UNIVERSITY OF MANITOBA

Final Design Report

MECH 4860

Department of Mechanical Engineering

Motor Coach Industries
Station 19 Hardware Fixtures

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Dear Reader

Please find enclosed the Final Design Report prepared by our Design Team, Group 15, for Hardware Fixture Improvements at Motor Coach Industries' manufacturing facility in Winnipeg, Manitoba, Canada. The Final Design Report presents the Design Team's Final Hardware Fixture designs and meets all criteria set by the final engineering design course MECH 4860. This report also serves to explain how the fixtures are to be utilized during the front suspension assembly process.

This report outlines the objectives and needs of the project, as well as the internal and external search methods that the Design Team utilized to gather information on the project. The design process included concept generation, and concept selection based on criterion and weighted scoring criteria for Hardware Fixture Layout, Hardware Fixture Stacking and Hardware Fixture Storage and was used to select the final Hardware Fixture design. The design team designed a total of five Hardware Fixtures for the front suspension assembly process including an instruction set and two recommendations for improvements within the assembly station.

Group 15 would like to thank course instructor Dr. Paul Labossiere, our advisor Dr. Juan Abello and our contacts at MCI, Chen Shesaf and Mark Yarovoy for the guidance and assistance provided to the team for the duration of the project as well as for providing the Design Team with the opportunity to gain valuable experience upon graduation.

Best Regards,

Devin Draward

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EXECUTIVE SUMMARY

Group 15 was tasked with the design of hardware fixtures for the front suspension assembly process in station 19 at Motor Coach Industries. The need for a hardware fixture design arose from assembly errors stemming from the current presentation of hardware and the lack of a hardware tracking system within the workstation. The design team was tasked with analyzing/determining areas within Station 19 that would benefit from the use of hardware fixtures as a means of organization and tracking of the hardware. The design team was also tasked with the final design of the hardware fixtures including CAD models for each hardware fixture identified for the use of 3D printing.

The client specified that the hardware fixture design must error proof the front suspension and steering gear installation by ensuring that only the correct type and correct amount of hardware is installed on the coach. The client also specified that the hardware fixtures should be stackable, for ease of storage within the Station 19. The Design Team identified five areas where the use of hardware fixtures would be appropriate, and identified several other problem areas within the workstation where the design team provided a recommendation for improvement, as requested by MCI.

The design team developed five hardware fixtures, for: the right and left independent front suspension assembly, the steering gear assembly, the front axle cart, and the mitre box within Station 19. The hardware fixtures allow the assembly operators to account for all of the hardware installed on the coach and also ensure that only the proper hardware will be installed. All fixtures were developed with consideration to appearance and hardware layout. The fixtures are also equipped with an ergonomic handle for stacking capabilities and reliefs for easy removal of hardware. CAD models and engineering drawings have been created for each individual hardware fixture and handle. Finally, the Industrial Technology Center was selected to manufacture the five hardware fixtures for a total of $5700 CAD.

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1.0 INTRODUCTION

Motor Coach Industries, in partnership with the Department of Mechanical Engineering at the University of Manitoba, has tasked the Design Team with the design of hardware fixtures for the assembly process within Station 19 on the J Coach assembly line in the Winnipeg, Manitoba Manufacturing Plant. .As such, the following section serves to outline the steps that the Design Team undertook to gain a thorough understanding of the Client, and the Client's desires. Provided within this section is a brief background on the Client, Motor Coach Industries, along with details pertaining to Station 19, in which will be the focus of this project.

1.1 THE COMPANY

Motor Coach Industries (MCI), known for producing high quality intercity coaches, was founded in 1933 with headquarters located in Des Plaines, Illinois [1]. MCI has two manufacturing plants, one in Winnipeg, Manitoba and the other in Pembina, North Dakota. Within the Winnipeg facility, the D Coach and J Coach lines are manufactured.

1.2 THE STATION

In the Winnipeg, Manitoba manufacturing plant, the J Coach begins as purchased raw materials, and the plant itself is then responsible for the full manufacture of the coach. This means that the J Coach line completes the full assembly and testing verification of the coach itself, ensuring it is road worthy and meets customer needs. Within the J Coach assembly line, there are a multitude of different assembly steps and processes contained in unique work cells, referred to as stations. One such station is Station 19 for the J Coach assembly line, shown in Figure 1. Station 19 is where the installation of the front suspension and steering gear assemblies take place.

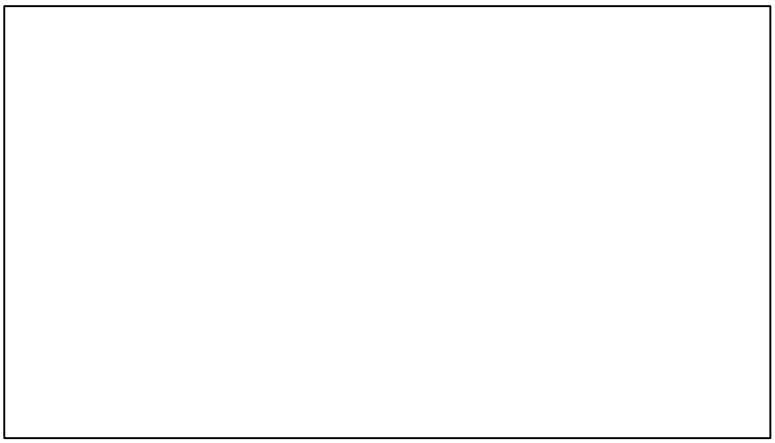


Figure 1: Main suspension assembly within Station 19 [2].

In Station 19, the front independent suspension assemblies on both the right and left sides of the coach are installed. Additionally, the steering gear is installed. In order to complete this process there is unique tools, hardware and fixtures within the station that the assembly line operators utilize to complete the assembly process. These items are located in designated spaces within Station 19 and items one through eight will be referred to as the areas of importance in Station 19. These areas of importance create the general layout of Station 19 and can be seen in Figure 2.

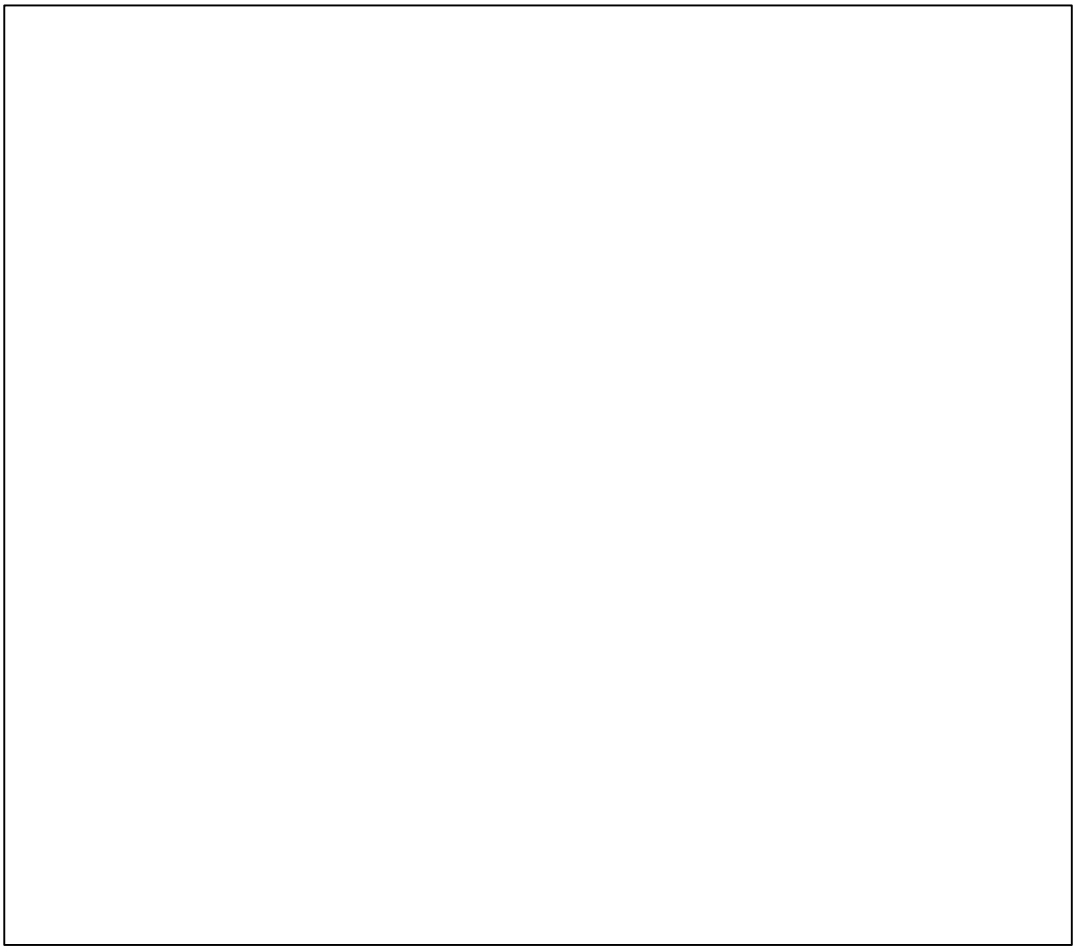


Figure 2: Layout of Station 19 (not to scale) [3].

Currently, MCI uses the areas of importance identified within Figure 2 to organize and store hardware, assembly tools and installation fixtures for the right and left independent suspension and steering gear assemblies. The functions and purpose of each area of interest is explained in Section 1.2.1.

1.2.1 AREAS OF INTEREST

The eight areas of interest in Station 19 are explained in detail within this section.

1. **Front Suspension Fixtures:** The front axle assemblies are placed on the front suspension fixture from the shipping zone using a crane. This fixture is then rolled over to the bus and is used to aid in the installation of the axles on to the J Coach. The front axle fixtures can be viewed in Figure 3.

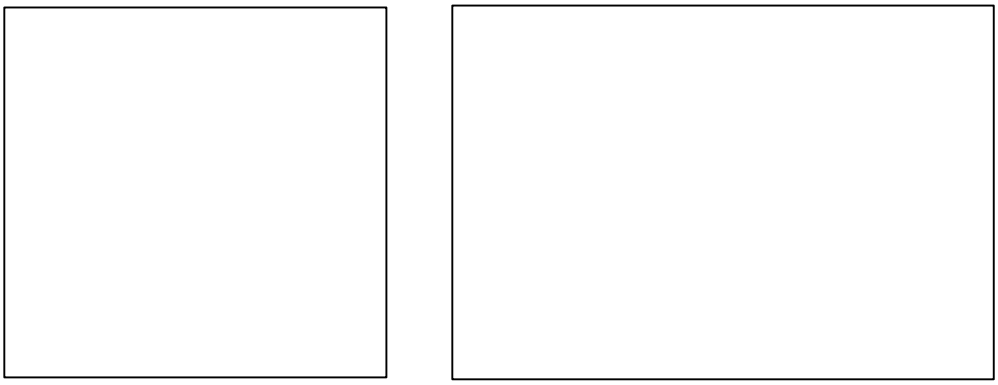


Figure 3: Front independent suspension fixtures [4].

Existing Front Suspension Hardware Fixture: MCI has implemented a hardware fixture for the front suspension assembly that is used for organizing the hardware required for installation. The operators place the required hardware into the fixture, and the assembled hardware fixture is then placed on the front suspension fixture before it is wheeled towards the coach for assembly. The existing hardware fixture can be viewed in Figure 4.

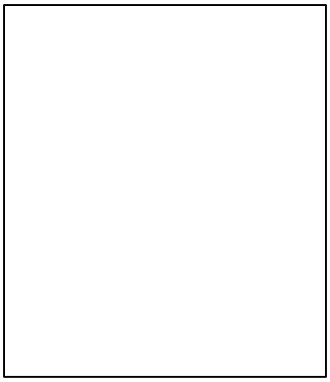


Figure 4: Front independent suspension hardware fixture [5].

2. **Steering Prep Table:** The steering linkages are brought to this table and prepared for installation. This is where the ball joints and steering arm specifications are verified prior to installation. In the current practice, the required fasteners are stored loose on the table. The steering prep table can be viewed in Figure 5.

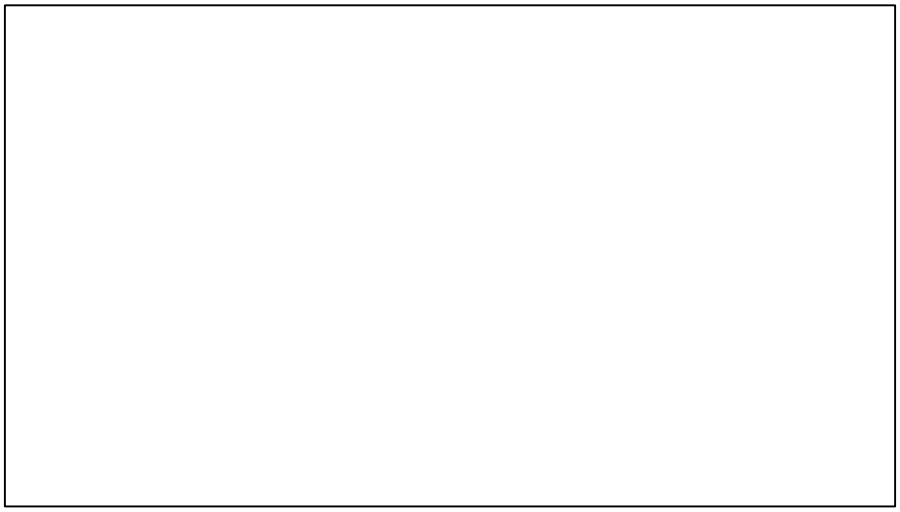


Figure 5: Steering prep table [6].

3. **Steering Gear Fixture:** The steering gear assembly is placed on the steering gear fixture from the shipping zone using a crane. This fixture is then rolled over to the bus and is used to aid in the installation of the steering gear on to the J Coach. The steering gear fixture can be viewed in Figure 6. Again, the required fasteners are stored loose on the fixture.

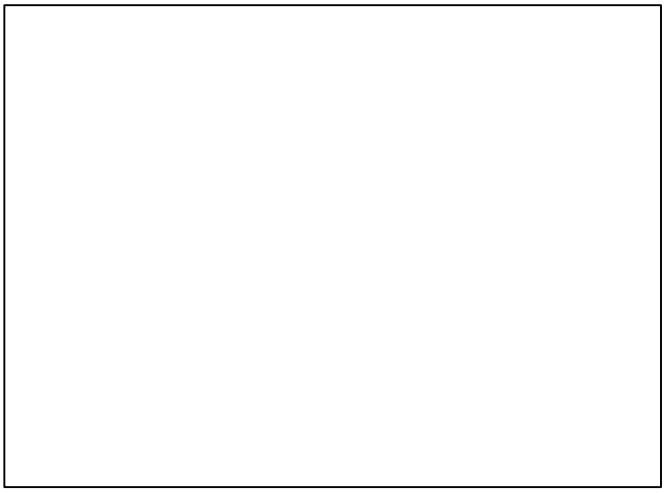


Figure 6: Steering gear fixture [7].

