M18C	Move gun to part			
307			10.6	APA	Press the trigger			
308			27.8		Tack Weld			
309			2	RL1	Release trigger			
310			5.2	M2C	Move the gun to next position			20
311			10.6	APA	Press the trigger			
312			27.8		tack Weld			
313			2	RL1	Release trigger			
314	Reach into the toolbox to get small square plate	R20C	19.8					
315	grab the small square plate	G1A	2					
316	Move small square plate	M24B	20.6					

317	Position small square plate on base	P3SS	52.1					
318			20.4	M18C	Move gun to part			
319			10.6	APA	Press the trigger			
320			27.8		Tack Weld			
321			2	RL1	Release trigger			
322			5.2	M2C	Move the gun to next position			
323			10.6	APA	Press the trigger			
324			27.8		tack Weld			
325			2	RL1	Release trigger			
326			13.5	M10C	Move gun to holder			
327			2	RL1	Release gun into holder			
328	grab the small bolt	G1A	2					
329	Move small bolt	M24B	20.6					
330	Position small bolt on small subassembly	P3S	48.6					
331			2	G1A	Grasp long plate			9
332			20.6	M24B	move long plate			
333	Position small subassembly onto long plate	P3S	48.6	P3S	Position small subassembly onto long plate			
334			7.3	R10HA	Move hand to gun			
335			2	G1A	Grab welding gun			49
336			20.4	M18C	Move gun to part			
337			10.6	APA	Press the trigger			

338			83.4		Weld half inch			
339			2	RL1	Release trigger			
340			10.3	M6C	Move the gun to next position			
341			10.6	APA	Press the trigger			
342			222.4		Weld 2 inches			
343			2	RL1	Release trigger			
344			5.2	M2C	Move the gun to next position			
345			10.6	APA	Press the trigger			
346			194.6		Weld 2 inches			
347			2	RL1	Release trigger			
348			20.4	M18C	Move the gun to next position			
349			10.6	APA	Press the trigger			
350			222.4		Weld 2 inches			
351			2	RL1	Release trigger			
352			5.2	M2C	Move the gun to next position			
353			10.6	APA	Press the trigger			
354			194.6		Weld 2 inches			
355			2	RL1	Release trigger			
356			2	G1A	Grasp long plate subassembly			11
357			20.6	M24B	move long plate subassembly			

358			48.6	P3S	Position long plate subassembly onto base			
359			56.2	M60C	Move the gun to next position			95
360			10.6	APA	Press the trigger			
361			27.8		tack Weld			
362			2	RL1	Release trigger			
363			11.8	M8C	Move the gun to next position			
364			10.6	APA	Press the trigger			
365			27.8		tack Weld			
366			2	RL1	Release trigger			
367			10.4	M6C	Move the gun to next position			
368			10.3	APA	Press the trigger			
369			27.8		tack Weld			
370			2	RL1	Release trigger			
371			8	M4C	Move the gun to next position			
372			10.3	APA	Press the trigger			
373			27.8		tack Weld			
374			2	RL1	Release trigger			
375			8	M4C	Move the gun to next position			
376			10.3	APA	Press the trigger			
377			139		Weld 1 inch			
378			2	RL1	Release trigger			
379			10.4	M6C	Move the gun to next position			
380			10.3	APA	Press the trigger			

381			417		Weld 6 inch			
382			2	RL1	Release trigger			
383			10.4	M6C	Move the gun to next position			
384			10.3	APA	Press the trigger			
385			278		Weld 1 inch			
386			2	RL1	Release trigger			
387			10.4	M6C	Move the gun to next position			
388			10.3	APA	Press the trigger			
389			1278.8		Weld 6 inch			
390			2	RL1	Release trigger			
391	Reach into the toolbox to get small square plate	R20C	19.8					6
392	grab the small square plate	G1A	2					
393	Move small square plate	M24B	20.6					
394	Position small square plate on base	P3SS	52.1					
395			7.3	R10HA	Move hand to gun			7
396			2	G1A	Grab welding gun			
397			20.4	M18C	Move gun to part			
398			10.6	APA	Press the trigger			
399			27.8		tack Weld			
400			2	RL1	Release trigger			
401			5.2	M2C	Move the gun to next position			
402			10.3	APA	Press the trigger			
403			27.8		tack Weld			

404			2	RL1	Release trigger			
405			13.5	M10C	Move gun to holder			
406			2	RL1	Release gun into holder			
407	Reach into the toolbox to get spring	R20C	19.8					
408	grab the Spring	G1A	2					13
409	Move Spring	M24B	20.6					
410	Position Spring on base	P3SS	52.1					
411			7.3	R10HA	Move hand to gun			
412			2	G1A	Grab welding gun			
413			20.4	M18C	Move gun to part			
414			10.6	APA	Press the trigger			
415			27.8		tack Weld			
416			2	RL1	Release trigger			14
417			5.2	M2C	Move the gun to next position			
418			10.3	APA	Press the trigger			
419			417		Weld 4 inches			
420			2	RL1	Release trigger			
421	Reach into the toolbox to get small square plate	R20C	19.8					
422	grab the small square plate	G1A	2					5
423	Move small square plate	M24B	20.6					
424	Position small square plate on base	P3SS	52.1					

425			7.3	R10HA	Move hand to gun			48
426			2	G1A	Grab welding gun			
427			20.4	M18C	Move gun to part			
428			10.6	APA	Press the trigger			
429			27.8		tack Weld			
430			2	RL1	Release trigger			
431			5.2	M2C	Move the gun to next position			
432			10.3	APA	Press the trigger			
433			27.8		tack Weld			
434			2	RL1	Release trigger			
435			5.2	M2C	Move the gun to next position			
436			10.3	APA	Press the trigger			
437			417		Weld 3 inches			
438			2	RL1	Release trigger			
439			5.2	M2C	Move the gun to next position			
440			10.3	APA	Press the trigger			
441			417		Weld 3 inches			
442			2	RL1	Release trigger			
443			20.4	M18C	Move the gun to next position			
444			10.3	APA	Press the trigger			
445			417		Weld 3 inches			
446			2	RL1	Release trigger			
447			5.2	M2C	Move the gun to next position			

448			10.3	APA	Press the trigger			
449			417		Weld 3 inches			
450			2	RL1	Release trigger			
451			13.5	M10C	Move gun to holder			
452			2	RL1	Release gun into holder			
453	grab the small bolt	G1A	2					
454	Move small bolt	M24B	20.6					
455	Position small bolt on L subassembly	P3S	48.6					
456			2	G1A	Grasp medium plate			10
457			20.6	M24B	move medium plate			
458	Position L subassembly onto medium plate	P3S	48.6	P3S	Position L subassembly onto Medium plate			
459			7.3	R10HA	Move hand to gun			
460			2	G1A	Grab welding gun			
461			20.4	M18C	Move gun to part			
462			10.6	APA	Press the trigger			12
463			250.2		Weld			
464			2	RL1	Release trigger			
465			13.5	M10C	Move gun to holder			
466			2	RL1	Release gun into holder			
467			2	G1A	Grasp medium assembly			27

468			20.6	M24B	move medium assembly			
469			43	P3S	Position medium assembly onto base			
470			19.8	R20C	Reach into the toolbox to get crowbar			
471			2	G1A	grab the crowbar			
472			25.5	M24C	Move crowbar			
473			53.4	P3NS	Position crowbar			
474			48.6	P3S	Position medium assembly onto base			
475			7.3	R10HA	Move hand to gun			9
476			2	G1A	Grab welding gun			
477			20.4	M18C	Move gun to part			
478			10.6	APA	Press the trigger			
479			250.2		Weld			
480			2	RL1	Release trigger			
481			13.5	M10C	Move gun to holder			
482			2	RL1	Release gun into holder			
483			19.8	R20C	Reach to get crowbar			16
484			2	G1A	grab the crowbar			
485			25.5	M24C	Move crowbar			
486			19.8	R20C	Reach to get long subassembly			
487			2	G1A	grab the long subassembly			

488			25.5	M24C	Move long subassembly			
489			53.4	P3NS	Position long subassembly onto medium subassembly			
490			19.8	R20C	Reach to get crowbar			
491			2	G1A	grab the crowbar			
492			25.5	M24C	Move crowbar			
493			53.4	P3NS	Position crowbar			
494			7.3	R10HA	Move hand to gun			12
495			2	G1A	Grab welding gun			
496			20.4	M18C	Move gun to part			
497			10.6	APA	Press the trigger			
498			250.2		Weld			
499			2	RL1	Release trigger			
500			13.5	M10C	Move gun to holder			
501			2	RL1	Release gun into holder			
502			2	G1A	Grasp top			98
503			20.6	M24B	move top to base			
504	Reach to the clamp	R24C	22.5	R24C	Reach to the clamp			
505	grab the clamp	G1A	2	G1A	grab the clamp			
506	Move clamp to base	M24C	25.5	M24C	Move clamp to base			
507	Position clamp onto side of base	P3NS	47.8	P3NS	Position clamp onto side of base			
508			53.4	P3NS	Position top to base			
509			7.3	R10HA	Move hand to gun			145

510			2	G1A	Grab welding gun			
511			20.4	M18C	Move gun to part			
512			10.6	APA	Press the trigger			
513			27.8		tack Weld			
514			2	RL1	Release trigger			
515			86.8	M96C	Move the gun to next position			
516			10.3	APA	Press the trigger			
517			27.8		tack Weld			
518			2	RL1	Release trigger			
519			5.2	M2C	Move the gun to next position			
520			10.3	APA	Press the trigger			
521			27.8		tack Weld			
522			2	RL1	Release trigger			
523			25.5	M24C	Move the gun to next position			
524			10.3	APA	Press the trigger			
525			27.8		tack Weld			
526			2	RL1	Release trigger			
527			10.3	M6C	Move the gun to next position			
528			10.3	APA	Press the trigger			
529			27.8		tack Weld			
530			2	RL1	Release trigger			
531			10.3	M6C	Move the gun to next position			
532			10.3	APA	Press the trigger			
533			27.8		tack Weld			

534			2	RL1	Release trigger			
535			86.8	M96C	Move the gun to next position			
536			10.3	APA	Press the trigger			
537			27.8		tack Weld			
538			2	RL1	Release trigger			
539			25.5	M24C	Move the gun to next position			
540			10.3	APA	Press the trigger			
541			27.8		tack Weld			
542			2	RL1	Release trigger			
543			10.3	M6C	Move the gun to next position			
544			10.3	APA	Press the trigger			
545			27.8		tack Weld			
546			2	RL1	Release trigger			
547			10.3	M6C	Move the gun to next position			
548			10.3	APA	Press the trigger			
549			27.8		tack Weld			
550			2	RL1	Release trigger			
551			10.3	M48C	Move the gun to next position			
552			10.3	APA	Press the trigger			
553			27.8		tack Weld			
554			2	RL1	Release trigger			
555			10.3	M6C	Move the gun to next position			
556			10.3	APA	Press the trigger			
557			27.8		tack Weld			

558			2	RL1	Release trigger			
559			10.3	M6C	Move the gun to next position			
560			10.3	APA	Press the trigger			
561			27.8		tack Weld			
562			2	RL1	Release trigger			
563			10.3	M6C	Move the gun to next position			
564			10.3	APA	Press the trigger			
565			27.8		tack Weld			
566			2	RL1	Release trigger			
567			10.3	M6C	Move the gun to next position			
568			10.3	APA	Press the trigger			
569			27.8		tack Weld			
570			2	RL1	Release trigger			
571			25.5	M24C	Move the gun to next position			
572			10.3	APA	Press the trigger			
573			27.8		tack Weld			
574			2	RL1	Release trigger			
575			10.3	M6C	Move the gun to next position			
576			10.3	APA	Press the trigger			
577			27.8		tack Weld			
578			2	RL1	Release trigger			
579			10.3	M6C	Move the gun to next position			
580			10.3	APA	Press the trigger			
581			27.8		tack Weld			

582			2	RL1	Release trigger			
583			10.3	M6C	Move the gun to next position			
584			10.3	APA	Press the trigger			
585			27.8		tack Weld			
586			2	RL1	Release trigger			
587			10.3	M6C	Move the gun to next position			
588			10.3	APA	Press the trigger			
589			27.8		tack Weld			
590			2	RL1	Release trigger			
591			86.8	M96C	Move the gun to next position			
592			10.3	APA	Press the trigger			
593			27.8		tack Weld			
594			2	RL1	Release trigger			
595			10.3	M6C	Move the gun to next position			
596			10.3	APA	Press the trigger			
597			27.8		tack Weld			
598			2	RL1	Release trigger			
599			10.3	M6C	Move the gun to next position			
600			10.3	APA	Press the trigger			
601			27.8		tack Weld			
602			2	RL1	Release trigger			
603			10.3	M6C	Move the gun to next position			
604			10.3	APA	Press the trigger			
605			27.8		tack Weld			

606			2	RL1	Release trigger			
607			10.3	M6C	Move the gun to next position			
608			10.3	APA	Press the trigger			
609			27.8		tack Weld			
610			2	RL1	Release trigger			
611			86.8	M96C	Move the gun to next position			
612			10.3	APA	Press the trigger			
613			27.8		tack Weld			
614			2	RL1	Release trigger			
615			10.3	M6C	Move the gun to next position			
616			10.3	APA	Press the trigger			
617			27.8		tack Weld			
618			2	RL1	Release trigger			
619			10.3	M6C	Move the gun to next position			
620			10.3	APA	Press the trigger			
621			27.8		tack Weld			
622			2	RL1	Release trigger			
623			10.3	M6C	Move the gun to next position			
624			10.3	APA	Press the trigger			
625			27.8		tack Weld			
626			2	RL1	Release trigger			
627			10.3	M6C	Move the gun to next position			
628			10.3	APA	Press the trigger			
629			27.8		tack Weld			

630			2	RL1	Release trigger			
631			10.3	M6C	Move the gun to next position			
632			10.3	APA	Press the trigger			
633			27.8		tack Weld			
634			2	RL1	Release trigger			
635			86.8	M96C	Move the gun to next position			
636			10.3	APA	Press the trigger			
637			556		Weld 2 inches			
638			2	RL1	Release trigger			
639			10.3	M6C	Move the gun to next position			
640			10.3	APA	Press the trigger			
641			1112		Weld 6 inch			
642			2	RL1	Release trigger			
643			86.8	M96C	Move the gun to next position			563
644			10.3	APA	Press the trigger			
645			194.6		Weld 2 inches			
646			2	RL1	Release trigger			
647			10.3	M6C	Move the gun to next position			
648			10.3	APA	Press the trigger			
649			472.6		Weld 6 inch			
650			2	RL1	Release trigger			
651			10.3	M6C	Move the gun to next position			
652			10.3	APA	Press the trigger			