4. **Primary Tool Cart:** The primary tool cart is used for general tool storage and can be viewed in Figure 7. The logbook for the steering gear, suspension assemblies, mitre box and steering shaft serial numbers is stored at this location.

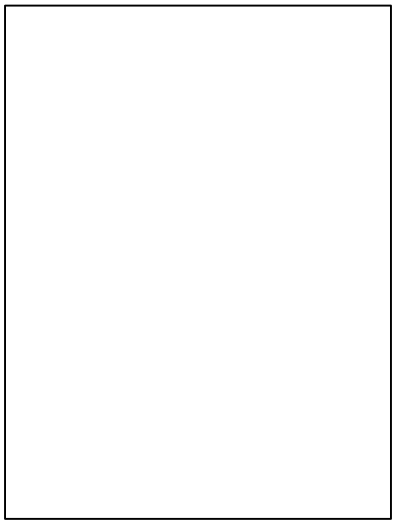


Figure 7: Primary tool cart [8].

5. **Front Axle Cart:** The front axle cart is used to store hand tools, hardware, and a hydraulic jack. The front axle cart is positioned immediately beside where the front axle is installed onto the coach. The front axle cart can be viewed in Figure 8. The sway bar, steering lines and brake lines are placed on the front axle cart prior to installation.

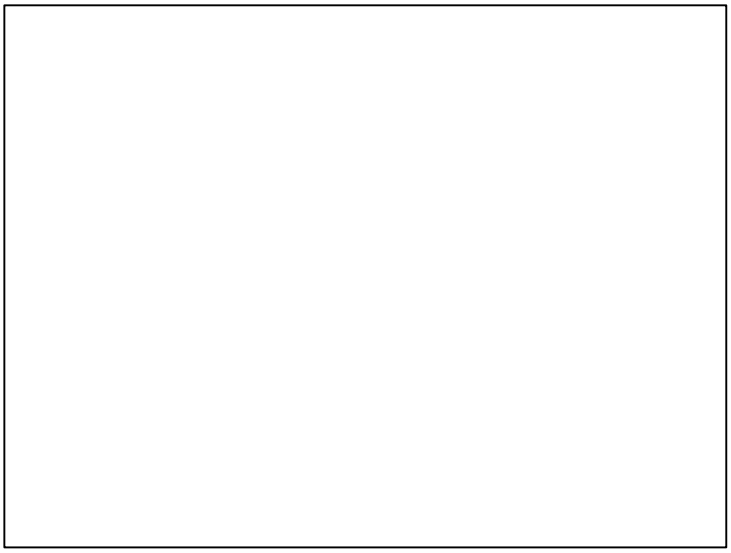


Figure 8: Front axle cart [9].

6. **Shipping Zone:** Shipping containers for the front suspension assemblies and steering gear are transported to the designated shipping zone by forklift. The shipping zone can be viewed in Figure 9.

Figure 9: Station 19 shipping zone (empty) [10].

7. **Warehouse Cart:** The warehouse cart contains secondary equipment such as brake lines, sway bars, mitre boxes, steering shafts, steering arms and fasteners. The warehouse cart can be viewed in Figure 10.

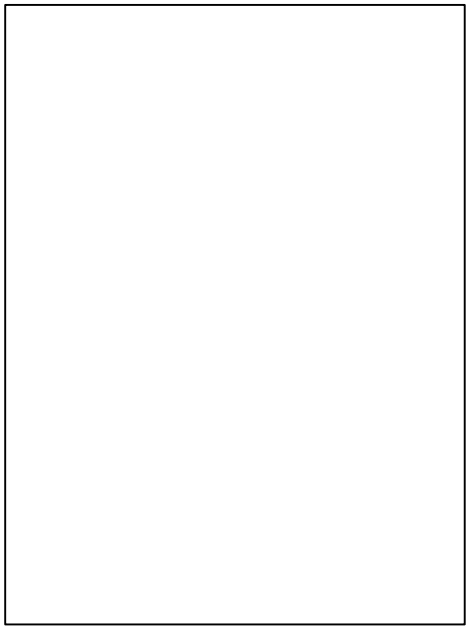


Figure 10: Warehouse cart [11].

8. **Hardware Prep Cart:** All hardware needed to complete the assembly processes within Station 19 are located in bins and labeled with the proper part number. When required hardware reaches a minimum number, the bin is simply replenished to the maximum allowable amount of hardware. This process reflects the lean manufacturing principle known as Kanban. The Kanban system does not allow for hardware tracking, nor does it allow the operators to be certain that they have installed all the hardware necessary to complete the assembly process. The hardware prep table can be viewed in Figure 11.

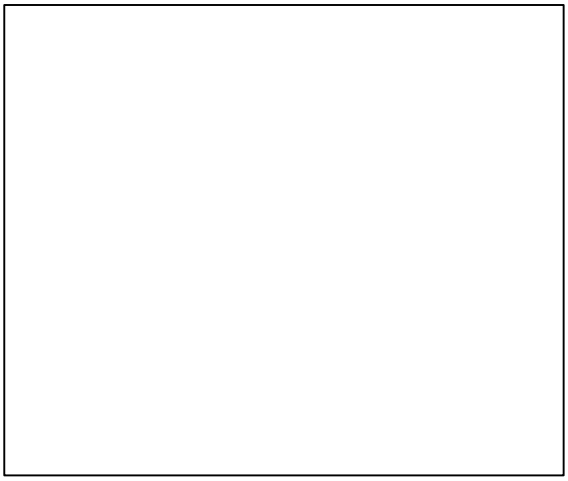


Figure 11: Hardware prep cart [12].

These are the eight main areas within Station 19 that are used to perform the installation of the front suspension and steering gear assemblies. As such, these are the eight areas that the Design Team focused on during site visits to MCI.

1.3 The Process

In order to better understand the processes and inherent challenges present during the assembly of the front suspension within Station 19, the Design Team, upon the recommendation of our contacts at MCI, observed the front suspension installation process and identified four steps pertinent to the assembly process within Station 19 [13]. Currently, assembly operators within Station 19 experience difficulties that hinder their capability to complete their job successfully. Assembling the front suspension and steering assembly requires the workers to move constantly in and around the wheel wells of the bus. All of this is repeated multiple times per day, and can cause physical fatigue.

1.3.1 Assembly Steps

The four assembly steps are explained and outlined within this section.

1. **Steering Gear Installation:** Once the steering gear assembly is fixed to the steering gear fixture, the fixture assembly is brought to the coach. As explained previously, the fasteners are stored loose on the steering gear fixture. This is the first critical front axle component installed on the Coach in Station 19. This process can be seen in Figure 12.

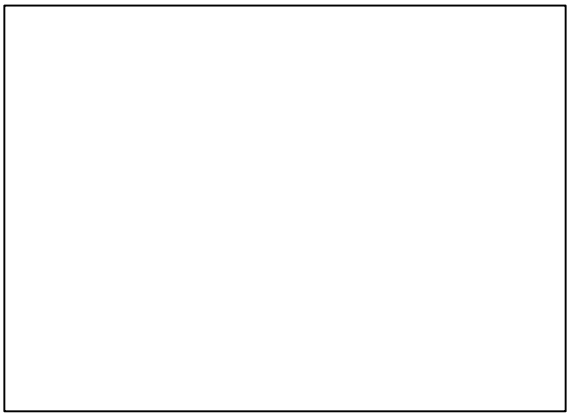


Figure 12: Steering gear installation [14].

2. **Mitre Box and Steering Shaft Installation:** Following the installation of the steering gear, the mitre box and steering shaft are transported to the coach by the assembly operators from the warehouse cart and installed. The hardware for this installation is stored loose on the front axle cart prior to being installed and torqued to specification. The steering gear and steering shaft, after installation, can be seen in Figure 13 and are identified by the orange torque seal on the fasteners of either component.

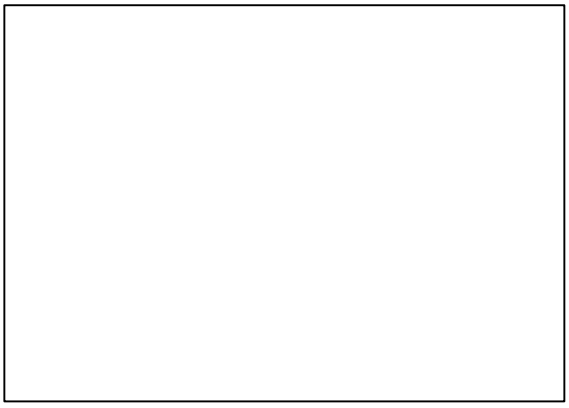


Figure 13: Mitre box and steering shaft after installation [15].

3. **Front Suspension Installation:** Both the left and right front independent suspension assemblies are installed following the mitre box and steering shaft. The front suspension fixtures and existing hardware fixtures are utilized for this operation, and the assembly operators have noted that the hardware fixture itself is difficult to pick up and that the hardware is difficult to remove. It is to be noted that both the sway bar and air spring assemblies are installed at this time as well. Additionally, the front axle cart is utilized to store the hardware for the sway bar until installation. The front suspension assembly can be seen in Figure 14.

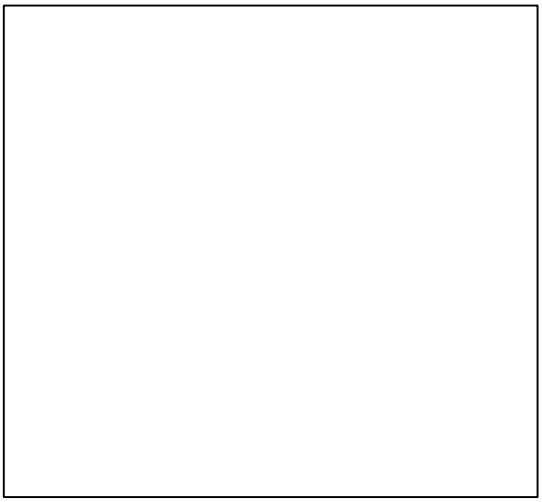


Figure 14: Front suspension installation [16].

4. **Steering Arm Installation:** Finally, the steering arms (tie rods) are installed onto the coach after their length specifications have been verified using the jig on the steering prep table. The fasteners for the steering arms are brought to the coach individually by the assembly operators. Additionally, all steering and brake lines are checked for proper installation and fasteners are checked to ensure their torque seal is present. Finally, the interior steering shaft is installed into the steering column at this time.

The four steps outlined above serve to provide a background on the assembly process within Station 19, as observed by the Design Team. It is to be noted that this assembly process takes approximately two hours and fifty minutes to complete [17].

1.4 OBSERVATION SUMMARY

Problems associated with current processes in Station 19 (specifically the eight areas of interest) and the four critical process steps observed by the Design Team and stated by MCI, are summarized in Table I. These observations serve to provide the basis for the station improvements required by MCI.

TABLE I: NOTES AND OBSERVATIONS ON STATION 19 ASSEMBLY PROCESS

Area/Process	Notes and Observations
Steering Gear Installation	Steering gear fixture contains tools and hardware with no fixed location. Hardware is placed on the fixture loosely and there is no way of tracking if all necessary hardware has been installed. A fixture is needed for all necessary hardware to ensure components have been installed.
Mitre Box and Steering Shaft Installation	Hardware is brought to the coach individually and there is no way of tracking if all necessary hardware has been installed. A fixture is needed for all necessary hardware to ensure components have been installed.
Front Suspension Installation	Existing hardware fixture is difficult to pick up and the hardware is difficult to remove. Easy to install incorrect washers into fixtures. Part numbers are not identified on the hardware fixture. Ergonomics of fixture are unsatisfactory.
Steering Arm Installation	Castle nuts for the steering arms have no fixed location on the steering prep table nor is there a hardware fixture. There is no way of identifying if the appropriate hardware has been installed.
Front Axle Cart	Cart was disorganized. There were locations for tools but there was loose hardware on the cart and there were tools such as torque wrenches with no storage location. Sway bar and steering/brake lines placed on cart prior to installation.
Primary Tool Cart	Operators keep a logbook where they write down all the part numbers from the front axle assemblies and steering gear assemblies and have to input them into the computer at a later time.
Hardware Prep Cart	Kanban system to hold hardware components is causing issues in the installation process because it is uncertain whether each necessary component has been installed for both the front axle assemblies and steering gear assembly. Different size components are difficult to distinguish from one another and end up in the same bin at times, causing confusing to the operators and potentially the wrong size hardware can be installed. Washers are separated or stuck together and the incorrect number of washers is sometimes installed. Hardware bins are placed on the table of the cart even though there is unutilized storage space on the steering prep table.

The above observations were used by the Design Team to help define the scope of the project in further discussions with MCI. Additionally, the observations were used by the Design Team to perform a preliminary brainstorming session to identify possible improvements within Station 19.

2.0 PROJECT OBJECTIVES

In addition to defining the problems that the Client is currently experiencing, a successful Design Team must also define the objectives and overall goals of the project with the Client. This is to ensure that all stakeholders of the project are in agreement with the overall direction of the project. Provided in this section is the purpose, the scope and the expected deliverables that the Design Team has defined and identified after extensive discussions with the Client.

2.1 PURPOSE

The goal of this design project is to implement solutions that address the presentation and accountability of hardware by the design of fixtures and storage space within Station 19. This will serve to improve the overall work experience for individuals who work and interact with the equipment. Adequate hardware fixtures will also ensure that all hardware is accounted for during the installation processes pertinent to Station 19.

2.2 SCOPE

The objectives of this design project are to analyze the areas within Station 19 that would benefit from hardware fixtures and to present the hardware fixtures in stackable kits for operator use and storage purposes, potentially eliminating the need for the Kanban system within Station 19 [13]. At the completion of the design process MCI will be provided with 3D CAD models, ready for manufacture and implementation, where appropriate. However, proper Engineering Drawings of the fixtures themselves are not a requirement, but exploded assemblies and general dimensions will be provided for visualization purposes.

2.3 DELIVERABLES

To achieve the objectives of this project, the Design Team has identified the following components that will satisfy the customer needs. The deliverables themselves are separated into two groupings: hardware fixtures, and recommendations for further improvement. The deliverables were identified from the observations identified in Section 1.0 in conjunction with an action plan created from a high level Failure Modes and Effects Analysis presented in Appendix A

2.3.1 HARDWARE FIXTURES

The following hardware fixtures have been identified by the Design Team as requirements of this design project. These fixtures are *must have* items requested by the client in order to error proof the assembly process within Station 19 and complete 3D CAD models must be provided for each.

1. Front Independent Suspension Hardware Fixture – Left Hand Side
2. Front Independent Suspension Hardware Fixture – Right Hand Side
3. Steering Gear Assembly Hardware Fixture
4. Front Axle Cart Hardware Fixture
5. Mitre Box Hardware Fixture

2.3.2 RECOMMENDATIONS

The Client has requested that this project focus on error proofing the assembly process through the design of hardware fixtures for Station 19. However, the Client has also requested the Design Team provide the following recommendations.

2.3.2.1 CART RECOMMENDATION

The Design Team has addressed that the front axle cart could be organized in a more convenient manner for the assembly operators as the front axle cart is utilized for tool, hardware and component storage. Currently, the carts utilized within Station 19 are standardized and difficult to modify. The client has indicated that a product could be researched and recommended for implementation, if it is found that the product offers greater ease of adjustability for the assembly operators.

2.3.2.2 FIXTURE STORAGE RECOMMENDATION

The Design Team will also provide a recommendation for a storage solution for the designed hardware fixtures to address the issue of storing and organizing up to fifteen hardware fixtures. The solution will focus on utilizing any and all underutilized space prior to the implementation of additional carts for storage, whilst considering the importance of an ergonomic design for the assembly operators. Concepts for the storage recommendation will be evaluated but only a conceptual model will be provided.

2.3.3 INSTRUCTIONS

The Design Team must provide an overview that explains where the hardware fixtures are to be assembled, placed and stored (according to the storage recommendation) within Station 19

3.0 SPECIFICATIONS

The essential criterion for any design change within this project is that it must error-proof the current assembly process implemented by MCI in Station 19, and eliminate the chance that a worker may incorrectly install hardware during the assembly process. This includes both the installation of the incorrect parts in the wrong locations, and also the incorrect quantity of the correct parts in the correct locations. The client also desires that the proposed designs consider the importance of ergonomics in the workplace. As mentioned in Section 1.3, part of assembling the front suspension and steering assembly requires the workers to move constantly in and around the wheel wells of the bus. All of this is repeated multiple times per day, and can cause physical fatigue. Thus, all changes to the assembly process shall add convenience for the assembly operators. As such, the customer needs and the metrics determined to meet the basic client requirements discussed above can be found within this section of the report.

3.1 DESIGN NEEDS

The implementation of the solutions themselves must function properly in order to be utilized by the assembly workers and not be bypassed during the assembly process. Essentially, the Design Team needs to present and store the hardware to the assembly operators in a simple and easy to understand layout that will improve their efficiency in performing the assembly process and eliminate chances of errors. The design needs can be seen in Table II.

TABLE II: DESIGN NEEDS

#	Need	Importance
1	Changes need to improve ergonomics (user friendliness)	3
2	Process needs to be efficient	4
3	Fixtures need to be easy to understand	5
4	Any new additions to Station 19 need to be portable or located out of the way for/during the process of moving busses between stations	5
5	Any added components need to function normally after repeated dropping, impact and prolonged usage	4
6	Any added changes need to fit within the existing work areas	5
7	New components must adhere to safety protocols	5

#	Need	Importance
8	Carts are easy to modify (recommendation)	4
9	Design changes are affordable	3
10	Only the correct quantity of parts can be loaded into fixture	5
11	Only the correct parts fit in fixture	5
12	Parts are easy to remove from the fixture	5
13	The fixture does not add to workload	3
14	Makes assembly more efficient	4
15	Makes the work area more organized	5
16	Fixture organization, stacking, storage and instructions are simple to follow and maintain	5
17	Light weight	5
18	Easy to repair or replace	2

3.2 METRICS

Metrics were established by the Design Team to aid in establishing baseline specifications of the process improvements proposed by the Design Team. The metrics are used to establish what the deliverables must satisfy in order to meet the client's needs. The specific metrics established by the Design Team for this project can be seen in Table III. Table IV presents the relation between the customer needs and the metrics for this design project.

TABLE III: METRICS

Metric #	Needs #'s	Metric	Imp	Units
1	1.2.3,12,13,14,15,16	Time to install component	1	s
2	7,8	WSHR 217/2006 [18]	5	Binary
3	2,10,11,14,16	Hardware capacity/count	4	List
4	2,10,11,14,16	Tool capacity/count	4	List
5	9,16,18	Manufacturing cost	5	$ CAD
6	1,2,10,11,17	Total mass	2	kg
7	1,2,6,10,11,17	Total area	5	mm^2
8	1,2,3,6,12,13,14,15,16	Preparation time	3	s
9	5,16	Useable cycles	5	k-cycles
10	1,3,4,5,6,7,9,12,13	Design acceptance by end user	5	subjective

TABLE IV: NEEDS VERSUS METRICS

	Metric	1	2	3	4	5	6	7	8	9	10
	Need	Time to install component	WSHR 217/2006 [15]	Hardware Capacity/Count	Tool Capacity/Count	Manufacturing Costs	Total Mass	Total Area	Preparation Time	Useable cycles	Design acceptance by end user
1	Changes need to consider/improve ergonomics (user friendliness)	*					*	*	*		*
2	Process needs to be efficient	*		*	*		*	*	*		
3	Process needs to be easy to understand for new workers	*							*		*
4	Any new additions to the station need to be portable or out of the way for/during the process of moving buses between stations										*
5	Any added components need to function normally after repeated dropping impact									*	*
6	Any added changes need to fit within the existing work areas							*	*		*
7	Safety protocols and safety considerations need to be addressed		*								*
8	Any new components need to be safe		*								
9	Implementation of design needs to be affordable					*					*
10	Only the correct quantity of parts can be loaded into fixture			*	*		*	*			
11	Only the correct hardware fit into the fixture			*	*		*	*			
12	Hardware is easy to remove from the fixture	*							*		*
13	The fixture does not add to workload	*							*		*
14	The fixture makes the task more efficient	*		*	*				*		
15	The fixture makes the work area more organized	*							*		
16	The fixture organization is simple to follow and maintain	*		*	*	*			*	*	
17	A movable fixture should be light if it is to be carried						*	*			
18	Easy to repair					*					

4.0 Constraints & Limitations

The constraints and limitations affect the freedom that the Design Team has in implementing solutions that meet the needs of the client, additionally they serve to outline the firm requirements that the deliverables must meet. The constraints and limitations identified below were created through discussion with our contacts at MCI, and the assembly operators within Station 19 [13, 19].

4.1 Standards and Safety

Any design changes that the team proposes must serve to improve the existing process and also satisfy all the requirements of our client, MCI. These requirements include MCI's production floor standards, including both safety requirements and protocols for the workplace, and also their general space layout for the workstations [13].

4.2 Assembly operator Preferences

The Design Team initially had the option of removing the hardware bins from the current location on the hardware prep cart and creating a process where hardware fixtures are filled outside of the station and brought to the workspace as required. However, the Design Team will not be removing the hardware bins, as the assembly operators prefer to prepare the hardware and fixtures themselves. Furthermore, there is sufficient dwell time within the station to allow for the assembly operators to prepare the hardware fixtures prior to component installation [19].

4.3 Hardware Storage & Identification

The client has also clarified that it is not the team's responsibility to develop any hardware routing plans or schedules, as the Design Team will be solely responsible for only the presentation of hardware used in the front steering and suspension assembly in Station 19. The Design Team will also not be in the position to change any of the current hardware used in the assembly process. However, the fixtures that the Design Team produces must allow for stacking within the workstation and must be labeled to allow for proper identification.

4.4 PORTABILITY

During the assembly of the steering axles and steering gear, the workers require that their equipment be movable. Thus, any hardware fixtures that are created must be light enough to carry and any recommendations for the front axle cart must adhere to these portability requirements needed by the operators.

4.5 STATION LAYOUT

Any new components must also fit into the existing work environment and not change the footprint of the current workspace. Additionally, any dead space present in Station 19 must be utilized prior to implementing new carts for the purpose of hardware storage.

4.6 MANUFACTURING

MCI has indicated a desire to receive a final design model using 3D CAD software and has recommended that the fixtures be fabricated using a 3D printing processes [13]. Additionally, as MCI uses the CAD suite Unigraphics as their software of choice, all of our final design submissions must be formatted and accessible for future use by the Engineering Department at MCI. MCI has suggested that the Industrial Technology Centre (ITC), located in Winnipeg, Manitoba, manufacture the hardware fixtures [20]. Note that although Engineering Drawings are not a requirement for this project, the Design Team will provide exploded assemblies and general dimensions for visualization purposes.

4.7 COST OF IMPLEMENTATION

A firm final cost value or budget for the project has not been established, as only CAD models are the required deliverables [13]. Moving forward, the Design Team has determined that given the nature of the workstation, any new fixtures or components are at risk of being damaged or dropped during normal workplace operation. This was confirmed by interviewing workstation employees and first hand observation by our team. Therefore, design changes must consider the cost of repairing or replacing fixtures and components either due to damage or as they near the end of their life cycle. Replacement must also be done in a timely manner so as to minimize the effect on the production line; 3D printed fixtures will allow for fast manufacturing and replacement of damaged or lost fixtures.

5.0 RESEARCH RESULTS

The Research Results section of the report outlines the teams internal and external search results related to the deliverables indicated in Section 2.0, which include the design of the hardware fixtures, recommendations concerning a storage location for the hardware bins and hardware fixtures, recommendations for the front axle cart organization issues and, finally, an instruction set on how the hardware fixtures are to be utilized. Included in the external search results are discussions with the client and assembly line operators of Station 19, including information received through two questionnaires, located in Appendix B, as well as an online search to find any relevant literature. Included in the internal search results are brainstorming sessions conducted by the Design Team.

5.1 HARDWARE FIXTURE RESEARCH

The first part of our search for the hardware fixtures included discussion with the client as well as creating a questionnaire for the engineers and assembly line operators. The general feedback received from the questionnaire was that they would like to keep the hardware bins within Station 19, instead of the original request of moving the bins into a different area, as the assembly line operators are the most familiar with the hardware part numbers. It was also stated that instead of having only one hardware fixture for each component, they would like three to ensure there is enough hardware available for three coaches to go through Station 19, and they would like the fixtures to be stackable for ease of storage and handling.

There are few relevant articles on fixtures that are used to hold hardware, as these types of devices are typically produced on a small scale, completed in-house and not sold publicly. However, the Design Team was able to find relevant literature on “hardware boxes” which gave us a good indication of what the preferred orientation for holding hardware/small tools is. Through our research we found that the preferred orientation is to lay the hardware/tool horizontally in its fixed location [21]. This ensures the hardware/tools are secure, acquires the least amount of vertical space, making it compact, and allows for easy storage.

The next step was to conduct a team brain storming session. The Design Team decided it would be beneficial to generate ideas for a general layout and organizational strategy that all five hardware fixtures would follow. The concepts described below represent the current hardware fixture orientation, and a brainstorming session on how to improve the current fixture through options 2 and 3; these concepts are also illustrated in Table V and will be further analyzed in the concept selection phase of the report.

Option 1: Current Fixture Orientation

- Fasteners are placed horizontally in the fixture
- Nuts and washers are placed vertically in the fixture
- The hardware fits exactly into the fixture, making it difficult for the hardware to be removed
- The washers are placed vertically into the fixture, accounting for the correct washer width, but the correct washer diameter cannot be verified.

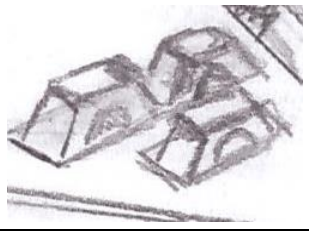
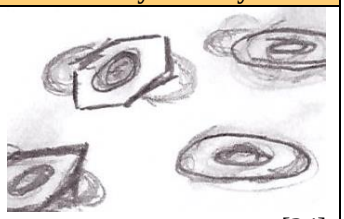
Option 2: Vertical Orientation

- Fasteners are placed vertically in the fixture
- Nuts and washers are placed vertically in the fixture
- There is potential to verify length of fasteners with this type of orientation
- It will be easier to remove the hardware if it is placed vertically
- Size of the fixture would have to be large to support the fasteners
- This type of fixture is not as ergonomic as option 1

Option 3: Horizontal Orientation/Hybrid

- Fasteners are placed horizontally in the fixture
- Nuts and washers are placed horizontally in the fixture
- This type of fixture will ensure that only the right width and diameter of washers will be installed
- A mechanism for easier release for the horizontally placed hardware would be implemented to improve option 1

TABLE V: HARDWARE FIXTURE ORIENTATION OPTIONS

Current Layout	Vertical Layout	Horizontal/hybrid Layout
 [22]	 [23]	 [24]

5.2 HARDWARE RESEARCH

The Design Team also engaged in discussions with the engineers and assembly operators at MCI to identify the hardware that had to be contained within the five hardware fixtures. Additionally, the Design Team also identified the locations in which the assembly operators would place the hardware fixtures during the assembly process in Station 19.

5.2.1 HARDWARE AMOUNTS

A site visit was conducted and the assembly operators obtained hardware samples for the Design Team [19]. The assembly operators also aided the Design Team in the identification of the hardware on the assembly instructions. This process ensured that the engineering team, assembly operators, and Design Team knew what hardware would be contained in each fixture. As such, the hardware and part numbers identified by the Design Team is summarized as follows. A general hardware description has also been provided.

1) Front Independent Suspension Hardware Fixture – Left Hand Side

TABLE VI: FRONT INDEPENDENT SUSPENSION HARDWARE - LEFT

Part Number	Description	Weight (g)	Amount
1901-2286	M18X1.5X70 Screw	187	4
1902-0405	Lock washer; M18; inner diameter: 19.5mm, outer diameter: 29 mm; thickness: 3.4mm.	9	12
1903-0781	M18 Nut; outside diameter: 27mm; thickness 15mm	48	8
Total Mass of Left Hand Suspension Hardware		1240	24

2) Front Independent Suspension Hardware Fixture – Right Hand Side

TABLE VII: FRONT INDEPENDENT SUSPENSION HARDWARE - RIGHT

Part Number	Description	Weight (g)	Amount
1901-2287	M18X 1.5X70 Screw	187	4
1902-0404	Lock washer M18; inner diameter: 19.5mm, outer diameter: 29 mm; thickness = 3.4mm.	9	12
1903-0781	M18 Nut; outside diameter: 27mm; thickness 15mm	48	4
1901-2286	M18X1.5X200 Screw	465	4
Total Mass of Right Hand Suspension Hardware		2908	24

3) Steering Gear Assembly Hardware Fixture

TABLE VIII: STEERING GEAR ASSEMBLY HARDWARE

Part Number	Description	Weight (g)	Amount
1901-2172	M20X100 Screw	311	4
1902-0414	Lock washer M20; inner diameter: 21.4mm, outer diameter: 30.7mm; thickness: 3.4mm.	9.2	8
1903-0775	M20X1.5 Nut; outside diameter: 30mm; thickness: 16mm.	65	4
Total Mass of Steering Gear Assembly Hardware		1577.6	16

4) Mitre Box Hardware Fixture

TABLE IX: MITRE BOX HARDWARE

Part Number	Description	Weight (g)	Amount
1901-1975	M12X50 Screw; Din 931.	60	4
1902-6004	Washer-Flat; M12	7	8
1903-6083	Lock Hex Nut; M12	20	4
Total Mass of Mitre Box Hardware		376	16

5) Front Axle Cart Hardware Fixture

TABLE X: FRONT AXLE CART HARDWARE

Part Number	Description	Weight (g)	Amount
1901-1536	1/2-13 UNC X 1.5 screw-cap	52	4
1903-0497	Nut-FLG 1/2-13 (Yellow Zinc Plating)	22	4
1903-0641	Nut-Hex slotted, 3/4 – 16 UNF	63	2
192-284	Washer-Flat, 1/2 steel, ZN plated	9	2
193-188	NYLock Nut 1/2 – 13 UNC, ZN PL	24	2
197-26	Cotter Pin; Diameter: 1/8”; Length: 1-3/8”.	7	4
No number	Cotter pin (larger than 197-26)	8	4
1201-1303	Bushing; outer diameter: 17mm; inner diameter: 14mm; height: 28mm.	16	2
1101-1094	M10X50; steering bolt	41.2	4
1101-1083	Lock nut; M10; thickness: 9.85mm	11.3	4
Total Mass of Front Axle Cart Hardware		790	32

5.2.2 FIXTURE PLACEMENT

The Design Team also had the assembly operators indicate locations where the hardware fixtures would be placed [19]. This was performed during the same site visit in which the hardware samples were obtained and the Design Team took measurements as required. This process allowed the Design Team to ensure that any space constraints were identified so that the hardware fixtures could be properly utilized within Station 19.