653			2585.4		Weld 24 inch			
654			2	RL1	Release trigger			
655			5.4	M2C	Move the gun to next position			
656			10.3	APA	Press the trigger			
657			111.2		Weld 2 inch			
658			2	RL1	Release trigger			
659			3.4	M1C	Move the gun to next position			
660			10.3	APA	Press the trigger			
661			500.4		Weld			
662			2	RL1	Release trigger			
663			86.8	M96C	Move the gun to next position			
664			10.3	APA	Press the trigger			
665			2446.4		Weld			
666			2	RL1	Release trigger			
667			3.4	M1C	Move the gun to next position			
668			10.3	APA	Press the trigger			
669			1251		Weld			
670			2	RL1	Release trigger			
671			3.4	M1C	Move the gun to next position			
672			10.3	APA	Press the trigger			
673			2446.4		Weld			
674			2	RL1	Release trigger			
675			3.4	M1C	Move the gun to next position			
676			10.3	APA	Press the trigger			

677			166.8		Weld			
678			2	RL1	Release trigger			
679			86.8	M96C	Move the gun to next position			
680			10.3	APA	Press the trigger			
681			2168.4		Weld			
682			2	RL1	Release trigger			
683			3.4	M1C	Move the gun to next position			
684			10.3	APA	Press the trigger			
685			2140.6		Weld			
686			2	RL1	Release trigger			
687			3.4	M1C	Move the gun to next position			
688			10.3	APA	Press the trigger			
689			1695.8		Weld			
690			2	RL1	Release trigger			
691			3.4	M1C	Move the gun to next position			
692			10.3	APA	Press the trigger			
693			695		Weld			
694			2	RL1	Release trigger			
695			13.5	M10C	Move gun to holder			
696			2	RL1	Release gun into holder			
697	grab the base assembly	G1A	2	G1A	grab the base assembly			
698	Flip base assembly	TL180	28.2	TL180	Flip base assembly			50
699	grab the base assembly	G1A	2	G1A	grab the base assembly			

700	turn base assembly	TL180	28.2	TL180	turn base assembly			
701	Reach into the toolbox to get L bracket	R20C	19.8					
702	grab the L bracket	G1A	2					
703	Move L bracket	M24B	20.6					
704			7.3	R10HA	Move hand to gun			70
705			2	G1A	Grab welding gun			
706			20.4	M18C	Move gun to part			
707			10.6	APA	Press the trigger			
708			139		Weld			
709			2	RL1	Release trigger			
710			3.4	M1C	Move the gun to next position			
711			10.3	APA	Press the trigger			
712			417		Weld			
713			2	RL1	Release trigger			
714			3.4	M1C	Move the gun to next position			
715			10.3	APA	Press the trigger			
716			1529		Weld			
717			2	RL1	Release trigger			
718			3.4	M1C	Move the gun to next position			
719			10.3	APA	Press the trigger			
720			528.2		Weld			
721			2	RL1	Release trigger			
722	Position L bracket onto	P3NS	53.4					140

	base assembly							
723			3.4	M1C	Move the gun to next position			
724			10.3	APA	Press the trigger			
725			27.8		tack Weld			
726			2	RL1	Release trigger			
727			5.2	M2C	Move the gun to next position			
728			10.3	APA	Press the trigger			
729			27.8		tack Weld			
730			2	RL1	Release trigger			
731			5.2	M2C	Move the gun to next position			
732			10.3	APA	Press the trigger			
733			139		tack Weld			
734			2	RL1	Release trigger			
735			5.2	M2C	Move the gun to next position			
736			10.3	APA	Press the trigger			
737			111.2		tack Weld			
738			2	RL1	Release trigger			
739			5.2	M2C	Move the gun to next position			
740			10.3	APA	Press the trigger			
741			166.8		tack Weld			
742			2	RL1	Release trigger			
743			15.2	M12C	Move the gun to next position			
744			10.3	APA	Press the trigger			

745			194.6		tack Weld			
746			2	RL1	Release trigger			
747			3.4	M1C	Move the gun to next position			
748			10.3	APA	Press the trigger			
749			194.6		Weld			
750			2	RL1	Release trigger			
751			25.5	M24C	Move the gun to next position			
752			10.3	APA	Press the trigger			
753			83.4		Weld			
754			2	RL1	Release trigger			
755	Position L bracket onto base assembly	P3NS	53.4					
756			86.8	M96C	Move the gun to next position			
757			10.3	APA	Press the trigger			
758			27.8		tack Weld			
759			2	RL1	Release trigger			
760			5.2	M2C	Move the gun to next position			
761			10.3	APA	Press the trigger			
762			27.8		tack Weld			
763			2	RL1	Release trigger			
764			5.2	M2C	Move the gun to next position			
765			10.3	APA	Press the trigger			
766			139		tack Weld			
767			2	RL1	Release trigger			

768			5.2	M2C	Move the gun to next position			
769			10.3	APA	Press the trigger			
770			111.2		tack Weld			
771			2	RL1	Release trigger			
772			5.2	M2C	Move the gun to next position			
773			10.3	APA	Press the trigger			
774			166.8		tack Weld			
775			2	RL1	Release trigger			
776			15.2	M12C	Move the gun to next position			
777			10.3	APA	Press the trigger			
778			194.6		tack Weld			
779			2	RL1	Release trigger			
780			3.4	M1C	Move the gun to next position			
781			10.3	APA	Press the trigger			
782			194.6		Weld			
783			2	RL1	Release trigger			
		Total TMU	40705					
		Total sec	1465.4					2331
		Total Min	24.423					38.85

MTM Manual (Trail-2)								
SL No	**Left hand description**	**LH motion**	**TMU**	**RH motion**	**Right hand description**	**Body Motion**	**Body Description**	**Actual time taken**
1			37.2			TBC2	Operator turned 90	20
2			53			W10FT	Operator moved to the Parts cart	
3	Grab the base	G1A	2	G1A	grab the base			
4	Move base to work area	M72B	60.39	M72B	Move base to work area			
5	Position the base on the work table	P2NS	26.6	P2NS	Position the base on the work table			
6			21.2			W4FT	Operator moved to the worktable	
7	Turn the base 160	TL180	28.2	TL180	Turn base 180			
8			37.2			TBC2	Operator turned 90	110
9			53			W10FT	Operator moved to the Parts cart	
10	Grasped the top with crane	G5	0	G5	Grasped the top with crane			
11	Move Top to work area	M48B	42.82	M48B	Move Top to work area			
12			10.6			W2FT	Operator moved to the toolbox	100
13	grab the toolbox	G1A	2	G1A	grab the toolbox			
14			10.6			W2FT	Operator moved the toolbox to the worktable	
15	grab 2 plates from toolbox	G1A	2	G1A	grab 2 plates from toolbox			

16	Release the plate	RL1	2	RL1	Release the plate			
17	grab the plate	G1A	2	G1A	grab the plate			
18	Position the plate on the jig	P3SS	46.5	P3SS	Position the plate on the jig			
19			19.8	R20C	Reach into the toolbox to get cylinder			
20			2	G1A	grab the cylinder			
21			22.1	M20C	Move cylinder to jig			
22			43	P3S	Position cylinder onto jig			
23	Reach into the toolbox to get cylinder	R20C	19.8					
24			19.8	R20C	Reach into the toolbox to get cylinder sleeve			
25	grab the cylinder	G1A	2					
26			2	G1A	grab the cylinder sleeve			
27	Move cylinder to jig	M20C	22.1					
28	Position cylinder onto jig	P3S	43					
29			22.1	M20C	Move cylinder to jig			
30			43	P3S	Position cylinder sleeve onto jig			
31			10.5	R18HA	Move hand to gun			40

32			2	G1A	Grab welding gun			
33			20.4	M18C	Move gun to part			
34			10.6	APA	Press the trigger			
35			27.8		Tack Weld			
36			2	RL1	Release trigger			
37			9.2	M2C	Move the gun to next position			
38			10.6	APA	Press the trigger			
39			55.6		Tack Weld			
40			2	RL1	Release trigger			
41			25.5	M24C	Move the gun to next position			
42			10.6	APA	Press the trigger			
43			27.8		Tack Weld			
44			2	RL1	Release trigger			
45			9.2	M2C	Move the gun to next position			
46			10.6	APA	Press the trigger			
47			55.6		Tack Weld			
48			2	RL1	Release trigger			
49			20.4	M18C	Move gun to holder			
50			2	RL1	Release gun into holder			
51	grab the plate assembly	G1A	2	G1A	grab the plate assembly			
52	Move plate assembly	M24B	20.6	M24B	Move plate assembly			20
53	grab the plate	G1A	2					
54	Position the plate on the jig	P3SS	46.5					

55			19.8	R20C	Reach into the toolbox to get cylinder sleeve			
56			2	G1A	grab the cylinder sleeve			
57			43	P3S	Position cylinder sleeve onto jig			
58	Reach into the toolbox to get cylinder	R20C	19.8					
59	grab the cylinder	G1A	2					
60	Position cylinder onto jig	P3S	43					
61			10.5	R18HA	Move hand to gun			
62			2	G1A	Grab welding gun			
63			20.4	M18C	Move gun to part			
64			10.6	APA	Press the trigger			
65			27.8		Tack Weld			
66			2	RL1	Release trigger			
67			9.2	M2C	Move the gun to next position			17
68			10.6	APA	Press the trigger			
69			55.6		Tack Weld			
70			2	RL1	Release trigger			
71			25.5	M24C	Move the gun to next position			
72			10.6	APA	Press the trigger			
73			27.8		Tack Weld			
74			2	RL1	Release trigger			

75			9.2	M2C	Move the gun to next position			
76			10.6	APA	Press the trigger			
77			55.6		Tack Weld			
78			2	RL1	Release trigger			
79			20.4	M18C	Move gun to holder			
80			2	RL1	Release gun into holder			
81	grab the plate assembly	G1A	2	G1A	grab the plate assembly			
82	Move plate assembly	M24B	20.6	M24B	Move plate assembly			
83	grab the cylinder from jig	G1A	2					
84	Remove the cylinder from jig	M20B	18.2					
85	Grasp Jig	G1A	2	G1A	Grasp Jig			
86	Move jig aside	M24B	20.6	M24B	Move jig aside			
87	Grasp Jig 2	G1A	2	G1A	Grasp Jig 2			
88	Move jig 2 to work table	M24B	20.6	M24B	Move jig 2 to work table			50
89			19.8	R20C	Reach into the toolbox to get small cylinder			
90			2	G1A	grab the small cylinder			
91			43	P3S	Position small cylinder onto jig			
92	Reach into the toolbox to get small plate	R20C	19.8					
93	grab the plate	G1A	2					
94	Position plate onto jig	P3S	43					

95	Reach into the toolbox to get small ring	R20C	19.8					
96	grab the small ring	G1A	2					
97	Position small ring onto jig	P3S	43					
98	Reach into the toolbox to get triangular plate	R20C	19.8					
99	grab the triangular plate	G1A	2					
100	Position triangular plate onto jig	P3S	43					
101	Reach into the toolbox to get S plate	R20C	19.8					
102	grab the S plate	G1A	2					
103	Position S plate onto jig	P3S	43					
104	Reach into the toolbox to get Square bend	R20C	19.8					
105	grab the Square bend	G1A	2					
106	Position Square bend onto jig	P3S	43					
107			10.5	R18HA	Move hand to gun			35
108			2	G1A	Grab welding gun			
109			20.4	M18C	Move gun to part			
110			10.6	APA	Press the trigger			
111			27.8		Tack Weld			
112			2	RL1	Release trigger			

113			5.2	M2C	Move the gun to next position			
114			10.6	APA	Press the trigger			
115			55.6		Tack Weld			
116			2	RL1	Release trigger			
117			11.1	M7C	Move the gun to next position			
118			10.6	APA	Press the trigger			
119			250.2		Weld 1 inch			
120			2	RL1	Release trigger			
121			11.1	M7C	Move the gun to next position			
122			10.6	APA	Press the trigger			
123			250.2		Weld 1 inch			
124			2	RL1	Release trigger			
125			3.4	M1C	Move the gun to next position			
126			10.6	APA	Press the trigger			
127			250.2		Weld 1 inch			
128			2	RL1	Release trigger			
129			13.5	M10C	Move gun to holder			67
130			2	RL1	Release gun into holder			
131			10.8	R7C	Reach to the S subassembly on jig			
132			2	G1A	grab the S subassembly			
133			9.4	TS180	Flip S subassembly			
134			8.4	R4C	Reach to the triangle subassembly on jig			

135			2	G1A	grab the triangle subassembly			
136			5.2	M2C	Move triangle subassembly			
137	Reach into the toolbox to get small plate with hole	R20C	19.8					
138	grab the small plate with hole	G1A	2					
139	Position small plate with hole onto triangle subassembly	P3S	43					
140	Reach into the toolbox to get bolts	R20C	19.8	R20C	Reach into the toolbox to get bolts			
141	grab the bolts	G1A	2	G1A	grab the bolts			
142	Position bolts onto triangle subassembly	P3S	43	P3S	Position bolts onto triangle subassembly			
143			7.3	R10HA	Move hand to gun			
144			2	G1A	Grab welding gun			
145			20.4	M18C	Move gun to part			25
146			10.6	APA	Press the trigger			
147			27.8		Tack Weld			
148			2	RL1	Release trigger			
149			3.4	M1C	Move the gun to next position			
150			10.6	APA	Press the trigger			
151			250.2		Weld 1 inch			
152			2	RL1	Release trigger			

153			3.4	M1C	Move the gun to next position			
154			10.6	APA	Press the trigger			
155			250.2		Weld 1 inch			
156			2	RL1	Release trigger			
157			13.5	M10C	Move gun to holder			
158			2	RL1	Release gun into holder			
159	grab the triangle subassembly	G1A	2	G1A	grab the subassembly 1			8
160	Move triangle subassembly	M24B	20.6	M24B	Move subassembly 1			
161			7.3	R10HA	Move hand to gun			
162			2	G1A	Grab welding gun			
163			20.4	M18C	Move gun to part			
164			10.6	APA	Press the trigger			
165			27.8		Tack Weld			
166			2	RL1	Release trigger			
167	Reach to the small plate subassembly on jig	R7C	10.8					26
168	grab the small plate subassembly	G1A	2					
169	Flip small plate subassembly	TS180	9.4					
170			9.2	M5C	Move the gun to next position			
171			10.6	APA	Press the trigger			
172			250.2		Weld 1 inch			
173			2	RL1	Release trigger			

174	Reach to the small plate subassembly on jig	R7C	10.8					
175	grab the small plate subassembly	G1A	2					
176	Flip small plate subassembly	TS180	9.4					
177			9.2	M5C	Move the gun to next position			
178			10.6	APA	Press the trigger			
179			250.2		Weld 1 inch			
180			2	RL1	Release trigger			
181	Reach to the small plate subassembly on jig	R7C	10.8					14
182	grab the small plate subassembly	G1A	2					
183	Move small plate subassembly	M24B	20.6					
184	Reach into the toolbox to get L plate	R20C	19.8					
185	grab the L plate	G1A	2					
186	Position L plate onto jig	P3S	43					
187	Reach into the toolbox to get cylinder	R20C	19.8					
188	grab the Cylinder	G1A	2					
189	Position Cylinder onto jig	P3S	43					
190			7.3	R10HA	Move hand to gun			20
191			2	G1A	Grab welding gun			