1) **Front Independent Suspension Hardware Fixtures (Left and Right)**

   The left and right hardware fixtures have identical space requirements, as outlined by the red triangles in Figure 15. The red triangles identify the constrained area that the left and right front independent suspension hardware fixtures must fit in.

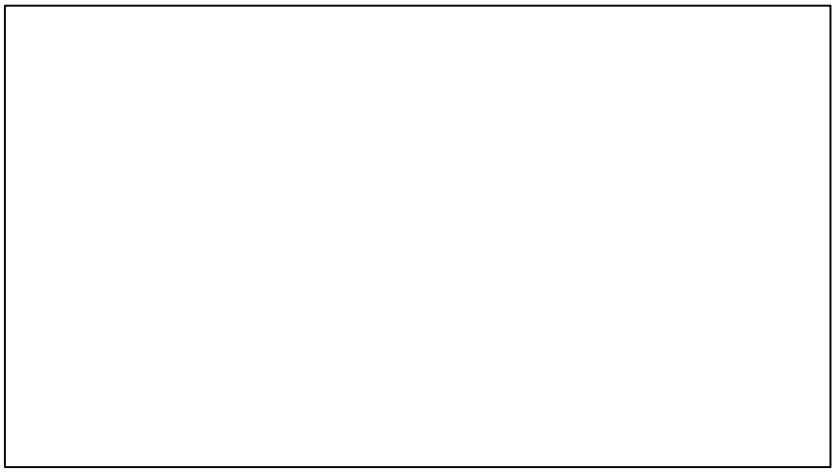


Figure 15 Intended front independent suspension hardware fixture location (Left and Right) [25].

For added clarity, a dimensioned sketch of the constrained area that the left and right front independent suspension hardware fixtures must fit in can be seen in Figure 16.

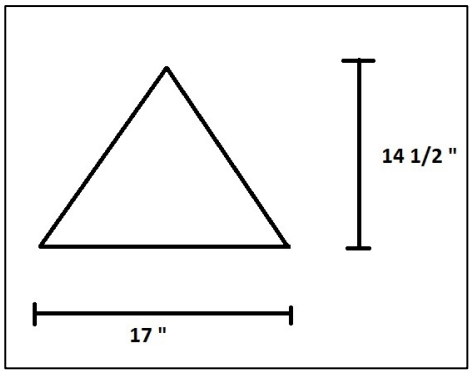


Figure 16 Dimensions of the left and right fixture location [26].

2) Steering Gear Assembly Hardware Fixture

The red outline on the steering gear fixture in Figure 17 indicates the location where the steering gear hardware fixture is to be placed during the assembly process. The indicated footprint is approximately 12" x 12," which will provide sufficient space for the fixture. It is to be noted that the battery charger currently on the fixture is not placed at that location during the assembly process in Station 19.

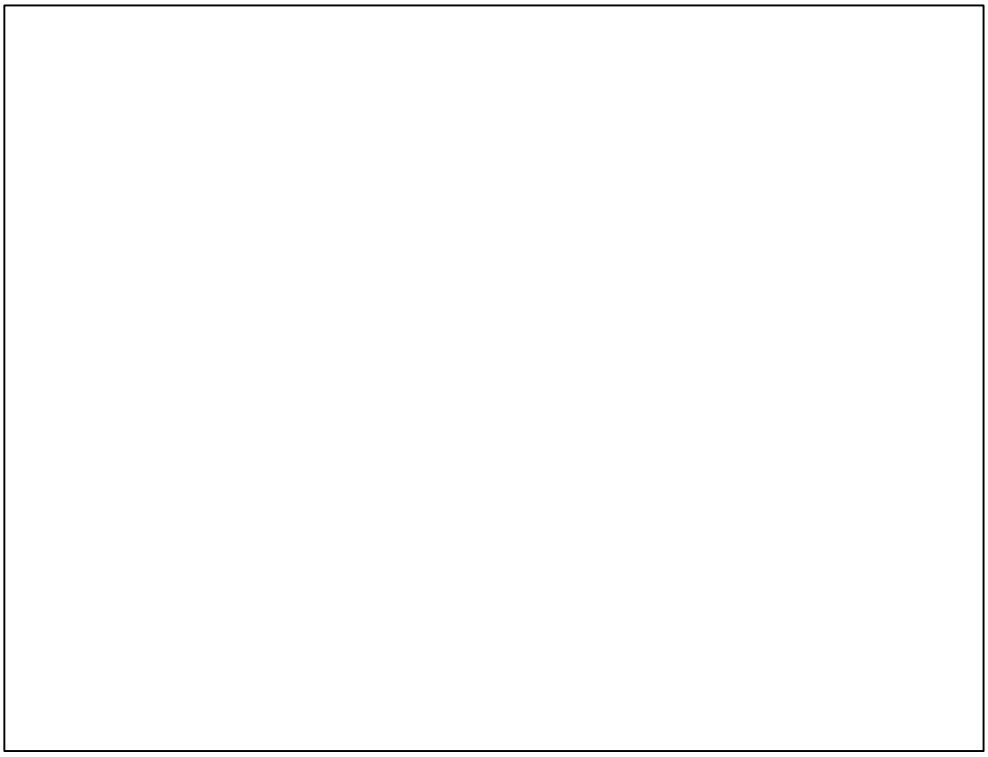


Figure 17 Steering gear hardware fixture location [27].

3) Front Axle Cart Hardware Fixture

The location for the front axle cart hardware fixture can be seen as the red rectangle in the sketch provided in Figure 18. The dimensions of the constrained space are approximately 6” x 23.75,” and the steering gear assembly hardware fixture must fit within this space. Furthermore, the hardware fixture for the front axle cart will replace the soft rubber part bins currently in use on the front axle cart.

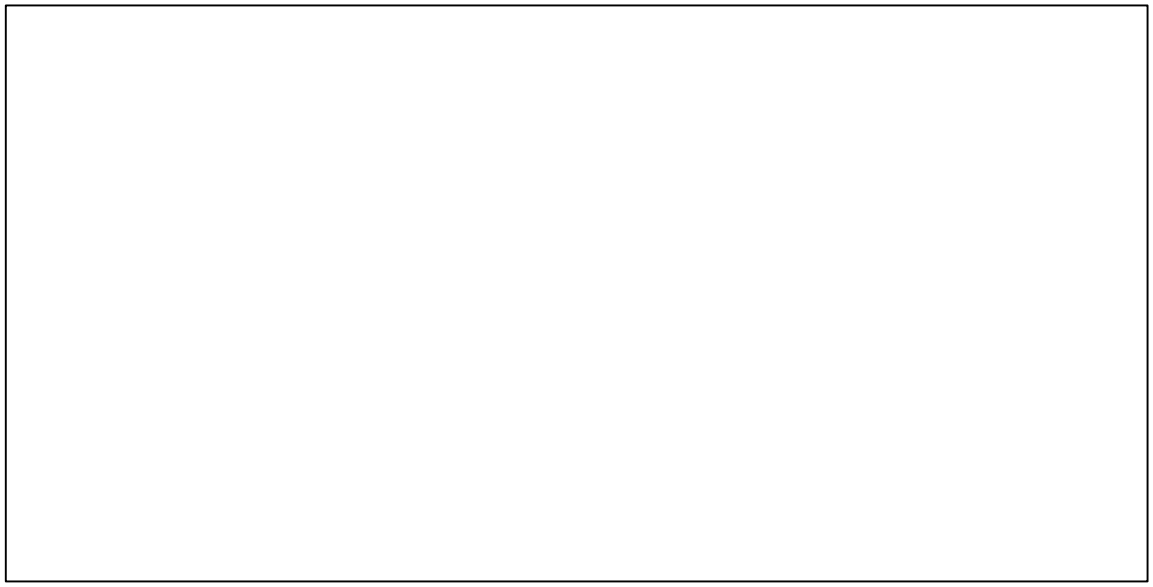


Figure 18 Front axle cart hardware location [28].

4) Mitre Box Hardware Fixture

The mitre box hardware fixture is to be placed on the hardware prep table and brought to the coach when required. Due to the small amount of hardware that needs to be accounted for with this fixture, there are no dimensional constraints that the Design Team identified.

5.3 STORAGE RESEARCH

Through initial discussion with the client as well as results through the questionnaire, it was requested that the hardware bins that are located on the surface of the hardware prep table be moved to the blue steering prep table shown in Figure 19 [19]. Additionally, the hardware fixtures are to be stored in the same location. It was mentioned on the questionnaire that the surface of the hardware prep table (where a portion of the hardware bins are currently located) is cluttered and there is no room to work. The removal of the hardware bins to the steering gear prep table, which is currently identified as open space within the work area, will provide a location for the assembly line operators to prepare the hardware fixtures.

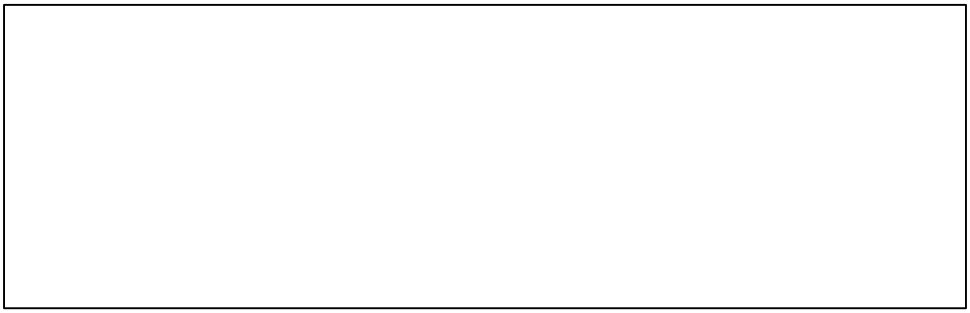


Figure 19 Hardware bins (green) to be moved to the steering prep table [29].

Due to the fact that we are limited on the location of where the hardware bins and hardware fixtures will be stored, the Design Team conducted some preliminary research on how these components could be stored. One option that was found was aluminum shelving and extruded tubing from the Rexroth Bosch Group [30]. The aluminum material can be used for a wide variety of applications, but for the case of the hardware fixtures and hardware bins, the aluminum material could be used to create an organized storage location. Following up with the client, the Design Team suggested that this type of aluminum material be explored to create the storage design, and it is currently being looked into by the company. The Design Team is also well aware that a cheaper option may be utilized, such as producing the storage design in house with supplies that are already on hand.

Knowing that we wanted to keep the storage design as simple as possible, the brainstorming session performed by the Design Team resulted in ideas such as the use of a simple shelf, a cabinet, rolling drawers, or a simple feature allowing the attachment of the bins and hardware fixtures to the steering prep table would all be sufficient ways of storing the hardware bins and

fixtures in this location. These ideas from the brainstorming session will be further analyzed in the concept selection phase of the report.

5.4 Front Axle Cart Research

Due to the fact that the client would only like a recommendation for the front axle cart, we will not be going into the design aspect of selecting a concept. Wanting to provide a suitable recommendation, we included the front axle cart in the questionnaire to receive feedback from the engineers and assembly line workers. Results from the questionnaire showed that the client is not satisfied with how the cart is currently organized. Currently the tools lay loose on the surface of the cart or are placed on the bottom shelf with no designated location [19]. The team conducted some research and determined that if the recommendation were not implemented through supplies in house, another option would be the aluminum shelving and extruded tubing from Rexroth Bosch Group [30].

The Design Team also conducted some preliminary brainstorming on what the recommendation should include. The use of the extruded tubing and shelving is one option, as it would completely replace the current cart and allow for proper organization. Another option would be to provide recommendations on how to improve the current layout, recommending a location for the hydraulic pump to be physically mounted, as well as provide a proper location for the wrenches and other tools lying lose on the cart, while still keeping the Styrofoam layout.

5.5 Operation Instructions

The request for an instruction set on how the hardware fixtures are to be used was first identified through the questionnaire supplied to the client. Through an initial brainstorming session we determined that the instruction set should include the following:

- Outline the order that the hardware should be installed in the fixture through assembly drawings
- Location on where and how hardware fixtures should to be stored
- Location where hardware fixtures should be placed when in use
- Any checks that need to be performed by the assembly line operators when inserting the hardware into the fixtures (for example ensuring that the part number is correct)

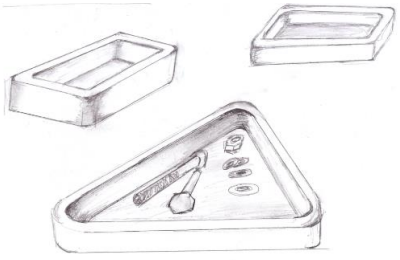
6.0 CONCEPT GENERATION

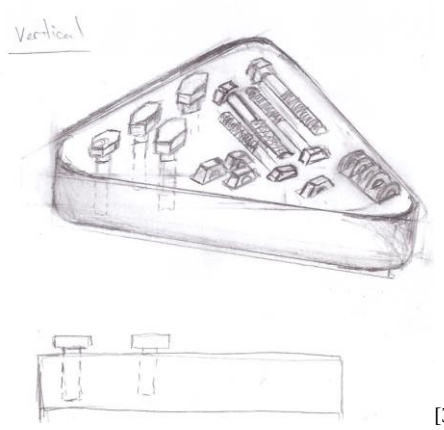
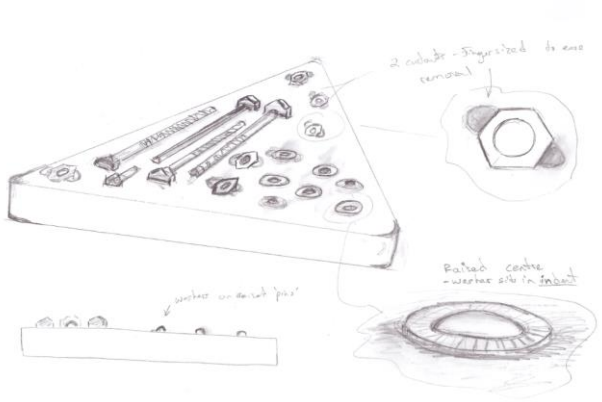
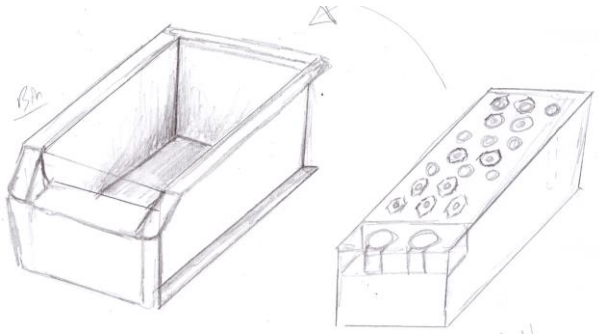
As the client needs have been determined and finalized, design concepts were developed. The following section outlines and presents an overview of the concepts that were created by the Design Team for evaluation purposes prior to concept analysis and selection. The concepts themselves have been separated into three primary areas for this report: general fixture layout, stacking methods and storage considerations for underutilized space identified within Station 19.

6.1 HARDWARE FIXTURE LAYOUTS

The first concepts that were developed involved the layout of the hardware fixtures. The layout of the hardware is a critical aspect to consider, as there are constraints that limit the size and dimensions of the hardware fixtures. As such, the Design Team identified six fixture layout concepts for consideration that make the best use of the available space within Station 19. The advantages and disadvantages of the fixture layout concepts can be seen in Table XI.

TABLE XI: HARDWARE FIXTURE LAYOUTS

Concept	Advantages	Disadvantages	Image
Store Hardware Loose on Carts	• No Cost	• Cannot verify hardware installation • Disorganized • Inconvenient	 [31]
Hardware Bowl	• Simple, low cost solution • Contains all hardware • Can be stacked	• Part Numbers are not identified • Cannot verify hardware installation • Disorganized	 [32]
Existing Hardware Fixture	• Contains all hardware • Hardware installation can be verified	• Part numbers are not identified • Cannot be stacked • Difficult to remove hardware • Easy to install incorrect hardware	 [33]

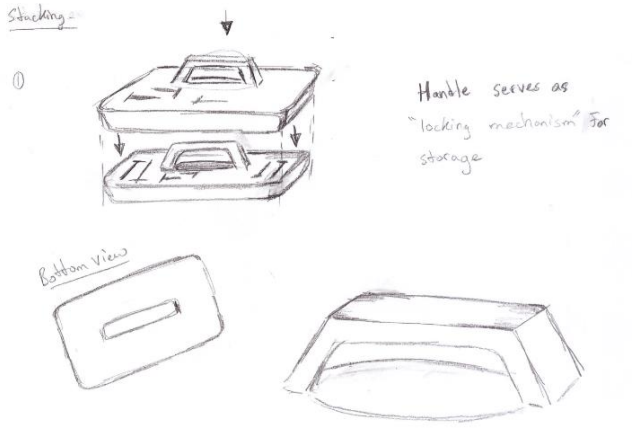
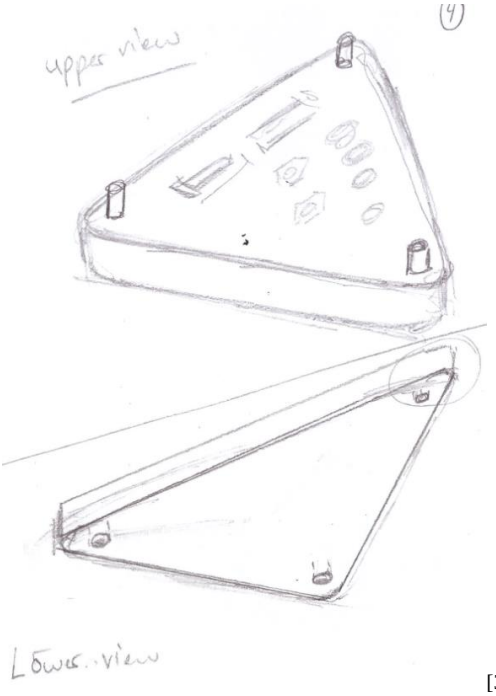
Concept	Advantages	Disadvantages	Image
Vertical Hardware Fixture	• Contains all hardware • Hardware installation can be verified • Part numbers are identified • Hard to install incorrect hardware • Easy to remove hardware	• Cannot be stacked efficiently • Large	 [34]
Horizontal/ Hybrid Fixture	• Contains all hardware • Hardware installation can be verified • Part numbers identified • Hard to install incorrect hardware • Easy to remove hardware • Smaller than Vert. Hrdwr. Fxtr. • Can be stacked	• Larger size than existing hardware fixture	 [35]
Bin Fixture	• Hardware installation can be verified • Part numbers identified • Hard to install incorrect hardware • Easy to remove hardware • Easy to store • Does not need to be stacked	• Largest concept • Difficult to contain all hardware in one fixture	 [36]

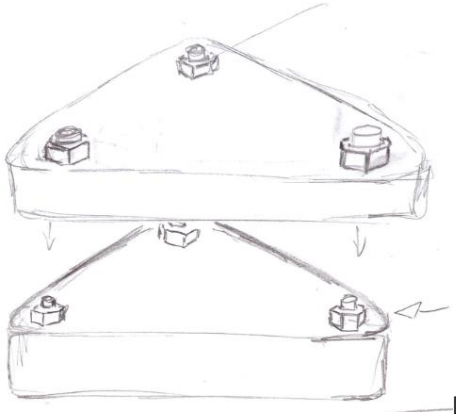
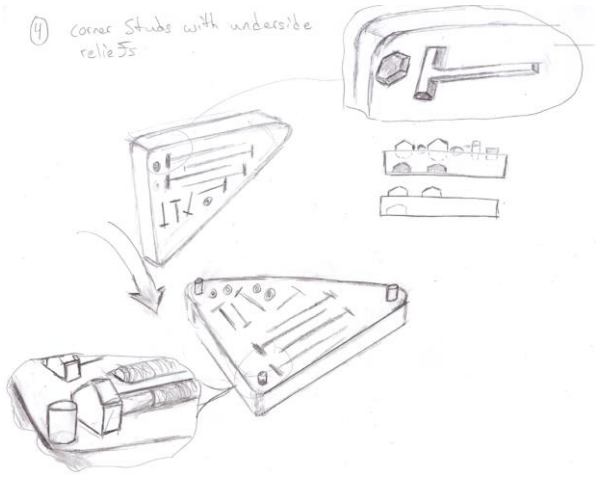
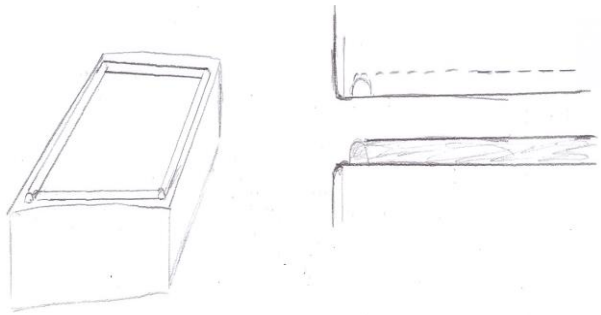
It is to be noted that the selected hardware fixture layout will be applied as a design methodology to all hardware fixtures that the Design Team creates. This will ensure client satisfaction.

6.2 HARDWARE FIXTURE STACKING METHODS

The client requested that the hardware fixtures be stackable for storage purposes within Station 19. As such, the Design Team created five stacking method concepts for further consideration. The advantages and disadvantages of the stacking method concepts can be seen in Table XII.

TABLE XII: THE STACKING METHOD CONCEPTS

Concept	Advantages	Disadvantages	Image
Through Handle	• Secure • Highly Portable	• Occupies significant space • Handle only on bottom portion of the hardware fixture	 [37]
Corner Studs	• Simple, low cost solution	• Studs may interfere during installation process • Studs may get in the way • Needs clearance for bottom hardware	 [38]

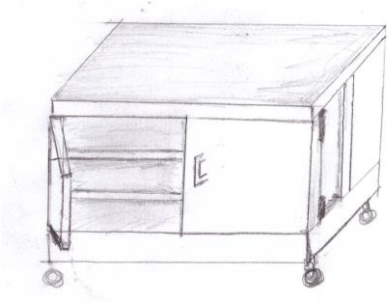
Concept	Advantages	Disadvantages	Image
Corner Studs – Nuts as Spacers	• Simple, low cost solution	• Studs may interfere during installation process • Studs may get in the way • Needs clearance for bottom hardware	 [39]
Corner Studs – Underside Relief	• Top fixture and bottom fixture interlock • Most compact storage solution • Underside relief ensures only specific fixtures can be stacked together	• Underside relief must be integrated into fixture • Slightly thicker hardware fixture	 [40]
Outer Raised Edge	• Simple solution • Ridge prevents dislodged hardware from falling off fixture • Ridge can be used to interlock top and bottom fixture • Second most compact storage solution	• Underside ridge relief must be integrated into fixture	 [41]

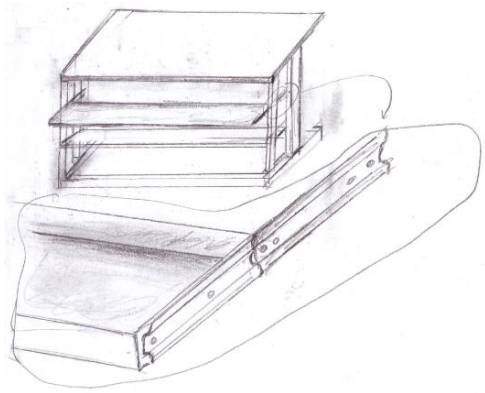
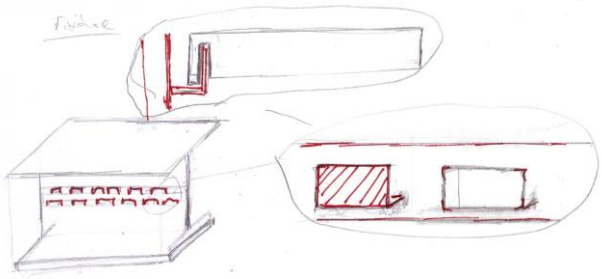
It is to be noted that the selected stacking method will be applied as a design methodology to all applicable hardware fixtures that the Design Team creates. This will ensure that all hardware fixtures are stackable, as requested by the client.

6.3 FIXTURE STORAGE CONCEPTS

To complete the integration of the hardware fixtures within Station 19, the storage of the hardware fixtures had to be addressed. The concepts created by the Design Team for the storage of the hardware fixtures focus on using any underutilized storage space within Station 19. To accomplish these tasks, the concepts outlined in Table XIII were developed and both the advantages and disadvantages of the concepts identified. Note that the storage concept will not be formally developed within this report.

TABLE XIII: FIXTURE STORAGE CONCEPTS

Concept	Advantages	Disadvantages	Image
Relocate Hardware Bins to Steering Prep Table	• Provides extra workspace on the hardware prep table • Utilizes existing dead space within Station 19 • Steering prep table has means to mount and secure existing hardware bins • Allows assembly operators to prepare hardware themselves	• Constrained to utilizing the existing structure; bin hooks are built into the cart, dimensions are restricted to current specifications	 [42]
Simple Shelf	• Simple, low cost solution • Can be implemented within existing space available on steering prep cart	• Less secure than a cabinet • Less secure than rolling drawers	 [43]
Cabinet	• Can be implemented within existing space available on steering prep cart • Stores and covers hardware fixtures	• Additional protection of hardware fixtures not absolutely necessary • Adds additional process steps	 [44]

Concept	Advantages	Disadvantages	Image
Rolling Drawers	• Can be implemented within existing space available on steering prep cart • Stores, covers and protects hardware fixtures	• Expensive • Limited benefit to assembly operators • Additional protection of hardware fixtures not absolutely necessary	 [45]
Hook Feature on Hardware Fixture	• Simple solution • Eliminates shelving on steering prep cart • Hardware fixtures can be stored directly on steering prep cart • Elegant storage solution	• Hook feature can be easily damaged	 [46]

It is to be noted that for the storage concepts, the Design Team has identified that there is sufficient space on the steering prep cart to both relocate the existing hardware bins and store the hardware fixtures. Thus, the selected concepts will be implemented to function with the existing steering prep cart.

The tables presented within this portion of the report serve to summarize the concepts that the Design Team has created for the purpose of this project. These concepts will be evaluated so that the best concepts are combined for implementation. The selection process that the Design Team utilized is presented in the following section.

7.0 CONCEPT SELECTION

Upon the completion of the individual and team brainstorming sessions, the Design Team had a collection of concepts that could be grouped into three categories: hardware fixture layouts, hardware fixture stacking methods, and fixture storage. Due to the nature of the design project, the three categories could first be screened and then be scored separately before utilizing concept fusion to ensure all aspects of the chosen concepts are compatible with one another moving forward.

7.1 CONCEPT SCREENING

The Design Team began with a process of screening the hardware fixture layouts, hardware fixture stacking methods, and fixture storage against a list of selected criteria that are based on the customer and project needs [47]. This first screening process was designed to eliminate any unreasonable concepts that were inherently flawed and also identify concepts that could potentially be combined quickly and efficiently. A reference concept was selected as the baseline, and then all other concepts were compared in the different criteria. Each concept could score one of three ratings; a plus (+) if it improved upon the baseline, a minus (-) if it was worse, or an even zero (0) if it met the criteria equally well. The net score was then tallied to determine which concepts moved to the next stage. Concept screening was the first step the Design Team took towards selecting and identifying the final concepts.

7.1.1 HARDWARE FIXTURE LAYOUT SCREENING

The Design Team first screened the hardware fixture layout concepts and selected the existing hardware fixture as a benchmark for the hardware fixture layout. Table XIV summarizes the hardware fixture layout screening process.