192			20.4	M18C	Move gun to part			
193			10.6	APA	Press the trigger			
194			27.8		Tack Weld			
195			2	RL1	Release trigger			
196	Reach to the L subassembly on jig	R7C	10.8					
197	grab the L subassembly	G1A	2					
198	Flip L subassembly	TS180	9.4					
199			9.2	M5C	Move the gun to next position			
200			10.6	APA	Press the trigger			
201			250.2		Weld 1 inch			
202			2	RL1	Release trigger			
203	Reach to the L subassembly on jig	R7C	10.8					
204	grab the L subassembly	G1A	2					
205	Flip L subassembly	TS180	9.4					
206			9.2	M5C	Move the gun to next position			
207			10.6	APA	Press the trigger			
208			250.2		Weld 1 inch			
209			2	RL1	Release trigger			
210	Reach to the L subassembly on jig	R7C	10.8					
211	grab the L subassembly	G1A	2					30
212	Move L subassembly	M24B	20.6					
213	Grasp Jig	G1A	2	G1A	Grasp Jig 2			

214	move jig aside	M24B	20.6	M24B	Move jig 2 aside			
215	Grasp plate assembly	G1A	2	G1A	Grasp plate assembly			
216	Grasp plate assembly	M24B	20.6	M24B	Grasp plate assembly			
217	Position plate assembly onto side of base	P3NS	47.8	P3NS	Position plate assembly onto side of base			
218	Reach to the clamp	R24C	22.5	R24C	Reach to the clamp			55
219	grab the clamp	G1A	2	G1A	grab the clamp			
220	Move clamp to base	M24C	25.5	M24C	Move clamp to base			
221	Position clamp onto side of base	P3NS	47.8	P3NS	Position clamp onto side of base			
222			15.3	R30HA	Move hand to gun			
223			2	G1A	Grab welding gun			
224			30.7	M30C	Move gun to part			
225			10.6	APA	Press the trigger			
226			27.8		Tack Weld			
227			2	RL1	Release trigger			
228			10.3	M6C	Move the gun to next position			22
229			10.6	APA	Press the trigger			
230			27.8		tack Weld			
231			2	RL1	Release trigger			
232			10.3	M6C	Move the gun to next position			
233			10.6	APA	Press the trigger			
234			27.8		tack Weld			
235			2	RL1	Release trigger			

236			10.3	M6C	Move the gun to next position			
237			10.6	APA	Press the trigger			
238			55.6		tack Weld			
239			2	RL1	Release trigger			
240			20.4	M18C	Move the gun to next position			
241			10.6	APA	Press the trigger			
242			27.8		tack Weld			
243			2	RL1	Release trigger			
244			13.5	M10C	Move gun to holder			
245			2	RL1	Release gun into holder			
246	Reach to the clamp	R24C	22.5	R24C	Reach to the clamp			
247	grab the clamp	G1A	2	G1A	grab the clamp			
248	move clamp to other side	M96C	86.8	M96C	move clamp to other side			
249	Grasp plate assembly	G1A	2	G1A	Grasp plate assembly			
250	move plate assembly	M24B	20.6	M24B	move plate assembly			
251	Position plate assembly onto side of base	P3NS	47.8	P3NS	Position plate assembly onto side of base			60
252	Reach to the clamp	R12C	14.2	R12C	Reach to the clamp			
253	grab the clamp	G1A	2	G1A	grab the clamp			
254	Move clamp to base	M24C	25.5	M24C	Move clamp to base			
255	Position clamp onto side of base	P3NS	47.8	P3NS	Position clamp onto side of base			
256			7.3	R10HA	Move hand to gun			20
257			2	G1A	Grab welding gun			

258			20.4	M18C	Move gun to part			
259			10.6	APA	Press the trigger			
260			55.6		Tack Weld			
261			2	RL1	Release trigger			
262			10.3	M6C	Move the gun to next position			
263			10.6	APA	Press the trigger			
264			27.8		tack Weld			
265			2	RL1	Release trigger			
266			10.3	M6C	Move the gun to next position			
267			10.6	APA	Press the trigger			
268			55.6		tack Weld			
269			2	RL1	Release trigger			
270			10.3	M6C	Move the gun to next position			
271			10.6	APA	Press the trigger			
272			27.8		tack Weld			
273			2	RL1	Release trigger			
274			20.4	M18C	Move the gun to next position			
275			10.6	APA	Press the trigger			
276			27.8		tack Weld			
277			2	RL1	Release trigger			
278			13.5	M10C	Move gun to holder			
279			2	RL1	Release gun into holder			
280	Reach to the clamp	R24C	22.5	R24C	Reach to the clamp			90
281	grab the clamp	G1A	2	G1A	grab the clamp			
282	Move clamp aside	M24C	25.5	M24C	Move clamp aside			

283	Reach to toolbox	R24C	22.5	R24C	Reach to the toolbox			
284	grab the toolbox	G1A	2	G1A	grab the toolbox			
285	Move clamp toolbox	M24C	25.5	M24C	Move clamp toolbox			
286	grab the base	G1A	2	G1A	grab the base			
287	Flip base	TL180	28.2	TL180	Flip base			
288	Reach into the toolbox to get triangle Subassembly	R20C	19.8					
289	grab the triangle Subassembly	G1A	2					
290	Position triangle Subassembly onto base	P3NS	53.4					
291	Reach into the toolbox to get L subassembly	R20C	19.8					
292	grab the L subassembly	G1A	2					
293	Move L subassembly	M24B	20.6					
294	Reach into the toolbox to get small subassembly	R20C	19.8					
295	grab the small subassembly	G1A	2					
296	Move small subassembly	M24B	20.6					
297	Reach into the toolbox to get medium plate	R20C	19.8					
298	grab the medium plate	G1A	2					
299	Move medium plate	M24B	20.6					

300	Reach into the toolbox to get small square plate	R20C	19.8					
301	grab the small square plate	G1A	2					
302	Move small square plate	M24B	20.6					
303	Position small square plate on base	P3SS	52.1					
304			7.3	R10HA	Move hand to gun			
305			2	G1A	Grab welding gun			
306			20.4	M18C	Move gun to part			
307			10.6	APA	Press the trigger			
308			27.8		Tack Weld			
309			2	RL1	Release trigger			
310			5.2	M2C	Move the gun to next position			
311			10.6	APA	Press the trigger			
312			27.8		tack Weld			
313			2	RL1	Release trigger			20
314	Reach into the toolbox to get small square plate	R20C	19.8					
315	grab the small square plate	G1A	2					
316	Move small square plate	M24B	20.6					
317	Position small square plate on base	P3SS	52.1					
318			20.4	M18C	Move gun to part			
319			10.6	APA	Press the trigger			
320			55.6		Tack Weld			

321			2	RL1	Release trigger			
322			5.2	M2C	Move the gun to next position			
323			10.6	APA	Press the trigger			
324			27.8		tack Weld			
325			2	RL1	Release trigger			
326			13.5	M10C	Move gun to holder			
327			2	RL1	Release gun into holder			
328	grab the small bolt	G1A	2					9
329	Move small bolt	M24B	20.6					
330	Position small bolt on small subassembly	P3S	48.6					
331			2	G1A	Grasp long plate			
332			20.6	M24B	move long plate			
333	Position small subassembly onto long plate	P3S	48.6	P3S	Position small subassembly onto long plate			
334			7.3	R10HA	Move hand to gun			49
335			2	G1A	Grab welding gun			
336			20.4	M18C	Move gun to part			
337			10.6	APA	Press the trigger			
338			139		Weld half inch			
339			2	RL1	Release trigger			
340			10.3	M6C	Move the gun to next position			
341			10.6	APA	Press the trigger			

342			361.4		Weld 2 inches			
343			2	RL1	Release trigger			
344			5.2	M2C	Move the gun to next position			
345			10.6	APA	Press the trigger			
346			361.4		Weld 2 inches			
347			2	RL1	Release trigger			
348			20.4	M18C	Move the gun to next position			
349			10.6	APA	Press the trigger			
350			361.4		Weld 2 inches			
351			2	RL1	Release trigger			
352			5.2	M2C	Move the gun to next position			
353			10.6	APA	Press the trigger			
354			361.4		Weld 2 inches			
355			2	RL1	Release trigger			
356			2	G1A	Grasp long plate subassembly			
357			20.6	M24B	move long plate subassembly			11
358			48.6	P3S	Position long plate subassembly onto base			
359			56.2	M60C	Move the gun to next position			
360			10.6	APA	Press the trigger			95
361			27.8		tack Weld			
362			2	RL1	Release trigger			

363			11.8	M8C	Move the gun to next position			
364			10.6	APA	Press the trigger			
365			27.8		tack Weld			
366			2	RL1	Release trigger			
367			10.4	M6C	Move the gun to next position			
368			10.3	APA	Press the trigger			
369			55.6		tack Weld			
370			2	RL1	Release trigger			
371			8	M4C	Move the gun to next position			
372			10.3	APA	Press the trigger			
373			27.8		tack Weld			
374			2	RL1	Release trigger			
375			8	M4C	Move the gun to next position			
376			10.3	APA	Press the trigger			
377			250.2		Weld 1 inch			
378			2	RL1	Release trigger			
379			10.4	M6C	Move the gun to next position			
380			10.3	APA	Press the trigger			
381			528.2		Weld 6 inch			
382			2	RL1	Release trigger			
383			10.4	M6C	Move the gun to next position			
384			10.3	APA	Press the trigger			
385			278		Weld 1 inch			
386			2	RL1	Release trigger			

387			10.4	M6C	Move the gun to next position			
388			10.3	APA	Press the trigger			
389			556		Weld 6 inch			
390			2	RL1	Release trigger			
391	Reach into the toolbox to get small square plate	R20C	19.8					6
392	grab the small square plate	G1A	2					
393	Move small square plate	M24B	20.6					
394	Position small square plate on base	P3SS	52.1					
395			7.3	R10HA	Move hand to gun			7
396			2	G1A	Grab welding gun			
397			20.4	M18C	Move gun to part			
398			10.6	APA	Press the trigger			
399			27.8		tack Weld			
400			2	RL1	Release trigger			
401			5.2	M2C	Move the gun to next position			
402			10.3	APA	Press the trigger			
403			55.6		tack Weld			
404			2	RL1	Release trigger			
405			13.5	M10C	Move gun to holder			
406			2	RL1	Release gun into holder			
407	Reach into the toolbox to get spring	R20C	19.8					13
408	grab the Spring	G1A	2					
409	Move Spring	M24B	20.6					

410	Position Spring on base	P3SS	52.1					
411			7.3	R10HA	Move hand to gun			
412			2	G1A	Grab welding gun			
413			20.4	M18C	Move gun to part			
414			10.6	APA	Press the trigger			
415			27.8		tack Weld			
416			2	RL1	Release trigger			14
417			5.2	M2C	Move the gun to next position			
418			10.3	APA	Press the trigger			
419			417		Weld 4 inches			
420			2	RL1	Release trigger			
421	Reach into the toolbox to get small square plate	R20C	19.8					
422	grab the small square plate	G1A	2					5
423	Move small square plate	M24B	20.6					
424	Position small square plate on base	P3SS	52.1					
425			7.3	R10HA	Move hand to gun			
426			2	G1A	Grab welding gun			
427			20.4	M18C	Move gun to part			
428			10.6	APA	Press the trigger			48
429			27.8		tack Weld			
430			2	RL1	Release trigger			
431			5.2	M2C	Move the gun to next position			

432			10.3	APA	Press the trigger			
433			27.8		tack Weld			
434			2	RL1	Release trigger			
435			5.2	M2C	Move the gun to next position			
436			10.3	APA	Press the trigger			
437			333.6		Weld 3 inches			
438			2	RL1	Release trigger			
439			5.2	M2C	Move the gun to next position			
440			10.3	APA	Press the trigger			
441			361.4		Weld 3 inches			
442			2	RL1	Release trigger			
443			20.4	M18C	Move the gun to next position			
444			10.3	APA	Press the trigger			
445			361.4		Weld 3 inches			
446			2	RL1	Release trigger			
447			5.2	M2C	Move the gun to next position			
448			10.3	APA	Press the trigger			
449			361.4		Weld 3 inches			
450			2	RL1	Release trigger			
451			13.5	M10C	Move gun to holder			
452			2	RL1	Release gun into holder			
453	grab the small bolt	G1A	2					10
454	Move small bolt	M24B	20.6					

455	Position small bolt on L subassembly	P3S	48.6					
456			2	G1A	Grasp medium plate			
457			20.6	M24B	move medium plate			
458	Position L subassembly onto medium plate	P3S	48.6	P3S	Position L subassembly onto Medium plate			
459			7.3	R10HA	Move hand to gun			12
460			2	G1A	Grab welding gun			
461			20.4	M18C	Move gun to part			
462			10.6	APA	Press the trigger			
463			139		Weld			
464			2	RL1	Release trigger			
465			13.5	M10C	Move gun to holder			
466			2	RL1	Release gun into holder			
467			2	G1A	Grasp medium assembly			23
468			20.6	M24B	move medium assembly			
469			43	P3S	Position medium assembly onto base			
470			19.8	R20C	Reach into the toolbox to get crowbar			
471			2	G1A	grab the crowbar			
472			25.5	M24C	Move crowbar			

473			53.4	P3NS	Position crowbar			
474			48.6	P3S	Position medium assembly onto base			
475			7.3	R10HA	Move hand to gun			9
476			2	G1A	Grab welding gun			
477			20.4	M18C	Move gun to part			
478			10.6	APA	Press the trigger			
479			139		Weld			
480			2	RL1	Release trigger			
481			13.5	M10C	Move gun to holder			
482			2	RL1	Release gun into holder			
483			19.8	R20C	Reach to get crowbar			12
484			2	G1A	grab the crowbar			
485			25.5	M24C	Move crowbar			
486			19.8	R20C	Reach to get long subassembly			
487			2	G1A	grab the long subassembly			
488			25.5	M24C	Move long subassembly			
489			53.4	P3NS	Position long subassembly onto medium subassembly			
490			19.8	R20C	Reach to get crowbar			
491			2	G1A	grab the crowbar			
492			25.5	M24C	Move crowbar			
493			53.4	P3NS	Position crowbar			