TABLE XIV: HARDWARE FIXTURE LAYOUT SCREENING

	Concept Variants					
Selection Criteria	**A - Hardware Loose on carts**	**B - Hardware Bowl**	**C - Bin Fixture**	**D - Vertical Hardware fixtures**	**E - Hybrid Fixture**	**(Reference) Existing Fixture**
Consideration/Improvement of Ergonomics	0	+	+	+	+	0
Easy to Understanding and Use	-	-	+	+	+	0
Easy to Move (portable)	-	0	0	0	0	0
Durable/Rugged	0	-	0	0	0	0
Fits into Workspace	0	0	-	0	0	0
Safety	-	-	0	0	0	0
Ease of Manufacturing	+	+	0	0	-	0
Cost of Manufacturing	+	+	-	-	-	0
Holds Correct Parts	-	-	+	+	+	0
Stackable/Storable	-	+	+	-	+	0
Pluses	2	4	4	3	4	
Sames	3	2	4	5	4	
Minuses	5	4	2	2	2	
Net	-3	0	2	1	2	
Rank (1-5)	5	4	1(T)	3	1(T)	
Continue (Y or N)	**N**	**N**	**Y**	**Y**	**Y**	

Table XIV shows that the bin fixture, vertical fixture and the hybrid fixture passed concept screening and will be evaluated further in the concept scoring phase of this report. It is to be noted that the hardware bowl was eliminated as the hardware lays loose and hardware part numbers cannot be identified. Furthermore, the existing fixture layout will also be scored against the hardware bin, vertical fixture and hybrid fixture to serve as a baseline.

7.1.2 HARDWARE FIXTURE STACKING SCREENING

The fixture stacking concepts were then screened and the Design Team selected, again, the existing hardware fixture as a benchmark. Table XV summarizes the hardware fixture stacking concept screening.

TABLE XV: HARDWARE FIXTURE STACKING SCREENING

	Concept Variants					
Selection Criteria	**A - Through Handle**	**B - Corner Studs**	**C - Corner studs with nut spacers**	**D - Corner Studs Underside Reliefs**	**E - Outer Raised Edge**	**(Reference) Current Fixture**
Stack multiple trays (2-3)	+	+	+	+	+	0
Ease of use of stacking feature	+	+	+	+	+	0
Cost to manufacture	-	-	-	-	-	0
Durability	0	0	0	0	0	0
Portability of Fixture	+	0	0	0	0	0
Compact size	-	0	-	-	0	0
Reliability (difficult to knock over)	+	+	+	+	0	0
Pluses	4	3	3	3	2	
Sames	1	3	2	2	4	
Minuses	2	1	2	2	1	
Net	2	2	1	1	1	
Rank (1-5)	1 (T)	1 (T)	3 (T)	3 (T)	3 (T)	
Continue (Y or N)	**Y**	**Y**	**N**	**N**	**N**	

From Table XV above, the through handle and corner stud stacking concepts passed concept screening and will be evaluated further in the concept scoring phase of this report.

7.1.3 FIXTURE STORAGE SCREENING

The fixture storage concepts were then screened. The Design Team selected the simple shelf concept as a benchmark. Table XVI summarizes the fixture storage concept screening.

TABLE XVI: FIXTURE STORAGE SCREENING

	Concept Variants			
Selection Criteria	**A - Cabinet with Shelves**	**B - Rolling Drawers**	**C - Hook Feature on Fixture**	**D - Simple Shelf (Reference)**
Ease of access	-	+	0	0
Holds at least 3 of each fixture	0	0	0	0
Easy to organize	-	0	-	0
Easy to identify Kits	-	-	0	0
Fixtures are protected from being knocked over/off	+	0	-	0
Cost to Manufacture	-	0	-	0
Ease of implementation	0	0	-	0
Durability	+	0	-	0
Pluses	2	1	0	0
Sames	2	6	3	8
Minuses	4	1	5	0
Net	-2	0	-5	0
Rank (1-5)	3	1	4	1
Continue (Y or N)	**N**	**Y**	**N**	**Y**

For the fixture storage screening, the Design Team selected the simple shelf concept as a benchmark. Both the rolling drawers and the simple shelf fixture storage concepts will be evaluated further in the concept scoring phase of this report.

7.2 Selection Criteria Importance Weighting

Following the initial concept screening process, the team had to further consolidate concepts to determine concepts for further development. In order to proceed, we evaluated the importance of the criteria that was used to screen the initial concepts [47]. The method used for determining the importance of each selection criteria was a decision matrix comparing each criterion against one another; the concept with higher importance earned the box. The weight was determined by tallying up the total number of occurrences of each criterion then dividing by the total number of available slots. A unique matrix was generated for each of the three concept categories.

7.2.1 Hardware Fixture Layout Criteria Weighting

The criteria weighting matrix for the hardware fixture layout can be seen in Table XVII.

TABLE XVII: HARDWARE FIXTURE LAYOUT CRITERIA WEIGHTING

		Consideration/Improvement of Ergonomics	Ease of Understanding and Use	Easy to Move (portable)	Durable/Rugged	Fits into Workspace	Safety	Ease of Manufacturing	Cost of Manufacturing	Holds Correct Parts	Stackable/ Storable
Selection Criteria		A	B	C	D	E	F	G	H	I	J
A	**Consideration/Improvement of Ergonomics**		B	C	D	E	F	G	A	I	J
B	**Ease of Understanding and Use**			B	B	B	B	B	B	I	B
C	**Easy to Move (portable)**				D	C	F	C	C	I	J
D	**Durable/Rugged**					E	F	D	D	I	J
E	**Fits into Workspace**						E	E	E	I	E
F	**Safety**							F	F	I	F
G	**Ease of Manufacturing**								G	I	J
H	**Cost of Manufacturing**									I	J
I	**Holds Correct Parts**										I
J	**Stackable/Storable**										
Total Hits		1	8	4	4	6	6	2	0	9	5
Weightings		0.02	0.18	0.09	0.09	0.13	0.13	0.04	0.00	0.20	0.11

From Table XVII, cost of manufacturing is the least important criteria, whereas containing the correct parts is the most important criteria for the selected hardware fixture layout to adhere to.

7.2.2 HARDWARE FIXTURE STACKING CRITERIA WEIGHTING

The weighting matrix for the hardware fixture stacking criteria can be seen in Table XVIII.

TABLE XVIII: HARDWARE FIXTURE STACKING CRITERIA WEIGHTING

		Stack multiple trays (2-3)	Ease of use of stacking feature	Cost to manufacture	Durability	Portability of Fixture	Compact size	Reliability (difficult to knock over)
Selection Criteria		**A**	**B**	**C**	**D**	**E**	**F**	**G**
A	**Stack multiple trays (2-3)**		A	A	A	E	F	A
B	**Ease of use of stacking feature**			B	D	E	F	B
C	**Cost to manufacture**				D	E	F	G
D	**Durability**					E	D	D
E	**Portability of Fixture**						E	E
F	**Compact size**							G
G	**Reliability (difficult to knock over)**							
Total Hits		4	2	0	4	6	3	2
Weightings		0.190	0.095	0.000	0.190	0.286	0.143	0.095

From Table XVIII, cost of manufacturing identified as the least important criteria whereas portability identified as the most important criteria for the selected hardware fixture stacking method to provide.

7.2.3 FIXTURE STORAGE CRITERIA WEIGHTING

The weighting matrix for the fixture storage criteria can be seen in Table XIX.

TABLE XIX: FIXTURE STORAGE CRETERIA WEIGHTING

		Ease of access	Holds at least 3 of each fixture	Easy to organize	Easy to identify Kits	Fixtures are protected from being knocked over/off	Cost to Manufacture	Ease of implementation	Durability
Selection Criteria		**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**
A	**Ease of access**		B	A	D	E	A	A	H
B	**Holds at least 3 of each fixture**			B	B	E	B	G	B
C	**Easy to organize**				C	E	F	G	H
D	**Easy to identify Kits**					F	D	G	H
E	**Fixtures are protected from being knocked over/off**						E	E	E
F	**Cost to Manufacture**							G	H
G	**Ease of implementation**								G
H	**Durability**								
Total Hits		3	5	1	2	6	2	5	4
Weightings		0.107	0.179	0.036	0.071	0.214	0.071	0.179	0.143

Table XIX shows that shelving organization identified as the least important criteria. Fixture protection identified as the most important criteria for the selected hardware fixture storage method to provide.

The results of the criteria weighting matrices has determined that the cost of manufacturing scored an importance weight of zero in the categories of hardware fixture design and stacking design, while scoring very low for storage concepts. Although our client has not indicated a cost

ceiling for the project, we must consider the manufacturing costs of our final design. It is to be noted cost of manufacturing having a weighted score of near zero was expected by the Design Team, as limited budget constraints have been presented to the Design Team in this project.

7.3 Concept Scoring

Using the weighting results from the criteria weighting matrices, the Design Team scored the remaining concepts in each of the three concept categories. Our selection criteria remained the same, but with the addition of weighting the Design Team was able to quantify our comparison to determine the concepts that would be further developed in the final design section of this report.

7.3.1 Hardware Fixture Layout Scoring

The weighted selection criteria for the layout of the hardware fixture was incorporated into a scoring matrix in order to determine the optimum fixture layout to develop. The hardware fixture layout scoring matrix can be seen in Table XX.

TABLE XX: HARDWARE FIXTURE LAYOUT SCORING

		Concept Variants							
		A-EXISTING		B-Bin Fixture		C - Vertical Fixture		D - Hybrid Fixture	
Selection Criteria	Weight	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score
Consideration/Improvement of Ergonomics	0.022	2	0.044	4	0.089	3	0.067	4	0.089
Ease of Understanding and Use	0.178	3	0.533	4	0.711	4	0.711	4	0.711
Easy to Move (portable)	0.089	4	0.356	4	0.356	4	0.356	3	0.267
Durable/Rugged	0.089	4	0.356	4	0.356	4	0.356	4	0.356
Fits into Workspace	0.133	4	0.533	3	0.400	3	0.400	3	0.400
Safety	0.133	4	0.533	4	0.533	4	0.533	4	0.533
Ease of Manufacturing	0.044	4	0.178	3	0.133	3	0.133	3	0.133
Cost of Manufacturing	0.000	4	0.000	3	0.000	2	0.000	4	0.000
Holds Correct Parts	0.200	3	0.600	4	0.800	4	0.800	4	0.800
Stackable/Storable	0.111	1	0.111	3	0.333	3	0.333	5	0.556
Total Score		3.24		3.71		3.69		3.84	
Rank (1-5)		4		2		3		1	
Continue (Y or N)		N		N		N		Y	

The hardware fixture layout scoring matrix illustrates that the hybrid fixture layout satisfied the design criteria the best, when scored against the other layout concepts. As such, the hybrid fixture layout will be developed further and implemented in the final fixture design.

7.3.2 HARDWARE FIXTURE STACKING CONCEPT SCORING

The weighted selection criteria for the stacking concepts was incorporated into a scoring matrix in order to determine the optimum stacking method. The stacking concepts scoring matrix can be seen in Table XXI.

TABLE XXI: HARDWARE FIXTURE STACKING CONCEPT SCORING

		Concept Variants			
		A - Through Handle		B - Corner Studs	
Selection Criteria	Weight	Score	Weighted Score	Score	Weighted Score
Stack multiple trays (2-3)	0.190	4	0.762	4	0.762
Ease of use of stacking feature	0.095	3	0.286	4	0.381
Cost to manufacture	0.000	3	0.000	3	0.000
Durability	0.190	4	0.762	3	0.571
Portability of Fixture	0.286	5	1.429	3	0.857
Compact size	0.143	3	0.429	4	0.571
Reliability (difficult to knock over)	0.095	5	0.476	3	0.286
Total Score		4.14		3.43	
Rank (1-5)		1		2	
Continue (Y or N)		**Y**		**N**	

It can be seen from Table XXI, that the through handle stacking method satisfied the design criteria better than the corner stud concept. As such, the through handle stacking method will be developed further and implemented in the final fixture design. Additionally, incorporating a handle into the fixture will greatly improve the ergonomics of the fixture, which the operators within Station 19 have requested on numerous occasions.

7.3.3 FIXTURE STORAGE CONCEPT SCORING

Finally, the weighted selection criteria for the fixture storage concepts was also used to create a scoring matrix in order to determine the best storage concept to develop. The fixture storage scoring matrix can be seen in Table XXII.

TABLE XXII: FIXTURE STORAGE CONCEPT SCORING

		Concept Variants					
		A - Simple Shelf		B - Roller Drawer		C - Cabinet	
Selection Criteria	Weight	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score
Ease of access	0.107	4	0.429	5	0.536	3	0.321
Holds at least 3 of each fixture	0.179	5	0.893	5	0.893	5	0.893
Easy to organize	0.036	3	0.107	4	0.143	3	0.107
Easy to identify Kits	0.071	4	0.286	3	0.214	3	0.214
Fixtures are protected from being knocked over/off	0.214	4	0.857	4	0.857	5	1.071
Cost to Manufacture	0.071	5	0.357	3	0.214	2	0.143
Ease of implementation	0.179	4	0.714	4	0.714	2	0.357
Durability	0.143	4	0.571	4	0.571	5	0.714
Total Score		4.21		4.14		3.82	
Rank (1-5)		1		1		2	
Continue (Y or N)		Y		N		N	

The fixture storage concept scoring matrix illustrates that the simple shelf concept satisfies the design criteria to a better extent than the roller drawer or cabinet concepts. As such, a simple shelf will be implemented on the existing steering prep cart for storage purposes.

7.4 Concept Selection Overview

From the results of our team's concept scoring and selection matrices, we will move forward with the development of a hybrid layout hardware fixture design, with a handle feature that serves two key purposes. The handle will first and foremost improve ergonomics, making it easier to pick up and move a loaded fixture. The handle will also act as a stacking locator to aid in the organization of pre-prepared fixtures in the workstation. The final fixture sketch is presented in Figure 20. It is to be noted that this fixture design will be implemented, as required, on all five fixtures that are to be created.

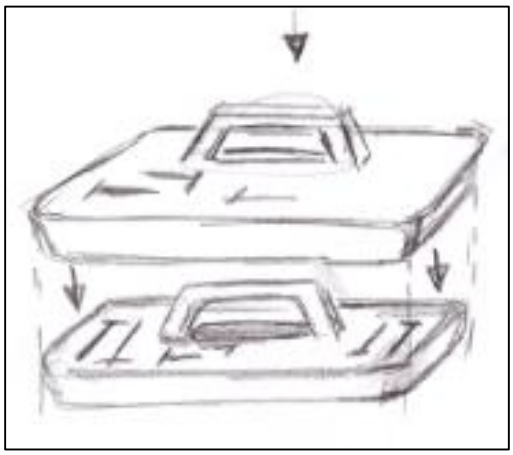


Figure 20: Sketch of selected hardware fixture concept [48].

The team will also proceed with the addition of simple shelving, as seen in Figure 21, to the steering prep cart in order to store the prepared hardware fixtures within the workstation. The simple shelving will also allow for quick implementation and modifications when necessary. Again, the Design Team is only required to develop a conceptual design for the fixture storage within Station 19.

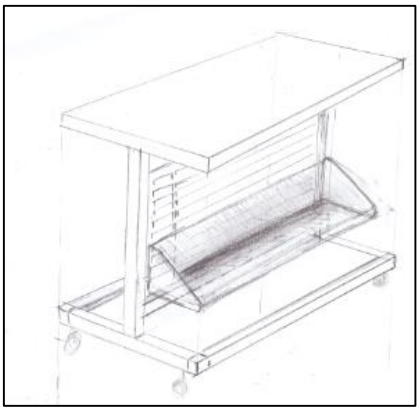


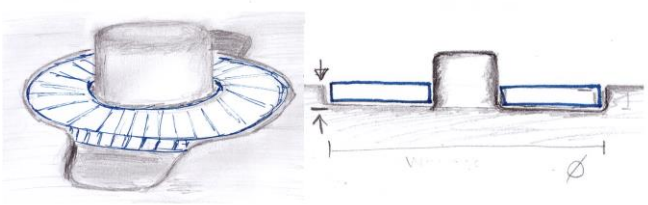
Figure 21 Simple shelving [49].

7.5 Concept Fusion

To verify that the three categories of concept designs will mesh with each other, the team performed a final brainstorming session to identify any potential issues that could result with integrating the selected concepts, prior to proceeding with further development. One of the important parameters in developing each of our designs is the size of the fixture itself; size affects how easy the fixture is to move, how well it will fit within the work station at various points, and finally, how the fixture will be stored. Our concept screening and selection determined a carry handle will be the best method of stacking while also improving ergonomics; however, the handle will require space as a feature on the fixture surface area. Balance of the fixture must also be considered for lifting and carrying, as the placement of the handle will affect how natural it feels to the user to pick up and carry. The team determined that the best method for assessing these issues will be design iterations during the design phase of this report, the hardware will need to be organized effectively around the handle to optimize space whilst maintaining a neutral weight balance.

Another area of concern that was outlined during our discussion with the client is how the hybrid hardware layout will address the current problems of the incorrect sized washers being mixed up. In the current assembly process, the larger washers are used only in the installation of the Steering Gear, thus restricting its inclusion to one fixture that will not have any smaller washers. Although the team determined a general hardware layout concept, we did not select the exact method of matching the correct washer to the correct fixture slot. With a flat layout, the washer's inner and outer diameters will be matched to the slot size, and the washer will be secured by a raised feature in the center. The flat washer placement that the team will develop is presented in Table XXIII.

TABLE XXIII: CONCEPT FUSION OF CRUSH WASHER LAYOUT

Layout	Image
Flat Layout of Crush Washer in Hardware Fixture:	 [50]
Fixture Slot Diameter matched precisely to Washer Diameter. Depth of fixture slot matched to thickness of washer, to ensure no extra parts stuck onto the two-piece washer. Simple feel test to ensure washer is flush with fixture surface	

8.0 DETAILS OF FINAL DESIGN

This section serves to outline the finalized details of the five hardware fixtures created by the design team. Within this section the ergonomic considerations for the fixtures are discussed and the handle design is overviewed. This is followed by detailed descriptions for each of the five hardware fixtures. Assembly and part drawings are also provided for visualization purposes. The fixtures are not intended to be manufactured from the drawings, but rather from the 3D CAD files produced by the Design Team.

8.1 ERGONOMICS

Ergonomics must be considered when determining the proper size of the handle as well as the size of the finger reliefs incorporated into the design of the fixtures. This is to ensure the fixtures can be carried easily and the assembly operators can remove the hardware without difficulty.

To incorporate proper ergonomic features, the Design Team investigated the average sizes of the male hand, as the assembly line operators are all male. From this investigation, the Design Team determined that the hand dimensions of the assembly operators lie within the 95th percentile. As such, the anthropometric estimates for the 95th percentile adult male, ranging in age from 19-65 years can be viewed in Table XXIV.

TABLE XXIV: ANTHROPOMETRIC ESTIMATES FOR THE ADULT MALE IN THE 95TH PERCENTILE [51, 52].

Dimension	95 Percentile
Hand length	205 - 209 mm
Palm length	116 mm
Thumb length	58 mm
Thumb breadth	26-27 mm
Index finger length	79 mm
Hand breadth	95 mm
Maximum grip diameter	59 mm

8.1.1 GRIPS

We are also concerned with the types of grips the assembly line operators will utilize when using the hardware fixtures. The two main grips the assembly line operators will be using is the power grip, and the pinch grip [53]:

8.1.1.1 THE POWER GRIP

The power grip will be used by the assembly line operators when lifting the hardware fixtures by means of the handle. An example of the power grip can be viewed in Figure 22 below and is described by the fingers being wrapped around the object with the thumb overlapping. The handle for the hardware fixtures should be long enough for all five fingers to be easily wrapped around the handle as well as the diameter should be thick enough to so that the fingers wrapped around the handle do not come in contact with the palm of the assembly line operators hand [53]. The Canadian Centre for Occupational Health and Safety (CCOHS) recommend that the handle diameter for the power grip be around 30 mm and the length of the handle be around 115 mm [54]. These dimensions indicate that for a 95th percentile male, with a hand breadth of 95mm and maximum grip diameter of 59mm, that the CCOHS handle design suggestions will be sufficient for the hardware fixtures.

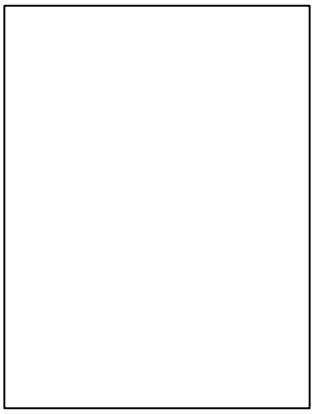


Figure 22: The power grip [53].

8.1.1.2 THE PINCH GRIP

The pinch grip will be used by the assembly line operators when removing the hardware from the fixtures and is defined as picking up objects using the grip from your index finger and thumb [53]. An example of the pinch grip can be viewed in Figure 23 below.

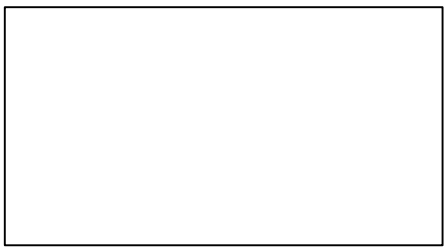


Figure 23: The pinch grip [53].

The main consideration for the pinch grip is to ensure that there is sufficient space for the index finger and the thumb of the assembly line operators to easily grasp the hardware. By placing finger reliefs into the fixture and ensuring that the hardware has a portion exposed above the top face of the fixtures, the assembly operators will not have any difficulty removing hardware from the fixtures.

8.1.1.3 GLOVES

When designing the hardware fixture handle and reliefs for the assembly operators in Station 19, the ergonomics of these features must consider the use of gloves. When completing the front suspension assembly it is required that the assembly line operators wear mechanic gloves.
In these instances, it is recommended that an additional 10 mm be added to the overall length of the handle of the tool, or in this case, the handle of the fixture [51].

8.2 HANDLE DESIGN

The purpose of the handle for the hardware fixtures was to improve the manner in which the assembly line operators transport the fixtures from location to location within Station 19. The handle will ensure that the fixtures are carried safely and it will help to eliminate the chance of the assembly line operators dropping the fixtures. The handle also allowed us to design the hardware fixtures in a manner in which all the hardware was equally distributed on each side of the handle. It is important to note that the handle was designed to be universal, and is used in the design of each hardware fixture for Station 19.

The handle for the hardware fixtures was designed taking into account the ergonomic considerations mentioned in Section 8.1. Following the ergonomic guidelines based on the average male hand in the 95th percentile, and knowing the assembly line operators would be using the power grip, the handle was designed to have the dimensions shown in Table XXV. A simple sketch can be viewed in Figure 24.

TABLE XXV: OVERVIEW OF HANDLE DIMENSIONS

Description	Length
Outside handle length	125 mm
Inside handle length	110 mm
Handle diameter	30 mm
Handle height	51.40 mm

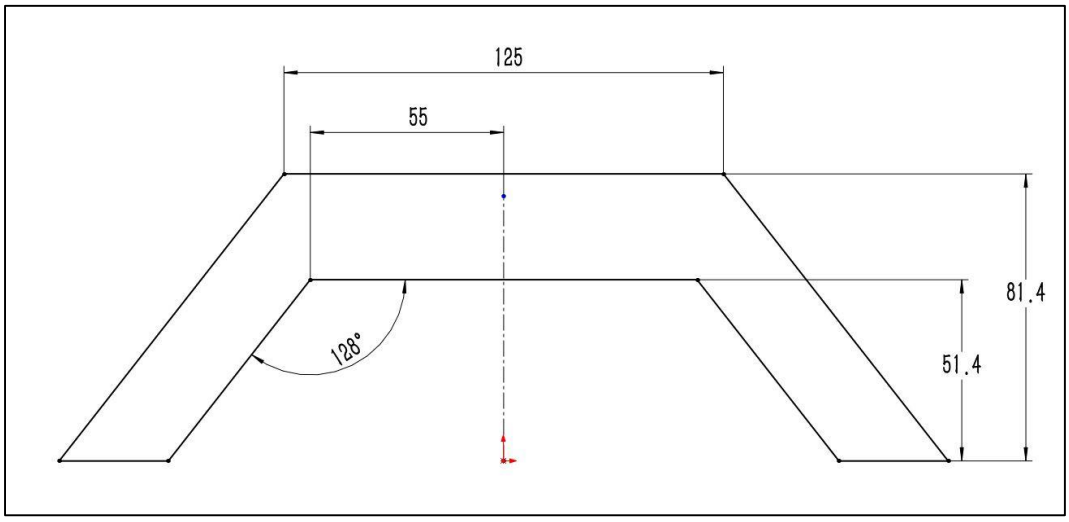


Figure 24: Handle sketch (dimensions in mm) [55].

A key feature of the handle is that it was designed with the arms placed on an angle of 128 degrees. The reason for this is to allow for the hardware fixtures to be stackable, which was a key feature requested from the Client. Additionally the arms being placed at an angle of 128 degrees, instead of 90 degrees, allows for more clearance for the assembly line operators to insert their hand into the handle. A final render of the universal handle can be viewed in Figure 25 below. General dimensions can be seen on the handle drawings provided on the following page.

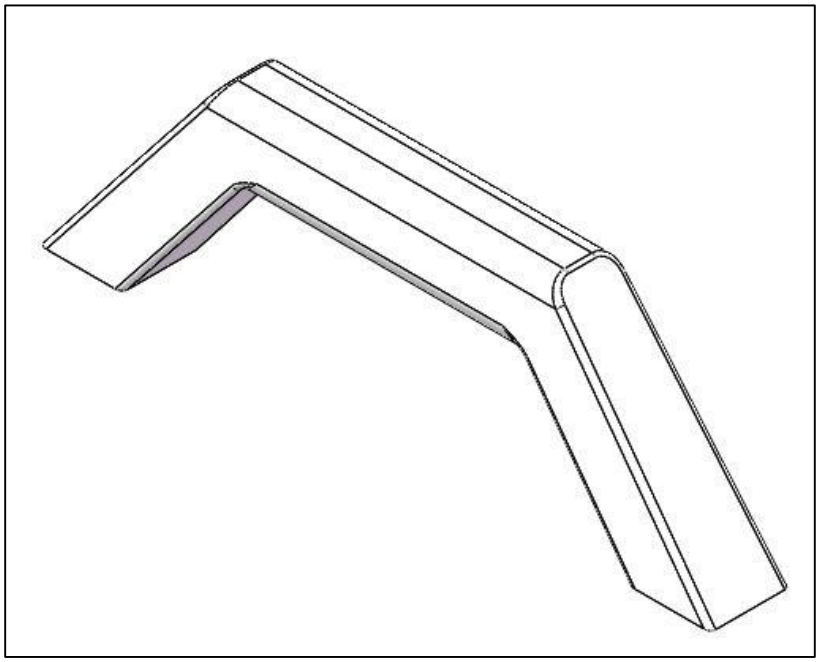
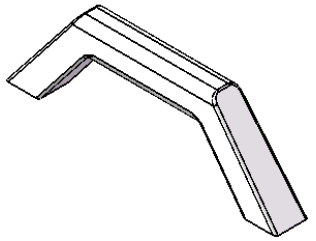
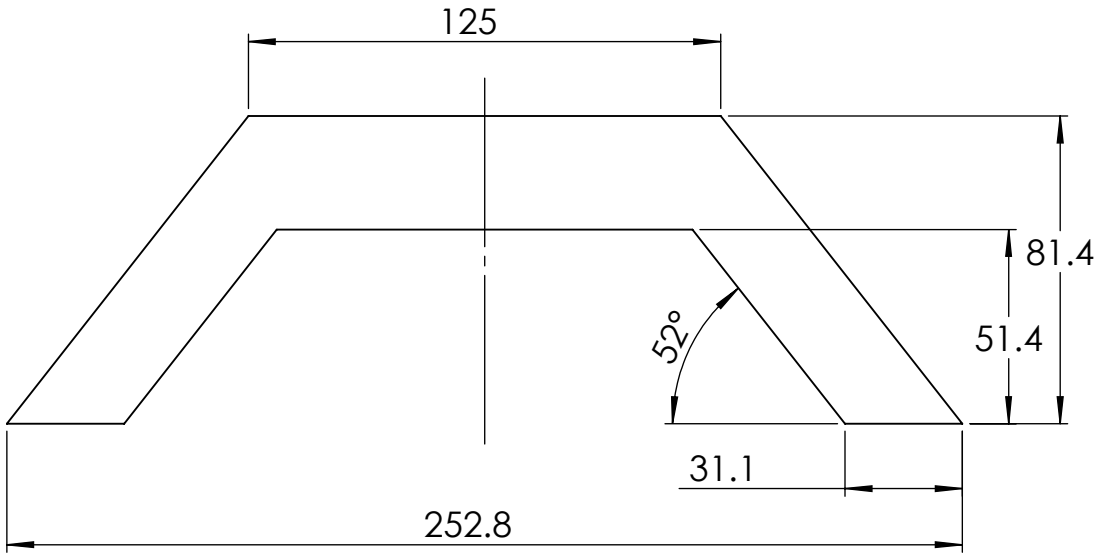
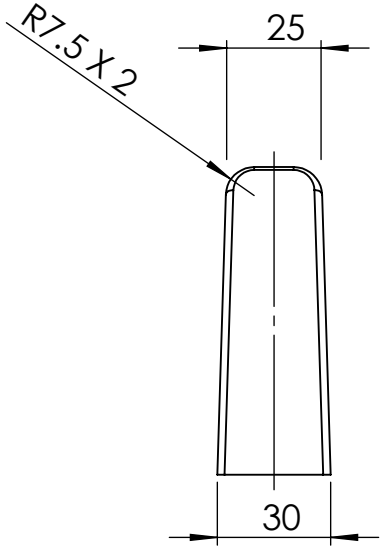


Figure 25: Render of the final handle design [56].