494			7.3	R10HA	Move hand to gun			12
495			2	G1A	Grab welding gun			
496			20.4	M18C	Move gun to part			
497			10.6	APA	Press the trigger			
498			139		Weld			
499			2	RL1	Release trigger			
500			13.5	M10C	Move gun to holder			
501			2	RL1	Release gun into holder			
502			2	G1A	Grasp top			90
503			20.6	M24B	move top to base			
504	Reach to the clamp	R24C	22.5	R24C	Reach to the clamp			
505	grab the clamp	G1A	2	G1A	grab the clamp			
506	Move clamp to base	M24C	25.5	M24C	Move clamp to base			
507	Position clamp onto side of base	P3NS	47.8	P3NS	Position clamp onto side of base			
508			53.4	P3NS	Position top to base			
509			7.3	R10HA	Move hand to gun			135
510			2	G1A	Grab welding gun			
511			20.4	M18C	Move gun to part			
512			10.6	APA	Press the trigger			
513			27.8		tack Weld			
514			2	RL1	Release trigger			
515			86.8	M96C	Move the gun to next position			
516			10.3	APA	Press the trigger			
517			27.8		tack Weld			
518			2	RL1	Release trigger			

519			5.2	M2C	Move the gun to next position			
520			10.3	APA	Press the trigger			
521			27.8		tack Weld			
522			2	RL1	Release trigger			
523			25.5	M24C	Move the gun to next position			
524			10.3	APA	Press the trigger			
525			27.8		tack Weld			
526			2	RL1	Release trigger			
527			10.3	M6C	Move the gun to next position			
528			10.3	APA	Press the trigger			
529			27.8		tack Weld			
530			2	RL1	Release trigger			
531			10.3	M6C	Move the gun to next position			
532			10.3	APA	Press the trigger			
533			27.8		tack Weld			
534			2	RL1	Release trigger			
535			86.8	M96C	Move the gun to next position			
536			10.3	APA	Press the trigger			
537			27.8		tack Weld			
538			2	RL1	Release trigger			
539			25.5	M24C	Move the gun to next position			
540			10.3	APA	Press the trigger			
541			27.8		tack Weld			
542			2	RL1	Release trigger			

543			10.3	M6C	Move the gun to next position			
544			10.3	APA	Press the trigger			
545			27.8		tack Weld			
546			2	RL1	Release trigger			
547			10.3	M6C	Move the gun to next position			
548			10.3	APA	Press the trigger			
549			27.8		tack Weld			
550			2	RL1	Release trigger			
551			10.3	M48C	Move the gun to next position			
552			10.3	APA	Press the trigger			
553			27.8		tack Weld			
554			2	RL1	Release trigger			
555			10.3	M6C	Move the gun to next position			
556			10.3	APA	Press the trigger			
557			27.8		tack Weld			
558			2	RL1	Release trigger			
559			10.3	M6C	Move the gun to next position			
560			10.3	APA	Press the trigger			
561			27.8		tack Weld			
562			2	RL1	Release trigger			
563			10.3	M6C	Move the gun to next position			
564			10.3	APA	Press the trigger			
565			27.8		tack Weld			
566			2	RL1	Release trigger			

567			10.3	M6C	Move the gun to next position			
568			10.3	APA	Press the trigger			
569			27.8		tack Weld			
570			2	RL1	Release trigger			
571			25.5	M24C	Move the gun to next position			
572			10.3	APA	Press the trigger			
573			27.8		tack Weld			
574			2	RL1	Release trigger			
575			10.3	M6C	Move the gun to next position			
576			10.3	APA	Press the trigger			
577			27.8		tack Weld			
578			2	RL1	Release trigger			
579			10.3	M6C	Move the gun to next position			
580			10.3	APA	Press the trigger			
581			27.8		tack Weld			
582			2	RL1	Release trigger			
583			10.3	M6C	Move the gun to next position			
584			10.3	APA	Press the trigger			
585			27.8		tack Weld			
586			2	RL1	Release trigger			
587			10.3	M6C	Move the gun to next position			
588			10.3	APA	Press the trigger			
589			27.8		tack Weld			
590			2	RL1	Release trigger			

591			86.8	M96C	Move the gun to next position			
592			10.3	APA	Press the trigger			
593			27.8		tack Weld			
594			2	RL1	Release trigger			
595			10.3	M6C	Move the gun to next position			
596			10.3	APA	Press the trigger			
597			27.8		tack Weld			
598			2	RL1	Release trigger			
599			10.3	M6C	Move the gun to next position			
600			10.3	APA	Press the trigger			
601			27.8		tack Weld			
602			2	RL1	Release trigger			
603			10.3	M6C	Move the gun to next position			
604			10.3	APA	Press the trigger			
605			27.8		tack Weld			
606			2	RL1	Release trigger			
607			10.3	M6C	Move the gun to next position			
608			10.3	APA	Press the trigger			
609			27.8		tack Weld			
610			2	RL1	Release trigger			
611			86.8	M96C	Move the gun to next position			
612			10.3	APA	Press the trigger			
613			27.8		tack Weld			
614			2	RL1	Release trigger			

615			10.3	M6C	Move the gun to next position			
616			10.3	APA	Press the trigger			
617			27.8		tack Weld			
618			2	RL1	Release trigger			
619			10.3	M6C	Move the gun to next position			
620			10.3	APA	Press the trigger			
621			27.8		tack Weld			
622			2	RL1	Release trigger			
623			10.3	M6C	Move the gun to next position			
624			10.3	APA	Press the trigger			
625			27.8		tack Weld			
626			2	RL1	Release trigger			
627			10.3	M6C	Move the gun to next position			
628			10.3	APA	Press the trigger			
629			27.8		tack Weld			
630			2	RL1	Release trigger			
631			10.3	M6C	Move the gun to next position			
632			10.3	APA	Press the trigger			
633			27.8		tack Weld			
634			2	RL1	Release trigger			
635			86.8	M96C	Move the gun to next position			
636			10.3	APA	Press the trigger			450
637			333.6		Weld 2 inches			
638			2	RL1	Release trigger			

639			10.3	M6C	Move the gun to next position			
640			10.3	APA	Press the trigger			
641			834		Weld 6 inch			
642			2	RL1	Release trigger			
643			86.8	M96C	Move the gun to next position			
644			10.3	APA	Press the trigger			
645			194.6		Weld 2 inches			
646			2	RL1	Release trigger			
647			10.3	M6C	Move the gun to next position			
648			10.3	APA	Press the trigger			
649			667.2		Weld 6 inch			
650			2	RL1	Release trigger			
651			10.3	M6C	Move the gun to next position			
652			10.3	APA	Press the trigger			
653			1751		Weld 24 inch			
654			2	RL1	Release trigger			
655			5.4	M2C	Move the gun to next position			
656			10.3	APA	Press the trigger			
657			111.2		Weld 2 inch			
658			2	RL1	Release trigger			
659			3.4	M1C	Move the gun to next position			
660			10.3	APA	Press the trigger			
661			500.4		Weld			

662			2	RL1	Release trigger			
663			86.8	M96C	Move the gun to next position			
664			10.3	APA	Press the trigger			
665			1890		Weld			
666			2	RL1	Release trigger			
667			3.4	M1C	Move the gun to next position			
668			10.3	APA	Press the trigger			
669			1251		Weld			
670			2	RL1	Release trigger			
671			3.4	M1C	Move the gun to next position			
672			10.3	APA	Press the trigger			
673			1946		Weld			
674			2	RL1	Release trigger			
675			3.4	M1C	Move the gun to next position			
676			10.3	APA	Press the trigger			
677			166.8		Weld			
678			2	RL1	Release trigger			
679			86.8	M96C	Move the gun to next position			
680			10.3	APA	Press the trigger			
681			1334		Weld			
682			2	RL1	Release trigger			
683			3.4	M1C	Move the gun to next position			
684			10.3	APA	Press the trigger			
685			1863		Weld			

686			2	RL1	Release trigger			
687			3.4	M1C	Move the gun to next position			
688			10.3	APA	Press the trigger			
689			1140		Weld			
690			2	RL1	Release trigger			
691			3.4	M1C	Move the gun to next position			
692			10.3	APA	Press the trigger			
693			695		Weld			
694			2	RL1	Release trigger			
695			13.5	M10C	Move gun to holder			
696			2	RL1	Release gun into holder			
697	grab the base assembly	G1A	2	G1A	grab the base assembly			
698	Flip base assembly	TL180	28.2	TL180	Flip base assembly			
699	grab the base assembly	G1A	2	G1A	grab the base assembly			
700	turn base assembly	TL180	28.2	TL180	turn base assembly			50
701	Reach into the toolbox to get L bracket	R20C	19.8					
702	grab the L bracket	G1A	2					
703	Move L bracket	M24B	20.6					
704			7.3	R10HA	Move hand to gun			
705			2	G1A	Grab welding gun			
706			20.4	M18C	Move gun to part			70
707			10.6	APA	Press the trigger			
708			139		Weld			

709			2	RL1	Release trigger			
710			3.4	M1C	Move the gun to next position			
711			10.3	APA	Press the trigger			
712			250.2		Weld			
713			2	RL1	Release trigger			
714			3.4	M1C	Move the gun to next position			
715			10.3	APA	Press the trigger			
716			1529		Weld			
717			2	RL1	Release trigger			
718			3.4	M1C	Move the gun to next position			
719			10.3	APA	Press the trigger			
720			417		Weld			
721			2	RL1	Release trigger			
722	Position L bracket onto base assembly	P3NS	53.4					135
723			3.4	M1C	Move the gun to next position			
724			10.3	APA	Press the trigger			
725			27.8		tack Weld			
726			2	RL1	Release trigger			
727			5.2	M2C	Move the gun to next position			
728			10.3	APA	Press the trigger			
729			27.8		tack Weld			
730			2	RL1	Release trigger			
731			5.2	M2C	Move the gun to next position			

732			10.3	APA	Press the trigger			
733			250.2		tack Weld			
734			2	RL1	Release trigger			
735			5.2	M2C	Move the gun to next position			
736			10.3	APA	Press the trigger			
737			111.2		tack Weld			
738			2	RL1	Release trigger			
739			5.2	M2C	Move the gun to next position			
740			10.3	APA	Press the trigger			
741			166.8		tack Weld			
742			2	RL1	Release trigger			
743			15.2	M12C	Move the gun to next position			
744			10.3	APA	Press the trigger			
745			194.6		tack Weld			
746			2	RL1	Release trigger			
747			3.4	M1C	Move the gun to next position			
748			10.3	APA	Press the trigger			
749			194.6		Weld			
750			2	RL1	Release trigger			
751			25.5	M24C	Move the gun to next position			
752			10.3	APA	Press the trigger			
753			83.4		Weld			
754			2	RL1	Release trigger			
755	Position L bracket onto base assembly	P3NS	53.4					

756			86.8	M96C	Move the gun to next position			
757			10.3	APA	Press the trigger			
758			27.8		tack Weld			
759			2	RL1	Release trigger			
760			5.2	M2C	Move the gun to next position			
761			10.3	APA	Press the trigger			
762			27.8		tack Weld			
763			2	RL1	Release trigger			
764			5.2	M2C	Move the gun to next position			
765			10.3	APA	Press the trigger			
766			139		tack Weld			
767			2	RL1	Release trigger			
768			5.2	M2C	Move the gun to next position			
769			10.3	APA	Press the trigger			
770			111.2		tack Weld			
771			2	RL1	Release trigger			
772			5.2	M2C	Move the gun to next position			
773			10.3	APA	Press the trigger			
774			166.8		tack Weld			
775			2	RL1	Release trigger			
776			15.2	M12C	Move the gun to next position			
777			10.3	APA	Press the trigger			
778			194.6		tack Weld			
779			2	RL1	Release trigger			

780			3.4	M1C	Move the gun to next position			
781			10.3	APA	Press the trigger			
782			194.6		Weld			
783			2	RL1	Release trigger			
		Total TMU	37258					
		Total sec	1341					2114
		Total Min	22.35					35.23333

MTM Manual (Trail-3)								
SL No	**Left hand description**	**LH motion**	**TMU**	**RH motion**	**Right hand description**	**Body Motion**	**Body Description**	**Actual time taken**
1			37.2			TBC2	Operator turned 90	20
2			53			W10FT	Operator moved to the Parts cart	
3	Grab the base	G1A	2	G1A	grab the base			
4	Move base to work area	M72B	60.39	M72B	Move base to work area			
5	Position the base on the work table	P2NS	26.6	P2NS	Position the base on the work table			
6			21.2			W4FT	Operator moved to the worktable	
7	Turn the base 160	TL180	28.2	TL180	Turn base 180			
8			37.2			TBC2	Operator turned 90	120
9			53			W10FT	Operator moved to the Parts cart	

10	Grasped the top with crane	G5	0	G5	Grasped the top with crane			
11	Move Top to work area	M48B	42.82	M48B	Move Top to work area			
12			10.6			W2FT	Operator moved to the toolbox	
13	grab the toolbox	G1A	2	G1A	grab the toolbox			
14			10.6			W2FT	Operator moved the toolbox to the worktable	
15	grab 2 plates from toolbox	G1A	2	G1A	grab 2 plates from toolbox			
16	Release the plate	RL1	2	RL1	Release the plate			
17	grab the plate	G1A	2	G1A	grab the plate			
18	Position the plate on the jig	P3SS	46.5	P3SS	Position the plate on the jig			
19			19.8	R20C	Reach into the toolbox to get cylinder			100
20			2	G1A	grab the cylinder			
21			22.1	M20C	Move cylinder to jig			
22			43	P3S	Position cylinder onto jig			
23	Reach into the toolbox to get cylinder	R20C	19.8					
24			19.8	R20C	Reach into the toolbox to get cylinder sleeve			
25	grab the cylinder	G1A	2					

26			2	G1A	grab the cylinder sleeve				
27	Move cylinder to jig	M20C	22.1						
28	Position cylinder onto jig	P3S	43						
29			22.1	M20C	Move cylinder to jig				
30			43	P3S	Position cylinder sleeve onto jig				
31			10.5	R18HA	Move hand to gun				
32			2	G1A	Grab welding gun				
33			20.4	M18C	Move gun to part				
34			10.6	APA	Press the trigger				
35			27.8		Tack Weld				
36			2	RL1	Release trigger				
37			9.2	M2C	Move the gun to next position				
38			10.6	APA	Press the trigger				
39			55.6		Tack Weld				40
40			2	RL1	Release trigger				
41			25.5	M24C	Move the gun to next position				
42			10.6	APA	Press the trigger				
43			27.8		Tack Weld				
44			2	RL1	Release trigger				
45			9.2	M2C	Move the gun to next position				
46			10.6	APA	Press the trigger				
47			55.6		Tack Weld				

48			2	RL1	Release trigger			
49			20.4	M18C	Move gun to holder			
50			2	RL1	Release gun into holder			20
51	grab the plate assembly	G1A	2	G1A	grab the plate assembly			
52	Move plate assembly	M24B	20.6	M24B	Move plate assembly			
53	grab the plate	G1A	2					
54	Position the plate on the jig	P3SS	46.5					
55			19.8	R20C	Reach into the toolbox to get cylinder sleeve			
56			2	G1A	grab the cylinder sleeve			
57			43	P3S	Position cylinder sleeve onto jig			
58	Reach into the toolbox to get cylinder	R20C	19.8					
59	grab the cylinder	G1A	2					
60	Position cylinder onto jig	P3S	43					
61			10.5	R18HA	Move hand to gun			17
62			2	G1A	Grab welding gun			
63			20.4	M18C	Move gun to part			
64			10.6	APA	Press the trigger			
65			27.8		Tack Weld			
66			2	RL1	Release trigger			

67			9.2	M2C	Move the gun to next position			
68			10.6	APA	Press the trigger			
69			55.6		Tack Weld			
70			2	RL1	Release trigger			
71			25.5	M24C	Move the gun to next position			
72			10.6	APA	Press the trigger			
73			27.8		Tack Weld			
74			2	RL1	Release trigger			
75			9.2	M2C	Move the gun to next position			
76			10.6	APA	Press the trigger			
77			55.6		Tack Weld			
78			2	RL1	Release trigger			
79			20.4	M18C	Move gun to holder			
80			2	RL1	Release gun into holder			
81	grab the plate assembly	G1A	2	G1A	grab the plate assembly			
82	Move plate assembly	M24B	20.6	M24B	Move plate assembly			
83	grab the cylinder from jig	G1A	2					56
84	Remove the cylinder from jig	M20B	18.2					
85	Grasp Jig	G1A	2	G1A	Grasp Jig			
86	Move jig aside	M24B	20.6	M24B	Move jig aside			
87	Grasp Jig 2	G1A	2	G1A	Grasp Jig 2			
88	Move jig 2 to work table	M24B	20.6	M24B	Move jig 2 to work table			

89			19.8	R20C	Reach into the toolbox to get small cylinder			
90			2	G1A	grab the small cylinder			
91			43	P3S	Position small cylinder onto jig			
92	Reach into the toolbox to get small plate	R20C	19.8					
93	grab the plate	G1A	2					
94	Position plate onto jig	P3S	43					
95	Reach into the toolbox to get small ring	R20C	19.8					
96	grab the small ring	G1A	2					
97	Position small ring onto jig	P3S	43					
98	Reach into the toolbox to get triangular plate	R20C	19.8					
99	grab the triangular plate	G1A	2					
100	Position triangular plate onto jig	P3S	43					
101	Reach into the toolbox to get S plate	R20C	19.8					
102	grab the S plate	G1A	2					
103	Position S plate onto jig	P3S	43					

104	Reach into the toolbox to get Square bend	R20C	19.8					
105	grab the Square bend	G1A	2					
106	Position Square bend onto jig	P3S	43					
107			10.5	R18HA	Move hand to gun			42
108			2	G1A	Grab welding gun			
109			20.4	M18C	Move gun to part			
110			10.6	APA	Press the trigger			
111			27.8		Tack Weld			
112			2	RL1	Release trigger			
113			5.2	M2C	Move the gun to next position			
114			10.6	APA	Press the trigger			
115			55.6		Tack Weld			
116			2	RL1	Release trigger			
117			11.1	M7C	Move the gun to next position			
118			10.6	APA	Press the trigger			
119			278		Weld 1 inch			
120			2	RL1	Release trigger			
121			11.1	M7C	Move the gun to next position			
122			10.6	APA	Press the trigger			
123			278		Weld 1 inch			
124			2	RL1	Release trigger			
125			3.4	M1C	Move the gun to next position			

126			10.6	APA	Press the trigger			
127			278		Weld 1 inch			
128			2	RL1	Release trigger			
129			13.5	M10C	Move gun to holder			
130			2	RL1	Release gun into holder			
131			10.8	R7C	Reach to the S subassembly on jig			
132			2	G1A	grab the S subassembly			
133			9.4	TS180	Flip S subassembly			
134			8.4	R4C	Reach to the triangle subassembly on jig			
135			2	G1A	grab the triangle subassembly			
136			5.2	M2C	Move triangle subassembly			67
137	Reach into the toolbox to get small plate with hole	R20C	19.8					
138	grab the small plate with hole	G1A	2					
139	Position small plate with hole onto triangle subassembly	P3S	43					
140	Reach into the toolbox to get bolts	R20C	19.8	R20C	Reach into the toolbox to get bolts			
141	grab the bolts	G1A	2	G1A	grab the bolts			

142	Position bolts onto triangle subassembly	P3S	43	P3S	Position bolts onto triangle subassembly			
143			7.3	R10HA	Move hand to gun			
144			2	G1A	Grab welding gun			
145			20.4	M18C	Move gun to part			
146			10.6	APA	Press the trigger			
147			27.8		Tack Weld			
148			2	RL1	Release trigger			
149			3.4	M1C	Move the gun to next position			
150			10.6	APA	Press the trigger			25
151			139		Weld 1 inch			
152			2	RL1	Release trigger			
153			3.4	M1C	Move the gun to next position			
154			10.6	APA	Press the trigger			
155			278		Weld 1 inch			
156			2	RL1	Release trigger			
157			13.5	M10C	Move gun to holder			
158			2	RL1	Release gun into holder			
159	grab the triangle subassembly	G1A	2	G1A	grab the subassembly 1			8
160	Move triangle subassembly	M24B	20.6	M24B	Move subassembly 1			
161			7.3	R10HA	Move hand to gun			
162			2	G1A	Grab welding gun			26
163			20.4	M18C	Move gun to part			

164			10.6	APA	Press the trigger			
165			27.8		Tack Weld			
166			2	RL1	Release trigger			
167	Reach to the small plate subassembly on jig	R7C	10.8					
168	grab the small plate subassembly	G1A	2					
169	Flip small plate subassembly	TS180	9.4					
170			9.2	M5C	Move the gun to next position			
171			10.6	APA	Press the trigger			
172			278		Weld 1 inch			
173			2	RL1	Release trigger			
174	Reach to the small plate subassembly on jig	R7C	10.8					
175	grab the small plate subassembly	G1A	2					
176	Flip small plate subassembly	TS180	9.4					
177			9.2	M5C	Move the gun to next position			
178			10.6	APA	Press the trigger			
179			278		Weld 1 inch			
180			2	RL1	Release trigger			
181	Reach to the small plate subassembly on jig	R7C	10.8					14
182	grab the small plate subassembly	G1A	2					

183	Move small plate subassembly	M24B	20.6					
184	Reach into the toolbox to get L plate	R20C	19.8					
185	grab the L plate	G1A	2					
186	Position L plate onto jig	P3S	43					
187	Reach into the toolbox to get cylinder	R20C	19.8					
188	grab the Cylinder	G1A	2					
189	Position Cylinder onto jig	P3S	43					
190			7.3	R10HA	Move hand to gun			20
191			2	G1A	Grab welding gun			
192			20.4	M18C	Move gun to part			
193			10.6	APA	Press the trigger			
194			27.8		Tack Weld			
195			2	RL1	Release trigger			
196	Reach to the L subassembly on jig	R7C	10.8					
197	grab the L subassembly	G1A	2					
198	Flip L subassembly	TS180	9.4					
199			9.2	M5C	Move the gun to next position			
200			10.6	APA	Press the trigger			
201			278		Weld 1 inch			
202			2	RL1	Release trigger			

203	Reach to the L subassembly on jig	R7C	10.8					
204	grab the L subassembly	G1A	2					
205	Flip L subassembly	TS180	9.4					
206			9.2	M5C	Move the gun to next position			
207			10.6	APA	Press the trigger			
208			278		Weld 1 inch			
209			2	RL1	Release trigger			
210	Reach to the L subassembly on jig	R7C	10.8					30
211	grab the L subassembly	G1A	2					
212	Move L subassembly	M24B	20.6					
213	Grasp Jig	G1A	2	G1A	Grasp Jig 2			
214	move jig aside	M24B	20.6	M24B	Move jig 2 aside			
215	Grasp plate assembly	G1A	2	G1A	Grasp plate assembly			60
216	Grasp plate assembly	M24B	20.6	M24B	Grasp plate assembly			
217	Position plate assembly onto side of base	P3NS	47.8	P3NS	Position plate assembly onto side of base			
218	Reach to the clamp	R24C	22.5	R24C	Reach to the clamp			
219	grab the clamp	G1A	2	G1A	grab the clamp			
220	Move clamp to base	M24C	25.5	M24C	Move clamp to base			
221	Position clamp onto side of base	P3NS	47.8	P3NS	Position clamp onto side of base			
222			15.3	R30HA	Move hand to gun			22

223			2	G1A	Grab welding gun			
224			30.7	M30C	Move gun to part			
225			10.6	APA	Press the trigger			
226			27.8		Tack Weld			
227			2	RL1	Release trigger			
228			10.3	M6C	Move the gun to next position			
229			10.6	APA	Press the trigger			
230			27.8		tack Weld			
231			2	RL1	Release trigger			
232			10.3	M6C	Move the gun to next position			
233			10.6	APA	Press the trigger			
234			27.8		tack Weld			
235			2	RL1	Release trigger			
236			10.3	M6C	Move the gun to next position			
237			10.6	APA	Press the trigger			
238			27.8		tack Weld			
239			2	RL1	Release trigger			
240			20.4	M18C	Move the gun to next position			
241			10.6	APA	Press the trigger			
242			27.8		tack Weld			
243			2	RL1	Release trigger			
244			13.5	M10C	Move gun to holder			
245			2	RL1	Release gun into holder			
246	Reach to the clamp	R24C	22.5	R24C	Reach to the clamp			70

247	grab the clamp	G1A	2	G1A	grab the clamp			
248	move clamp to other side	M96C	86.8	M96C	move clamp to other side			
249	Grasp plate assembly	G1A	2	G1A	Grasp plate assembly			
250	move plate assembly	M24B	20.6	M24B	move plate assembly			
251	Position plate assembly onto side of base	P3NS	47.8	P3NS	Position plate assembly onto side of base			
252	Reach to the clamp	R12C	14.2	R12C	Reach to the clamp			
253	grab the clamp	G1A	2	G1A	grab the clamp			
254	Move clamp to base	M24C	25.5	M24C	Move clamp to base			
255	Position clamp onto side of base	P3NS	47.8	P3NS	Position clamp onto side of base			
256			7.3	R10HA	Move hand to gun			
257			2	G1A	Grab welding gun			
258			20.4	M18C	Move gun to part			
259			10.6	APA	Press the trigger			
260			27.8		Tack Weld			
261			2	RL1	Release trigger			
262			10.3	M6C	Move the gun to next position			25
263			10.6	APA	Press the trigger			
264			27.8		tack Weld			
265			2	RL1	Release trigger			
266			10.3	M6C	Move the gun to next position			
267			10.6	APA	Press the trigger			
268			27.8		tack Weld			

269			2	RL1	Release trigger			
270			10.3	M6C	Move the gun to next position			
271			10.6	APA	Press the trigger			
272			27.8		tack Weld			
273			2	RL1	Release trigger			
274			20.4	M18C	Move the gun to next position			
275			10.6	APA	Press the trigger			
276			27.8		tack Weld			
277			2	RL1	Release trigger			
278			13.5	M10C	Move gun to holder			
279			2	RL1	Release gun into holder			
280	Reach to the clamp	R24C	22.5	R24C	Reach to the clamp			
281	grab the clamp	G1A	2	G1A	grab the clamp			
282	Move clamp aside	M24C	25.5	M24C	Move clamp aside			
283	Reach to toolbox	R24C	22.5	R24C	Reach to the toolbox			
284	grab the toolbox	G1A	2	G1A	grab the toolbox			120
285	Move clamp toolbox	M24C	25.5	M24C	Move clamp toolbox			
286	grab the base	G1A	2	G1A	grab the base			
287	Flip base	TL180	28.2	TL180	Flip base			
288	Reach into the toolbox to get triangle Subassembly	R20C	19.8					
289	grab the triangle Subassembly	G1A	2					

290	Position triangle Subassembly onto base	P3NS	53.4					
291	Reach into the toolbox to get L subassembly	R20C	19.8					
292	grab the L subassembly	G1A	2					
293	Move L subassembly	M24B	20.6					
294	Reach into the toolbox to get small subassembly	R20C	19.8					
295	grab the small subassembly	G1A	2					
296	Move small subassembly	M24B	20.6					
297	Reach into the toolbox to get medium plate	R20C	19.8					
298	grab the medium plate	G1A	2					
299	Move medium plate	M24B	20.6					
300	Reach into the toolbox to get small square plate	R20C	19.8					
301	grab the small square plate	G1A	2					
302	Move small square plate	M24B	20.6					
303	Position small square plate on base	P3SS	52.1					
304			7.3	R10HA	Move hand to gun			20
305			2	G1A	Grab welding gun			

306			20.4	M18C	Move gun to part			
307			10.6	APA	Press the trigger			
308			27.8		Tack Weld			
309			2	RL1	Release trigger			
310			5.2	M2C	Move the gun to next position			
311			10.6	APA	Press the trigger			
312			27.8		tack Weld			
313			2	RL1	Release trigger			
314	Reach into the toolbox to get small square plate	R20C	19.8					
315	grab the small square plate	G1A	2					
316	Move small square plate	M24B	20.6					
317	Position small square plate on base	P3SS	52.1					
318			20.4	M18C	Move gun to part			
319			10.6	APA	Press the trigger			
320			27.8		Tack Weld			
321			2	RL1	Release trigger			
322			5.2	M2C	Move the gun to next position			
323			10.6	APA	Press the trigger			
324			27.8		tack Weld			
325			2	RL1	Release trigger			
326			13.5	M10C	Move gun to holder			
327			2	RL1	Release gun into holder			
328	grab the small bolt	G1A	2					9

329	Move small bolt	M24B	20.6					
330	Position small bolt on small subassembly	P3S	48.6					
331			2	G1A	Grasp long plate			
332			20.6	M24B	move long plate			
333	Position small subassembly onto long plate	P3S	48.6	P3S	Position small subassembly onto long plate			
334			7.3	R10HA	Move hand to gun			
335			2	G1A	Grab welding gun			
336			20.4	M18C	Move gun to part			
337			10.6	APA	Press the trigger			
338			83.4		Weld half inch			
339			2	RL1	Release trigger			
340			10.3	M6C	Move the gun to next position			
341			10.6	APA	Press the trigger			49
342			500.4		Weld 2 inches			
343			2	RL1	Release trigger			
344			5.2	M2C	Move the gun to next position			
345			10.6	APA	Press the trigger			
346			500.4		Weld 2 inches			
347			2	RL1	Release trigger			
348			20.4	M18C	Move the gun to next position			

349			10.6	APA	Press the trigger			
350			500.4		Weld 2 inches			
351			2	RL1	Release trigger			
352			5.2	M2C	Move the gun to next position			
353			10.6	APA	Press the trigger			
354			500.4		Weld 2 inches			
355			2	RL1	Release trigger			
356			2	G1A	Grasp long plate subassembly			
357			20.6	M24B	move long plate subassembly			11
358			48.6	P3S	Position long plate subassembly onto base			
359			56.2	M60C	Move the gun to next position			
360			10.6	APA	Press the trigger			
361			27.8		tack Weld			
362			2	RL1	Release trigger			
363			11.8	M8C	Move the gun to next position			
364			10.6	APA	Press the trigger			95
365			27.8		tack Weld			
366			2	RL1	Release trigger			
367			10.4	M6C	Move the gun to next position			
368			10.3	APA	Press the trigger			
369			27.8		tack Weld			

370			2	RL1	Release trigger			
371			8	M4C	Move the gun to next position			
372			10.3	APA	Press the trigger			
373			27.8		tack Weld			
374			2	RL1	Release trigger			
375			8	M4C	Move the gun to next position			
376			10.3	APA	Press the trigger			
377			278		Weld 1 inch			
378			2	RL1	Release trigger			
379			10.4	M6C	Move the gun to next position			
380			10.3	APA	Press the trigger			
381			1529		Weld 6 inch			
382			2	RL1	Release trigger			
383			10.4	M6C	Move the gun to next position			
384			10.3	APA	Press the trigger			
385			278		Weld 1 inch			
386			2	RL1	Release trigger			
387			10.4	M6C	Move the gun to next position			
388			10.3	APA	Press the trigger			
389			1557		Weld 6 inch			
390			2	RL1	Release trigger			
391	Reach into the toolbox to get small square plate	R20C	19.8					6

392	grab the small square plate	G1A	2					
393	Move small square plate	M24B	20.6					
394	Position small square plate on base	P3SS	52.1					
395			7.3	R10HA	Move hand to gun			7
396			2	G1A	Grab welding gun			
397			20.4	M18C	Move gun to part			
398			10.6	APA	Press the trigger			
399			27.8		tack Weld			
400			2	RL1	Release trigger			
401			5.2	M2C	Move the gun to next position			
402			10.3	APA	Press the trigger			
403			27.8		tack Weld			
404			2	RL1	Release trigger			
405			13.5	M10C	Move gun to holder			
406			2	RL1	Release gun into holder			
407	Reach into the toolbox to get spring	R20C	19.8					13
408	grab the Spring	G1A	2					
409	Move Spring	M24B	20.6					
410	Position Spring on base	P3SS	52.1					
411			7.3	R10HA	Move hand to gun			14
412			2	G1A	Grab welding gun			
413			20.4	M18C	Move gun to part			
414			10.6	APA	Press the trigger			

415			27.8		tack Weld			
416			2	RL1	Release trigger			
417			5.2	M2C	Move the gun to next position			
418			10.3	APA	Press the trigger			
419			973		Weld 4 inches			
420			2	RL1	Release trigger			
421	Reach into the toolbox to get small square plate	R20C	19.8					5
422	grab the small square plate	G1A	2					
423	Move small square plate	M24B	20.6					
424	Position small square plate on base	P3SS	52.1					
425			7.3	R10HA	Move hand to gun			48
426			2	G1A	Grab welding gun			
427			20.4	M18C	Move gun to part			
428			10.6	APA	Press the trigger			
429			27.8		tack Weld			
430			2	RL1	Release trigger			
431			5.2	M2C	Move the gun to next position			
432			10.3	APA	Press the trigger			
433			27.8		tack Weld			
434			2	RL1	Release trigger			
435			5.2	M2C	Move the gun to next position			
436			10.3	APA	Press the trigger			

437			556		Weld 3 inches			
438			2	RL1	Release trigger			
439			5.2	M2C	Move the gun to next position			
440			10.3	APA	Press the trigger			
441			556		Weld 3 inches			
442			2	RL1	Release trigger			
443			20.4	M18C	Move the gun to next position			
444			10.3	APA	Press the trigger			
445			556		Weld 3 inches			
446			2	RL1	Release trigger			
447			5.2	M2C	Move the gun to next position			
448			10.3	APA	Press the trigger			
449			556		Weld 3 inches			
450			2	RL1	Release trigger			
451			13.5	M10C	Move gun to holder			
452			2	RL1	Release gun into holder			
453	grab the small bolt	G1A	2					
454	Move small bolt	M24B	20.6					
455	Position small bolt on L subassembly	P3S	48.6					10
456			2	G1A	Grasp medium plate			
457			20.6	M24B	move medium plate			

458	Position L subassembly onto medium plate	P3S	48.6	P3S	Position L subassembly onto Medium plate			
459			7.3	R10HA	Move hand to gun			12
460			2	G1A	Grab welding gun			
461			20.4	M18C	Move gun to part			
462			10.6	APA	Press the trigger			
463			250.2		Weld			
464			2	RL1	Release trigger			
465			13.5	M10C	Move gun to holder			
466			2	RL1	Release gun into holder			
467			2	G1A	Grasp medium assembly			27
468			20.6	M24B	move medium assembly			
469			43	P3S	Position medium assembly onto base			
470			19.8	R20C	Reach into the toolbox to get crowbar			
471			2	G1A	grab the crowbar			
472			25.5	M24C	Move crowbar			
473			53.4	P3NS	Position crowbar			
474			48.6	P3S	Position medium assembly onto base			
475			7.3	R10HA	Move hand to gun			9
476			2	G1A	Grab welding gun			

477			20.4	M18C	Move gun to part			
478			10.6	APA	Press the trigger			
479			250.2		Weld			
480			2	RL1	Release trigger			
481			13.5	M10C	Move gun to holder			
482			2	RL1	Release gun into holder			
483			19.8	R20C	Reach to get crowbar			16
484			2	G1A	grab the crowbar			
485			25.5	M24C	Move crowbar			
486			19.8	R20C	Reach to get long subassembly			
487			2	G1A	grab the long subassembly			
488			25.5	M24C	Move long subassembly			
489			53.4	P3NS	Position long subassembly onto medium subassembly			
490			19.8	R20C	Reach to get crowbar			
491			2	G1A	grab the crowbar			
492			25.5	M24C	Move crowbar			
493			53.4	P3NS	Position crowbar			
494			7.3	R10HA	Move hand to gun			12
495			2	G1A	Grab welding gun			
496			20.4	M18C	Move gun to part			
497			10.6	APA	Press the trigger			
498			139		Weld			

499			2	RL1	Release trigger			
500			13.5	M10C	Move gun to holder			
501			2	RL1	Release gun into holder			
502			2	G1A	Grasp top			98
503			20.6	M24B	move top to base			
504	Reach to the clamp	R24C	22.5	R24C	Reach to the clamp			
505	grab the clamp	G1A	2	G1A	grab the clamp			
506	Move clamp to base	M24C	25.5	M24C	Move clamp to base			
507	Position clamp onto side of base	P3NS	47.8	P3NS	Position clamp onto side of base			
508			53.4	P3NS	Position top to base			
509			7.3	R10HA	Move hand to gun			145
510			2	G1A	Grab welding gun			
511			20.4	M18C	Move gun to part			
512			10.6	APA	Press the trigger			
513			27.8		tack Weld			
514			2	RL1	Release trigger			
515			86.8	M96C	Move the gun to next position			
516			10.3	APA	Press the trigger			
517			27.8		tack Weld			
518			2	RL1	Release trigger			
519			5.2	M2C	Move the gun to next position			
520			10.3	APA	Press the trigger			
521			27.8		tack Weld			
522			2	RL1	Release trigger			

523			25.5	M24C	Move the gun to next position			
524			10.3	APA	Press the trigger			
525			27.8		tack Weld			
526			2	RL1	Release trigger			
527			10.3	M6C	Move the gun to next position			
528			10.3	APA	Press the trigger			
529			27.8		tack Weld			
530			2	RL1	Release trigger			
531			10.3	M6C	Move the gun to next position			
532			10.3	APA	Press the trigger			
533			27.8		tack Weld			
534			2	RL1	Release trigger			
535			86.8	M96C	Move the gun to next position			
536			10.3	APA	Press the trigger			
537			27.8		tack Weld			
538			2	RL1	Release trigger			
539			25.5	M24C	Move the gun to next position			
540			10.3	APA	Press the trigger			
541			27.8		tack Weld			
542			2	RL1	Release trigger			
543			10.3	M6C	Move the gun to next position			
544			10.3	APA	Press the trigger			
545			27.8		tack Weld			
546			2	RL1	Release trigger			

547			10.3	M6C	Move the gun to next position			
548			10.3	APA	Press the trigger			
549			27.8		tack Weld			
550			2	RL1	Release trigger			
551			10.3	M48C	Move the gun to next position			
552			10.3	APA	Press the trigger			
553			27.8		tack Weld			
554			2	RL1	Release trigger			
555			10.3	M6C	Move the gun to next position			
556			10.3	APA	Press the trigger			
557			27.8		tack Weld			
558			2	RL1	Release trigger			
559			10.3	M6C	Move the gun to next position			
560			10.3	APA	Press the trigger			
561			27.8		tack Weld			
562			2	RL1	Release trigger			
563			10.3	M6C	Move the gun to next position			
564			10.3	APA	Press the trigger			
565			27.8		tack Weld			
566			2	RL1	Release trigger			
567			10.3	M6C	Move the gun to next position			
568			10.3	APA	Press the trigger			
569			27.8		tack Weld			
570			2	RL1	Release trigger			

571			25.5	M24C	Move the gun to next position			
572			10.3	APA	Press the trigger			
573			27.8		tack Weld			
574			2	RL1	Release trigger			
575			10.3	M6C	Move the gun to next position			
576			10.3	APA	Press the trigger			
577			27.8		tack Weld			
578			2	RL1	Release trigger			
579			10.3	M6C	Move the gun to next position			
580			10.3	APA	Press the trigger			
581			27.8		tack Weld			
582			2	RL1	Release trigger			
583			10.3	M6C	Move the gun to next position			
584			10.3	APA	Press the trigger			
585			27.8		tack Weld			
586			2	RL1	Release trigger			
587			10.3	M6C	Move the gun to next position			
588			10.3	APA	Press the trigger			
589			27.8		tack Weld			
590			2	RL1	Release trigger			
591			86.8	M96C	Move the gun to next position			
592			10.3	APA	Press the trigger			
593			27.8		tack Weld			
594			2	RL1	Release trigger			

595			10.3	M6C	Move the gun to next position			
596			10.3	APA	Press the trigger			
597			27.8		tack Weld			
598			2	RL1	Release trigger			
599			10.3	M6C	Move the gun to next position			
600			10.3	APA	Press the trigger			
601			27.8		tack Weld			
602			2	RL1	Release trigger			
603			10.3	M6C	Move the gun to next position			
604			10.3	APA	Press the trigger			
605			27.8		tack Weld			
606			2	RL1	Release trigger			
607			10.3	M6C	Move the gun to next position			
608			10.3	APA	Press the trigger			
609			27.8		tack Weld			
610			2	RL1	Release trigger			
611			86.8	M96C	Move the gun to next position			
612			10.3	APA	Press the trigger			
613			27.8		tack Weld			
614			2	RL1	Release trigger			
615			10.3	M6C	Move the gun to next position			
616			10.3	APA	Press the trigger			
617			27.8		tack Weld			
618			2	RL1	Release trigger			

619			10.3	M6C	Move the gun to next position			
620			10.3	APA	Press the trigger			
621			27.8		tack Weld			
622			2	RL1	Release trigger			
623			10.3	M6C	Move the gun to next position			
624			10.3	APA	Press the trigger			
625			27.8		tack Weld			
626			2	RL1	Release trigger			
627			10.3	M6C	Move the gun to next position			
628			10.3	APA	Press the trigger			
629			27.8		tack Weld			
630			2	RL1	Release trigger			
631			10.3	M6C	Move the gun to next position			
632			10.3	APA	Press the trigger			
633			27.8		tack Weld			
634			2	RL1	Release trigger			
635			86.8	M96C	Move the gun to next position			
636			10.3	APA	Press the trigger			
637			278		Weld 2 inches			
638			2	RL1	Release trigger			660
639			10.3	M6C	Move the gun to next position			
640			10.3	APA	Press the trigger			
641			1390		Weld 6 inch			
642			2	RL1	Release trigger			

643			86.8	M96C	Move the gun to next position			
644			10.3	APA	Press the trigger			
645			194.6		Weld 2 inches			
646			2	RL1	Release trigger			
647			10.3	M6C	Move the gun to next position			
648			10.3	APA	Press the trigger			
649			750.6		Weld 6 inch			
650			2	RL1	Release trigger			
651			10.3	M6C	Move the gun to next position			
652			10.3	APA	Press the trigger			
653			2863		Weld 24 inch			
654			2	RL1	Release trigger			
655			5.4	M2C	Move the gun to next position			
656			10.3	APA	Press the trigger			
657			111.2		Weld 2 inch			
658			2	RL1	Release trigger			
659			3.4	M1C	Move the gun to next position			
660			10.3	APA	Press the trigger			
661			500.4		Weld			
662			2	RL1	Release trigger			
663			86.8	M96C	Move the gun to next position			
664			10.3	APA	Press the trigger			
665			2446		Weld			

666			2	RL1	Release trigger			
667			3.4	M1C	Move the gun to next position			
668			10.3	APA	Press the trigger			
669			1251		Weld			
670			2	RL1	Release trigger			
671			3.4	M1C	Move the gun to next position			
672			10.3	APA	Press the trigger			
673			1807		Weld			
674			2	RL1	Release trigger			
675			3.4	M1C	Move the gun to next position			
676			10.3	APA	Press the trigger			
677			166.8		Weld			
678			2	RL1	Release trigger			
679			86.8	M96C	Move the gun to next position			
680			10.3	APA	Press the trigger			
681			1334		Weld			
682			2	RL1	Release trigger			
683			3.4	M1C	Move the gun to next position			
684			10.3	APA	Press the trigger			
685			2141		Weld			
686			2	RL1	Release trigger			
687			3.4	M1C	Move the gun to next position			
688			10.3	APA	Press the trigger			
689			1362		Weld			

690			2	RL1	Release trigger			
691			3.4	M1C	Move the gun to next position			
692			10.3	APA	Press the trigger			
693			1251		Weld			
694			2	RL1	Release trigger			
695			13.5	M10C	Move gun to holder			
696			2	RL1	Release gun into holder			
697	grab the base assembly	G1A	2	G1A	grab the base assembly			
698	Flip base assembly	TL180	28.2	TL180	Flip base assembly			
699	grab the base assembly	G1A	2	G1A	grab the base assembly			
700	turn base assembly	TL180	28.2	TL180	turn base assembly			60
701	Reach into the toolbox to get L bracket	R20C	19.8					
702	grab the L bracket	G1A	2					
703	Move L bracket	M24B	20.6					
704			7.3	R10HA	Move hand to gun			
705			2	G1A	Grab welding gun			
706			20.4	M18C	Move gun to part			
707			10.6	APA	Press the trigger			80
708			417		Weld			
709			2	RL1	Release trigger			
710			3.4	M1C	Move the gun to next position			
711			10.3	APA	Press the trigger			

712			472.6		Weld			
713			2	RL1	Release trigger			
714			3.4	M1C	Move the gun to next position			
715			10.3	APA	Press the trigger			
716			1529		Weld			
717			2	RL1	Release trigger			
718			3.4	M1C	Move the gun to next position			
719			10.3	APA	Press the trigger			
720			583.8		Weld			
721			2	RL1	Release trigger			
722	Position L bracket onto base assembly	P3NS	53.4					
723			3.4	M1C	Move the gun to next position			
724			10.3	APA	Press the trigger			
725			27.8		tack Weld			
726			2	RL1	Release trigger			
727			5.2	M2C	Move the gun to next position			140
728			10.3	APA	Press the trigger			
729			27.8		tack Weld			
730			2	RL1	Release trigger			
731			5.2	M2C	Move the gun to next position			
732			10.3	APA	Press the trigger			
733			139		tack Weld			
734			2	RL1	Release trigger			

735			5.2	M2C	Move the gun to next position			
736			10.3	APA	Press the trigger			
737			111.2		tack Weld			
738			2	RL1	Release trigger			
739			5.2	M2C	Move the gun to next position			
740			10.3	APA	Press the trigger			
741			166.8		tack Weld			
742			2	RL1	Release trigger			
743			15.2	M12C	Move the gun to next position			
744			10.3	APA	Press the trigger			
745			194.6		tack Weld			
746			2	RL1	Release trigger			
747			3.4	M1C	Move the gun to next position			
748			10.3	APA	Press the trigger			
749			194.6		Weld			
750			2	RL1	Release trigger			
751			25.5	M24C	Move the gun to next position			
752			10.3	APA	Press the trigger			
753			83.4		Weld			
754			2	RL1	Release trigger			
755	Position L bracket onto base assembly	P3NS	53.4					
756			86.8	M96C	Move the gun to next position			
757			10.3	APA	Press the trigger			

758			27.8		tack Weld			
759			2	RL1	Release trigger			
760			5.2	M2C	Move the gun to next position			
761			10.3	APA	Press the trigger			
762			27.8		tack Weld			
763			2	RL1	Release trigger			
764			5.2	M2C	Move the gun to next position			
765			10.3	APA	Press the trigger			
766			139		tack Weld			
767			2	RL1	Release trigger			
768			5.2	M2C	Move the gun to next position			
769			10.3	APA	Press the trigger			
770			111.2		tack Weld			
771			2	RL1	Release trigger			
772			5.2	M2C	Move the gun to next position			
773			10.3	APA	Press the trigger			
774			166.8		tack Weld			
775			2	RL1	Release trigger			
776			15.2	M12C	Move the gun to next position			
777			10.3	APA	Press the trigger			
778			194.6		tack Weld			
779			2	RL1	Release trigger			
780			3.4	M1C	Move the gun to next position			
781			10.3	APA	Press the trigger			
782			194.6		Weld			

783			2	RL1	Release trigger			
		Total TMU	45042					
		Total sec	1622					2448
		Total Min	27.03					40.8

MOST Manual-1											
Sl No.	**General move**	**Get**			**Put**			**Return**	**Index**	**TMU**
0		**A**	**B**	**G**	**A**	**B**	**P**	**A**		
1	Get Base to work area	10	3	3	0	0	3	6	25	250
3	Get Top to work area	6	0	3	1	0	3	3	16	160
4	Get tool box with plates to work area	10	0	3	1	0	6	0	20	200
5	Placing Cylinders with sleeves on Jig 1	1	0	1	0	0	6	0	8	80
6	Welding Tacks									444.8
7	Put it aside (sub assembly 1)	0	0	0	0	0	3	0	3	30
8	Placing Cylinders with sleeves on Jig 1	1	0	1	0	0	6	0	8	80
9	Welding Tacks									500.4
10	Put it aside (sub assembly 2)	0	0	0	0	0	3	0	3	30
11	Get Jig 2 and Place parts	3	0	3	0	0	6	0	12	120
12	Welding									1112
13	Get Bolts	1	0	0	0	0	6	0	7	70
14	Welding (Triangle assembly)									556
15	Put it aside (Triangle assembly)	0	0	0	0	0	3	0	3	30
16	Welding (Small plate subassembly)									639.4
17	Put it aside (small plate subassembly)	0	0	0	0	0	3	0	3	30
18	Get parts from tool box and place on jig 2	1	0	1	0	0	6	0	8	80
19	Welding (L subassembly)									444.8
20	Put all welded parts into tool box	1	0	1	0	0	3	0	5	50
21	replace the Jigs	6	0	3	0	0	3	0	12	120
22	Place Subassembly 1 to the base	3	0	3	0	0	6	0	12	120

23	Get clamp and place clamp X2	1	0	1	0	0	6	0	8	80
24	Welding Tacks (subassembly 1 to the base)									444.8
25	Place Subassembly 2 to the base	3	0	3	0	0	6	0	12	120
26	Get clamp and place clamp X2	1	0	1	0	0	6	0	8	80
27	Welding Tacks (subassembly 2 to the base)									528.2
29	Get tool box with welded parts to work area	1	0	3	0	0	6	0	10	100
30	Welding									9452
31	Get the top	1	0	3	0	0	3	0	7	70
33	Adjust the top precicely	0	0	0	0	0	6	0	6	60
34	Clamp the top to the base	3	0	3	0	0	6	0	12	120
35	Welding Tacks									3670
36	Welding									5254
37	Clamp the part to the work area	1	0	3	0	0	6	0	10	100
38	Welding									11759
41	Get L brackets to the workpiece	3	0	3	0	0	3	0	9	90
42	Welding									1835
43	Part tack weld to the workpiece						6		6	60
44	Welding									1835
45	Part tack weld to the workpiece						6		6	60
46	Welding									3670
		Get			**Move**			**Return**	**Index**	**TMU**
0	**Controlled move**	**A**	**B**	**G**	**M**	**X**	**I**	**A**		
2	Turning the base	0	0	0	1	1	3	6	11	110
28	Flip the base	0	0	0	1	1	3	6	11	110
32	Flip the Top	0	0	0	1	1	3	6	11	110
39	Flip the workpiece	0	0	0	1	1	3	6	11	110
40	Turn the workpiece	0	0	0	1	1	3	6	11	110

MOST Manual - 2										
Sl No.	**General move**	**Get**			**Put**			**Return**	**Index**	**TMU**
0		**A**	**B**	**G**	**A**	**B**	**P**	**A**		
1	Get Base to work area	10	3	3	0	0	3	6	25	250
3	Get Top to work area	6	0	3	1	0	3	3	16	160
4	Get tool box with plates to work area	10	0	3	1	0	6	0	20	200
5	Placing Cylinders with sleeves on Jig 1	1	0	1	0	0	6	0	8	80
6	Welding Tacks									444.8
7	Put it aside (sub assembly 1)	0	0	0	0	0	3	0	3	30
8	Placing Cylinders with sleeves on Jig 1	1	0	1	0	0	6	0	8	80
9	Welding Tacks									500.4
10	Put it aside (sub assembly 2)	0	0	0	0	0	3	0	3	30
11	Get Jig 2 and Place parts	3	0	3	0	0	6	0	12	120
12	Welding									1112
13	Get Bolts	1	0	0	0	0	6	0	7	70
14	Welding (Triangle assembly)									556
15	Put it aside (Triangle assembly)	0	0	0	0	0	3	0	3	30
16	Welding (Small plate subassembly)									639.4
17	Put it aside (small plate subassembly)	0	0	0	0	0	3	0	3	30
18	Get parts from tool box and place on jig 2	1	0	1	0	0	6	0	8	80
19	Welding (L subassembly)									444.8
20	Put all welded parts into tool box	1	0	1	0	0	3	0	5	50
21	replace the Jigs	6	0	3	0	0	3	0	12	120
22	Place Subassembly 1 to the base	3	0	3	0	0	6	0	12	120
23	Get clamp and place clamp X2	1	0	1	0	0	6	0	8	80
24	Welding Tacks (subassembly 1 to the base)									444.8
25	Place Subassembly 2 to the base	3	0	3	0	0	6	0	12	120
26	Get clamp and place clamp X2	1	0	1	0	0	6	0	8	80
27	Welding Tacks (subassembly 2 to the base)									528.2
29	Get tool box with welded parts to work area	1	0	3	0	0	6	0	10	100
30	Welding									8340
31	Get the top	1	0	3	0	0	3	0	7	70
33	Adjust the top precicely	0	0	0	0	0	6	0	6	60
34	Clamp the top to the base	3	0	3	0	0	6	0	12	120
35	Welding Tacks									3114

36	Welding									4698
37	Clamp the part to the work area	1	0	3	0	0	6	0	10	100
38	Welding									10925
41	Get L brackets to the workpiece	3	0	3	0	0	3	0	9	90
42	Welding									1835
43	Part tack weld to the workpiece						6		6	60
44	Welding									1835
45	Part tack weld to the workpiece						6		6	60
46	Welding									3392
		Get			**Move**			**Return**	**Index**	**TMU**
0	**Controlled move**	**A**	**B**	**G**	**M**	**X**	**I**	**A**		
2	Turning the base	0	0	0	1	1	3	6	11	110
28	Flip the base	0	0	0	1	1	3	6	11	110
32	Flip the Top	0	0	0	1	1	3	6	11	110
39	Flip the workpiece	0	0	0	1	1	3	6	11	110
40	Turn the workpiece	0	0	0	1	1	3	6	11	110

MOST Manual - 3										
Sl No.	**General move**	**Get**			**Put**			**Return**	**Index**	**TMU**
0		**A**	**B**	**G**	**A**	**B**	**P**	**A**		
1	Get Base to work area	10	3	3	0	0	3	6	25	250
3	Get Top to work area	6	0	3	1	0	3	3	16	160
4	Get tool box with plates to work area	10	0	3	1	0	6	0	20	200
5	Placing Cylinders with sleeves on Jig 1	1	0	1	0	0	6	0	8	80
6	Welding Tacks									444.8
7	Put it aside (sub assembly 1)	0	0	0	0	0	3	0	3	30
8	Placing Cylinders with sleeves on Jig 1	1	0	1	0	0	6	0	8	80
9	Welding Tacks									500.4
10	Put it aside (sub assembly 2)	0	0	0	0	0	3	0	3	30
11	Get Jig 2 and Place parts	3	0	3	0	0	6	0	12	120
12	Welding									1251
13	Get Bolts	1	0	0	0	0	6	0	7	70
14	Welding (Triangle assembly)									556
15	Put it aside (Triangle assembly)	0	0	0	0	0	3	0	3	30

16	Welding (Small plate subassembly)									750.6
17	Put it aside (small plate subassembly)	0	0	0	0	0	3	0	3	30
18	Get parts from tool box and place on jig 2	1	0	1	0	0	6	0	8	80
19	Welding (L subassembly)									528.2
20	Put all welded parts into tool box	1	0	1	0	0	3	0	5	50
21	replace the Jigs	6	0	3	0	0	3	0	12	120
22	Place Subassembly 1 to the base	3	0	3	0	0	6	0	12	120
23	Get clamp and place clamp X2	1	0	1	0	0	6	0	8	80
24	Welding Tacks (subassembly 1 to the base)									444.8
25	Place Subassembly 2 to the base	3	0	3	0	0	6	0	12	120
26	Get clamp and place clamp X2	1	0	1	0	0	6	0	8	80
27	Welding Tacks (subassembly 2 to the base)									806.2
29	Get tool box with welded parts to work area	1	0	3	0	0	6	0	10	100
30	Welding									10842
31	Get the top	1	0	3	0	0	3	0	7	70
33	Adjust the top precicely	0	0	0	0	0	6	0	6	60
34	Clamp the top to the base	3	0	3	0	0	6	0	12	120
35	Welding Tacks									4782
36	Welding									6644
37	Clamp the part to the work area	1	0	3	0	0	6	0	10	100
38	Welding									13705
41	Get L brackets to the workpiece	3	0	3	0	0	3	0	9	90
42	Welding									1835
43	Part tack weld to the workpiece						6		6	60
44	Welding									1835
45	Part tack weld to the workpiece						6		6	60
46	Welding									3670
		Get			**Move**			**Return**	**Index**	**TMU**
0	**Controlled move**	**A**	**B**	**G**	**M**	**X**	**I**	**A**		
2	Turning the base	0	0	0	1	1	3	6	11	110
28	Flip the base	0	0	0	1	1	3	6	11	110
32	Flip the Top	0	0	0	1	1	3	6	11	110
39	Flip the workpiece	0	0	0	1	1	3	6	11	110
40	Turn the workpiece	0	0	0	1	1	3	6	11	110

MOST Robotic - 1										
Sl No.	**General move**	**Get**			**Put**			**Return**	**Index**	**TMU**
0		**A**	**B**	**G**	**A**	**B**	**P**	**A**		
1	Get Base to work area	10	3	3	0	0	3	6	25	250
3	Get Top to work area	6	0	3	1	0	3	3	16	160
4	Get tool box with plates to work area	10	0	3	1	0	6	0	20	200
5	Placing Cylinders with sleeves on Jig 1	1	0	1	0	0	6	0	8	80
6	Welding Tacks									444.8
7	Put it aside (sub assembly 1)	0	0	0	0	0	3	0	3	30
8	Placing Cylinders with sleeves on Jig 1	1	0	1	0	0	6	0	8	80
9	Welding Tacks									500.4
10	Put it aside (sub assembly 2)	0	0	0	0	0	3	0	3	30
11	Get Jig 2 and Place parts	3	0	3	0	0	6	0	12	120
12	Welding									1112
13	Get Bolts	1	0	0	0	0	6	0	7	70
14	Welding (Triangle assembly)									556
15	Put it aside (Triangle assembly)	0	0	0	0	0	3	0	3	30
16	Welding (Small plate subassembly)									639.4
17	Put it aside (small plate subassembly)	0	0	0	0	0	3	0	3	30
18	Get parts from tool box and place on jig 2	1	0	1	0	0	6	0	8	80
19	Welding (L subassembly)									444.8
20	Put all welded parts into tool box	1	0	1	0	0	3	0	5	50
21	replace the Jigs	6	0	3	0	0	3	0	12	120
22	Place Subassembly 1 to the base	3	0	3	0	0	6	0	12	120
23	Get clamp and place clamp X2	1	0	1	0	0	6	0	8	80
24	Welding Tacks (subassembly 1 to the base)									444.8
25	Place Subassembly 2 to the base	3	0	3	0	0	6	0	12	120
26	Get clamp and place clamp X2	1	0	1	0	0	6	0	8	80
27	Welding Tacks (subassembly 2 to the base)									528.2
29	Get tool box with welded parts to work area	1	0	3	0	0	6	0	10	100
30	Welding									12232
31	Get the top	1	0	3	0	0	3	0	7	70
33	Adjust the top precicely	0	0	0	0	0	6	0	6	60
34	Clamp the top to the base	3	0	3	0	0	6	0	12	120
35	Welding Tacks									3670

36	Welding									3169
37	Clamp the part to the work area	1	0	3	0	0	6	0	10	100
38	Welding									12427
41	Get L brackets to the workpiece	3	0	3	0	0	3	0	9	90
42	Welding									1835
43	Part tack weld to the workpiece						6		6	60
44	Welding									2391
45	Part tack weld to the workpiece						6		6	60
46	Welding									3670
		Get			**Move**			**Return**	**Index**	**TMU**
0	**Controlled move**	**A**	**B**	**G**	**M**	**X**	**I**	**A**		
2	Turning the base	0	0	0	1	1	3	6	11	110
28	Flip the base	0	0	0	1	1	3	6	11	110
32	Flip the Top	0	0	0	1	1	3	6	11	110
39	Flip the workpiece	0	0	0	1	1	3	6	11	110
40	Turn the workpiece	0	0	0	1	1	3	6	11	110

MOST ROBOTIC - 2										
Sl No.	**General move**	**Get**			**Put**			**Return**	**Index**	**TMU**
0		**A**	**B**	**G**	**A**	**B**	**P**	**A**		
1	Get Base to work area	10	3	3	0	0	3	6	25	250
3	Get Top to work area	6	0	3	1	0	3	3	16	160
4	Get tool box with plates to work area	10	0	3	1	0	6	0	20	200
5	Placing Cylinders with sleeves on Jig 1	1	0	1	0	0	6	0	8	80
6	Welding Tacks									444.8
7	Put it aside (sub assembly 1)	0	0	0	0	0	3	0	3	30
8	Placing Cylinders with sleeves on Jig 1	1	0	1	0	0	6	0	8	80
9	Welding Tacks									500.4
10	Put it aside (sub assembly 2)	0	0	0	0	0	3	0	3	30
11	Get Jig 2 and Place parts	3	0	3	0	0	6	0	12	120
12	Welding									1112
13	Get Bolts	1	0	0	0	0	6	0	7	70
14	Welding (Triangle assembly)									556
15	Put it aside (Triangle assembly)	0	0	0	0	0	3	0	3	30
16	Welding (Small plate subassembly)									639.4

17	Put it aside (small plate subassembly)	0	0	0	0	0	3	0	3	30
18	Get parts from tool box and place on jig 2	1	0	1	0	0	6	0	8	80
19	Welding (L subassembly)									444.8
20	Put all welded parts into tool box	1	0	1	0	0	3	0	5	50
21	replace the Jigs	6	0	3	0	0	3	0	12	120
22	Place Subassembly 1 to the base	3	0	3	0	0	6	0	12	120
23	Get clamp and place clamp X2	1	0	1	0	0	6	0	8	80
24	Welding Tacks (subassembly 1 to the base)									444.8
25	Place Subassembly 2 to the base	3	0	3	0	0	6	0	12	120
26	Get clamp and place clamp X2	1	0	1	0	0	6	0	8	80
27	Welding Tacks (subassembly 2 to the base)									528.2
29	Get tool box with welded parts to work area	1	0	3	0	0	6	0	10	100
30	Welding									8340
31	Get the top	1	0	3	0	0	3	0	7	70
33	Adjust the top precicely	0	0	0	0	0	6	0	6	60
34	Clamp the top to the base	3	0	3	0	0	6	0	12	120
35	Welding Tacks									3114
36	Welding									2836
37	Clamp the part to the work area	1	0	3	0	0	6	0	10	100
38	Welding									10842
41	Get L brackets to the workpiece	3	0	3	0	0	3	0	9	90
42	Welding									1835
43	Part tack weld to the workpiece						6		6	60
44	Welding									1835
45	Part tack weld to the workpiece						6		6	60
46	Welding									3392
		Get			**Move**			**Return**	**Index**	**TMU**
0	**Controlled move**	**A**	**B**	**G**	**M**	**X**	**I**	**A**		
2	Turning the base	0	0	0	1	1	3	6	11	110
28	Flip the base	0	0	0	1	1	3	6	11	110
32	Flip the Top	0	0	0	1	1	3	6	11	110

39	Flip the workpiece	0	0	0	1	1	3	6	11	110
40	Turn the workpiece	0	0	0	1	1	3	6	11	110

MOST ROBOTIC - 3										
Sl No.	**General move**	**Get**			**Put**			**Return**	**Index**	**TMU**
0		**A**	**B**	**G**	**A**	**B**	**P**	**A**		
1	Get Base to work area	10	3	3	0	0	3	6	25	250
3	Get Top to work area	6	0	3	1	0	3	3	16	160
4	Get tool box with plates to work area	10	0	3	1	0	6	0	20	200
5	Placing Cylinders with sleeves on Jig 1	1	0	1	0	0	6	0	8	80
6	Welding Tacks									444.8
7	Put it aside (sub assembly 1)	0	0	0	0	0	3	0	3	30
8	Placing Cylinders with sleeves on Jig 1	1	0	1	0	0	6	0	8	80
9	Welding Tacks									500.4
10	Put it aside (sub assembly 2)	0	0	0	0	0	3	0	3	30
11	Get Jig 2 and Place parts	3	0	3	0	0	6	0	12	120
12	Welding									1251
13	Get Bolts	1	0	0	0	0	6	0	7	70
14	Welding (Triangle assembly)									556
15	Put it aside (Triangle assembly)	0	0	0	0	0	3	0	3	30
16	Welding (Small plate subassembly)									750.6
17	Put it aside (small plate subassembly)	0	0	0	0	0	3	0	3	30
18	Get parts from tool box and place on jig 2	1	0	1	0	0	6	0	8	80
19	Welding (L subassembly)									528.2
20	Put all welded parts into tool box	1	0	1	0	0	3	0	5	50
21	replace the Jigs	6	0	3	0	0	3	0	12	120
22	Place Subassembly 1 to the base	3	0	3	0	0	6	0	12	120
23	Get clamp and place clamp X2	1	0	1	0	0	6	0	8	80

24	Welding Tacks (subassembly 1 to the base)									444.8
25	Place Subassembly 2 to the base	3	0	3	0	0	6	0	12	120
26	Get clamp and place clamp X2	1	0	1	0	0	6	0	8	80
27	Welding Tacks (subassembly 2 to the base)									806.2
29	Get tool box with welded parts to work area	1	0	3	0	0	6	0	10	100
30	Welding									11676
31	Get the top	1	0	3	0	0	3	0	7	70
33	Adjust the top precicely	0	0	0	0	0	6	0	6	60
34	Clamp the top to the base	3	0	3	0	0	6	0	12	120
35	Welding Tacks									5338
36	Welding									3364
37	Clamp the part to the work area	1	0	3	0	0	6	0	10	100
38	Welding									12010
41	Get L brackets to the workpiece	3	0	3	0	0	3	0	9	90
42	Welding									1835
43	Part tack weld to the workpiece						6		6	60
44	Welding									1529
45	Part tack weld to the workpiece						6		6	60
46	Welding									3586
		Get			**Move**			**Return**	**Index**	**TMU**
0	**Controlled move**	**A**	**B**	**G**	**M**	**X**	**I**	**A**		
2	Turning the base	0	0	0	1	1	3	6	11	110
28	Flip the base	0	0	0	1	1	3	6	11	110
32	Flip the Top	0	0	0	1	1	3	6	11	110
39	Flip the workpiece	0	0	0	1	1	3	6	11	110
40	Turn the workpiece	0	0	0	1	1	3	6	11	110

Actual Time Robotic - 1		
Sl No.	General move	Seconds
0		
1	Get Base to work area	120
2	Turning the base	
3	Get Top to work area	
4	Get tool box with plates to work area	240
5	Placing Cylinders with sleeves on Jig 1	
6	Welding Tacks	
7	Put it aside (sub assembly 1)	
8	Placing Cylinders with sleeves on Jig 1	
9	Welding Tacks	
10	Put it aside (sub assembly 2)	
11	Get Jig 2 and Place parts	
12	Welding	
13	Get Bolts	140
14	Welding (Triangle assembly)	
15	Put it aside (Triangle assembly)	
16	Welding (Small plate subassembly)	
17	Put it aside (small plate subassembly)	
18	Get parts from tool box and place on jig 2	
19	Welding (L subassembly)	
20	Put all welded parts into tool box	
21	replace the Jigs	
22	Place Subassembly 1 to the base	250
23	Get clamp and place clamp X2	
24	Welding Tacks (subassembly 1 to the base)	
25	Place Subassembly 2 to the base	
26	Get clamp and place clamp X2	
27	Welding Tacks (subassembly 2 to the base)	
28	Flip the base	
29	Get tool box with welded parts to work area	
30	Welding	428
31	Get the top	
32	Flip the Top	
33	Adjust the top precisely	
34	Clamp the top to the base	182
35	Welding Tacks	
36	Welding	700
37	Clamp the part to the work area	
38	Welding	
39	Flip the workpiece	250
40	Turn the workpiece	
41	Get L brackets to the workpiece	
42	Welding	
43	Part tack weld to the workpiece	

44	Welding	
45	Part tack weld to the workpiece	
46	Welding	
	Total	2310
	Total in minutes	38.5

Actual Time Robotic - 2

Sl No.	General move	Seconds
0		
1	Get Base to work area	110
2	Turning the base	
3	Get Top to work area	
4	Get tool box with plates to work area	187
5	Placing Cylinders with sleeves on Jig 1	
6	Welding Tacks	
7	Put it aside (sub assembly 1)	
8	Placing Cylinders with sleeves on Jig 1	
9	Welding Tacks	
10	Put it aside (sub assembly 2)	
11	Get Jig 2 and Place parts	
12	Welding	
13	Get Bolts	130
14	Welding (Triangle assembly)	
15	Put it aside (Triangle assembly)	
16	Welding (Small plate subassembly)	
17	Put it aside (small plate subassembly)	
18	Get parts from tool box and place on jig 2	
19	Welding (L subassembly)	
20	Put all welded parts into tool box	
21	replace the Jigs	
22	Place Subassembly 1 to the base	190
23	Get clamp and place clamp X2	
24	Welding Tacks (subassembly 1 to the base)	
25	Place Subassembly 2 to the base	
26	Get clamp and place clamp X2	
27	Welding Tacks (subassembly 2 to the base)	
28	Flip the base	
29	Get tool box with welded parts to work area	
30	Welding	390
31	Get the top	
32	Flip the Top	
33	Adjust the top precicely	
34	Clamp the top to the base	182
35	Welding Tacks	

36	Welding	670
37	Clamp the part to the work area	
38	Welding	
39	Flip the workpiece	250
40	Turn the workpiece	
41	Get L brackets to the workpiece	
42	Welding	
43	Part tack weld to the workpiece	
44	Welding	
45	Part tack weld to the workpiece	
46	Welding	
	Total	2109
	Total in minutes	35.15

Actual Time Robotic - 3		
Sl No.	**General move**	**Seconds**
0		
1	Get Base to work area	130
2	Turning the base	
3	Get Top to work area	
4	Get tool box with plates to work area	240
5	Placing Cylinders with sleeves on Jig 1	
6	Welding Tacks	
7	Put it aside (sub assembly 1)	
8	Placing Cylinders with sleeves on Jig 1	
9	Welding Tacks	
10	Put it aside (sub assembly 2)	
11	Get Jig 2 and Place parts	
12	Welding	
13	Get Bolts	150
14	Welding (Triangle assembly)	
15	Put it aside (Triangle assembly)	
16	Welding (Small plate subassembly)	
17	Put it aside (small plate subassembly)	
18	Get parts from tool box and place on jig 2	
19	Welding (L subassembly)	
20	Put all welded parts into tool box	
21	replace the Jigs	
22	Place Subassembly 1 to the base	270
23	Get clamp and place clamp X2	
24	Welding Tacks (subassembly 1 to the base)	
25	Place Subassembly 2 to the base	

26	Get clamp and place clamp X2	
27	Welding Tacks (subassembly 2 to the base)	
28	Flip the base	
29	Get tool box with welded parts to work area	
30	Welding	448
31	Get the top	
32	Flip the Top	
33	Adjust the top precicely	
34	Clamp the top to the base	182
35	Welding Tacks	
36	Welding	740
37	Clamp the part to the work area	
38	Welding	
39	Flip the workpiece	270
40	Turn the workpiece	
41	Get L brackets to the workpiece	
42	Welding	
43	Part tack weld to the workpiece	
44	Welding	
45	Part tack weld to the workpiece	
46	Welding	
	Total	2430
	Total in Minutes	40.5

Number of Parts	**Manual**	**Robotic**	**Robotic Optimized (Average Cycle Time = 508 Sec.)**	**Robotic Optimized (Average Cycle Time = 481 Sec.)**
1	9.1	108.92	108.47	108.03
2	18.2	117.84	116.94	116.06
3	27.3	126.76	125.41	124.09
4	36.4	135.68	133.88	132.12
5	45.5	144.6	142.35	140.15
6	54.6	153.52	150.82	148.18
7	63.7	162.44	159.29	156.21
8	72.8	171.36	167.76	164.24
9	81.9	180.28	176.23	172.27
10	91	189.2	184.7	180.3
11	100.1	198.12	193.17	188.33
12	109.2	207.04	201.64	196.36
13	118.3	215.96	210.11	204.39
14	127.4	224.88	218.58	212.42
15	136.5	233.8	227.05	220.45

16	145.6	242.72	235.52	228.48
17	154.7	251.64	243.99	236.51
18	163.8	260.56	252.46	244.54
19	172.9	269.48	260.93	252.57
20	182	278.4	269.4	260.6
21	191.1	287.32	277.87	268.63
22	200.2	296.24	286.34	276.66
23	209.3	305.16	294.81	284.69
24	218.4	314.08	303.28	292.72
25	227.5	323	311.75	300.75
26	236.6	331.92	320.22	308.78
27	245.7	340.84	328.69	316.81
28	254.8	349.76	337.16	324.84
29	263.9	358.68	345.63	332.87
30	273	367.6	354.1	340.9
31	282.1	376.52	362.57	348.93
32	291.2	385.44	371.04	356.96
33	300.3	394.36	379.51	364.99
34	309.4	403.28	387.98	373.02
35	318.5	412.2	396.45	381.05
36	327.6	421.12	404.92	389.08
37	336.7	430.04	413.39	397.11
38	345.8	438.96	421.86	405.14
39	354.9	447.88	430.33	413.17
40	364	456.8	438.8	421.2
50	455	546	523.5	501.5
60	546	635.2	608.2	581.8
70	637	724.4	692.9	662.1
80	728	813.6	777.6	742.4
90	819	902.8	862.3	822.7
91	828.1	911.72	870.77	830.73
92	837.2	920.64	879.24	838.76
93	846.3	929.56	887.71	846.79
94	855.4	938.48	896.18	854.82
95	864.5	947.4	904.65	862.85
100	910	992	947	903
150	1365	1438	1370.5	1304.5
200	1820	1884	1794	1706
300	2730	2776	2641	2509
400	3640	3668	3488	3312
500	4550	4560	4335	4115
600	5460	5452	5182	4918

700	6370	6344	6029	5721
800	7280	7236	6876	6524
900	8190	8128	7723	7327
1000	9100	9020	8570	8130