Note:
1. All Edges Fillet: 1.5 mm
2. For Additive Manufacturing Only (3D Printer)

SolidWorks

MECH 4860

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN METRIC
TOLERANCES:
ANGULAR: MACH ±0° 30'
TWO PLACE DECIMAL ±.127

UofM MECHANICAL ENGINEERING

INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14. 5M-1994		NAME	DATE
DO NOT SCALE DRAWING	DRAWN	D.D.	24/11/2015
MATERIAL ABS	CHECKED	B.J.	05/12/2015
FINISH ADDITIVE MANUFACTURING			

TITLE: **FIXTURE HANDLE**

SIZE	DISCRIPTION:	REV
A	FIXTURE HANDLE	3

SCALE: 1:2 | WEIGHT: 204.271 | SHEET 1 OF 1

5 4 3 2 1

8.3 LEFT-HAND SUSPENSION HARDWARE FIXTURE

The purpose of the left-hand suspension hardware fixture is to provide organization of the hardware required for the installation of the left suspension assembly and improve upon the existing methods used to keep the bolts, washers, and nuts within reach during the assembly process.

Previously, the required hardware was handpicked from hardware bins located within the workstation and set upon the flat top surface of the front suspension cart. The suspension cart is used to maneuver and lift the entire left hand wheel hub and A-arm assembly into place underneath the J-coach. Assembly operators were then responsible for ensuring the correct quantity and the correct part numbers were installed in their respective locations according to the provided work instructions.

The assembly process was then improved by MCI by creating a basic hardware tray that held only the correct number of components required. The hardware tray can also be carried to the work area and placed on the suspension cart. However, due to the relatively small (dimensional) differences in some of the hardware used within the workstation, the original fixture design allows the possibility for incorrect hardware to be loaded into the fixture. Assembly operators outlined the difficulty of lifting and carrying the triangle shaped fixture with no handle, as well as difficulty removing hardware from the tray due to extremely tight tolerances. To address the existing problems, a new left hand suspension fixture was created to organize and track hardware as it is installed, improve handling of the hardware fixture, and ultimately reduce the chance of user error. The new left hand suspension hardware fixture can be seen in Figure 26.

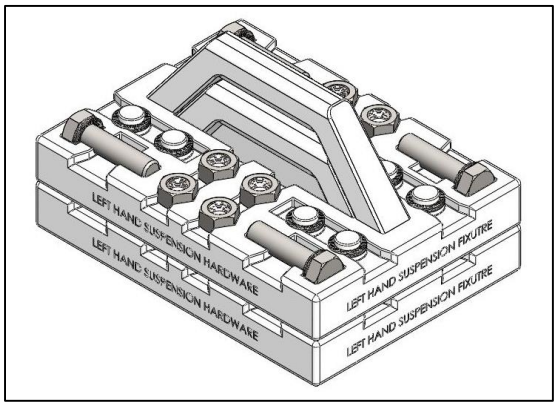


Figure 26: Fully assembled and stacked left-hand suspension fixture [57].

To ensure that this fixture is easy to maneuver, the fixture itself was designed around the handle described in Section 8.2. Again, the handle also serves a second function as a stacking feature, allowing multiple fixtures to be stored vertically, centered on the handle. The left-hand suspension fixture organizes the 24 components required in securing the left-hand suspension assembly to the frame of the J-coach in a symmetrical fashion, as identified in Table XXVI. This ensures that the fixture is naturally balanced, as the hardware is divided equally on the fixture. Figure 27 illustrates the overall layout of the fixture. Detailed specifications and hardware locations can be seen on the left suspension hardware fixture drawings provided immediately following Section 8.3.

TABLE XXVI: FRONT INDEPENDENT SUSPENSION HARDWARE - LEFT

Part Number	Description	Weight (g)	Amount
1901-2286	M18X1.5X70 Screw	187	4
1902-0405	Lock washer; M18; inner diameter: 19.5mm, outer diameter: 29 mm; thickness: 3.4mm.	9	12
1903-0781	M18 Nut; outside diameter: 27mm; thickness 15mm	48	8
Total Mass of Left Hand Suspension Hardware		1240	24

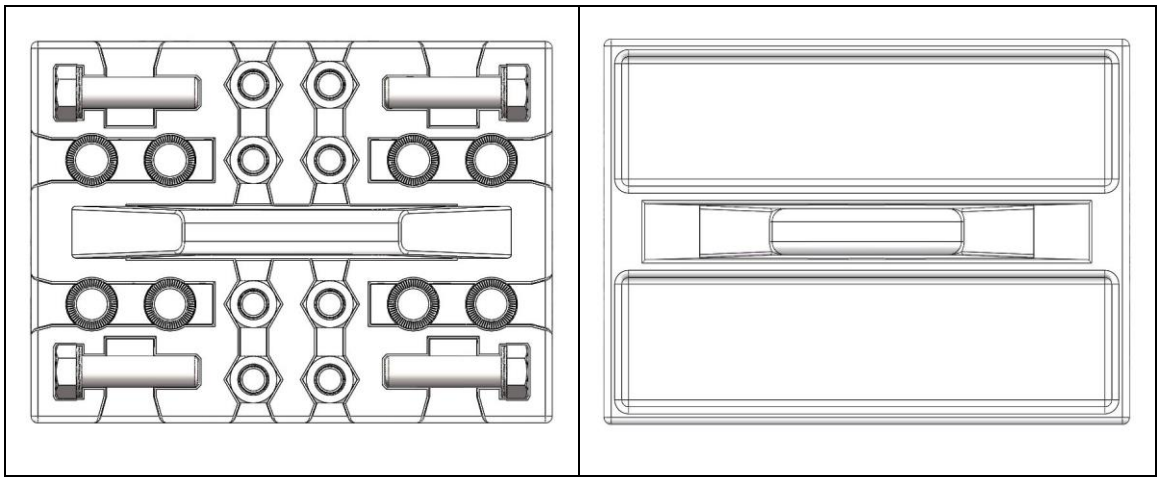


Figure 27: Top view (left) and bottom view (right) of left hand suspension hardware fixture [58].

In addition to presenting the steering gear in an organized fashion, the left hand suspension fixture has to ensure that only the correct parts, and correct quantity of parts, can be placed into the fixture. The hardware contained in the suspension fixture is dimensionally similar to the steering gear hardware, and thus the design of the suspension fixture must prevent the possibility that the steering gear hardware is placed into the suspension fixture.

In order to achieve this design requirement, the specific components prone to user error in the left-suspension fixture had their features modeled to a precise tolerance. The affected components are the suspension lock washer, part number 1902-0405, and suspension nut, part number 1903-0781 as there are four instances of each that are prone to error. A sample of these components is highlighted in Figure 28. The parts that the tolerances prevent from fitting into the suspension fixture are the steering gear lock washer, part number 1902-0414, and the steering gear nut, part number 1903-0775.

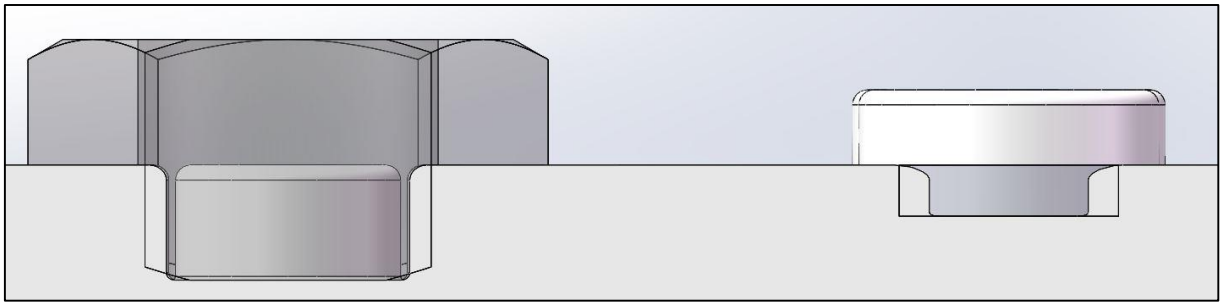


Figure 28: Interference occurs when steering gear nut (left) and steering gear washer (right) is inserted into the left hand suspension hardware fixture. [59]

Another issue that must be addressed is that an incorrect number of washers can be placed in the existing fixture. This stems from the fact that the lock washers are a unique two-piece design bonded together by adhesive, that when torqued in an assembly, the two halves lock together. However, if a third piece gets stuck to an existing two-piece assembly, the lock washer fails to function as designed and the affected assembly becomes a major safety concern. To address the issue, the design team established a visual and physical check to verify that only a single two-piece washer is placed into the left-hand suspension fixture, this is illustrated in Figure 29.

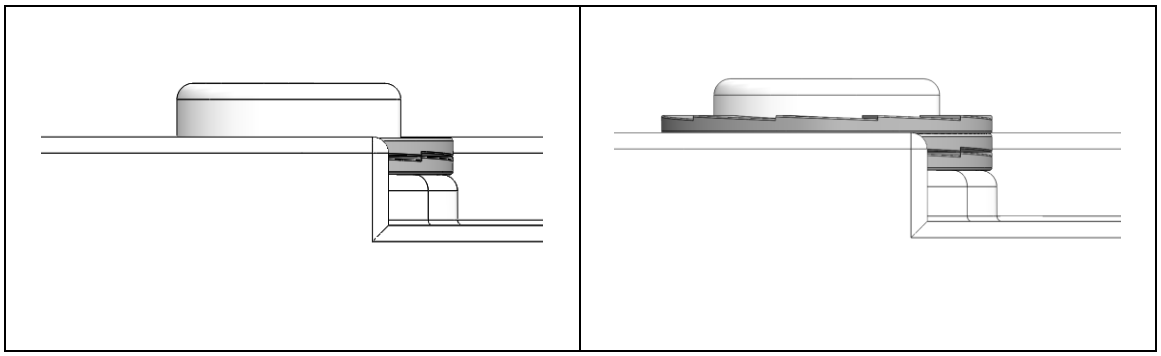
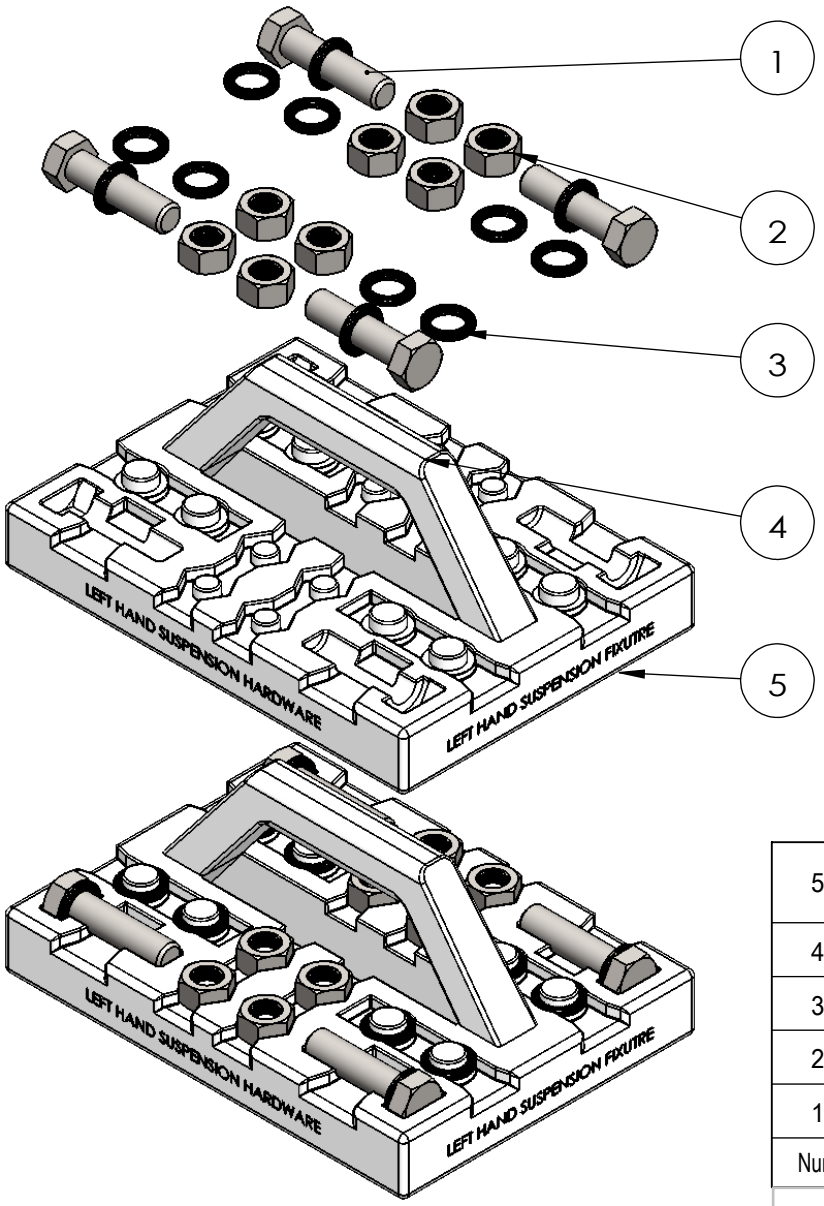
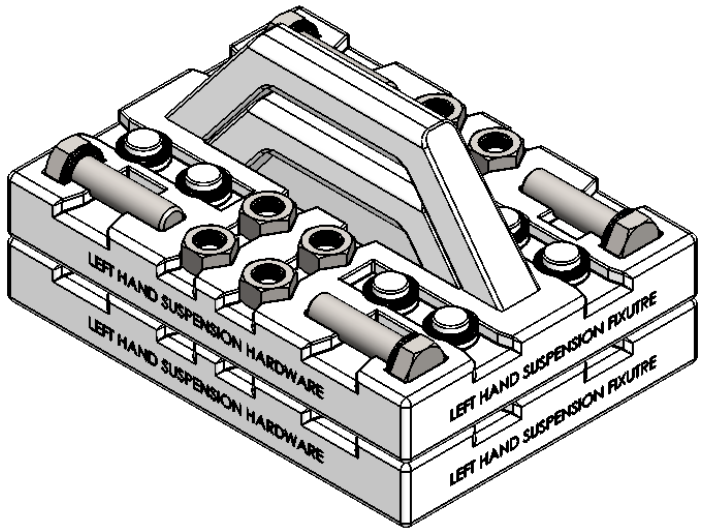


Figure 29: Suspension lock washer (1902-0405) thickness can be verified visually, and by touch [60].

When the correct washer is placed in the fixture, the top surface of the washer should be completely flush with the top surface of the fixture. If an incorrect number of washer halves are bonded together, the washer assembly will protrude above the top surface of the fixture. This can be quickly verified by the assembly operator, visually and also by passing a finger over the washer to determine if the part is flush by feel. The relief cut outs on either side of the washer provide space to easily lift the washer out of place even with gloves on hands.

With the above considerations in mind, the Design Team is confident that the left-hand suspension fixture meets the design needs of the client by addressing the current problems in the assembly process, and developing a new fixture that organizes the hardware with a fixture design that is ergonomic to the assembly operator and stackable. Furthermore, by ensuring that the tolerances of the features prone to user error will prevent incorrect hardware from being placed into the fixture itself, the risk of installing incorrect hardware onto the coach in Station 19 will be reduced, effectively error proofing the front suspension installation process. Additionally, the Risk Priority Number (RPN) will also be reduced if the left-hand front suspension hardware fixture is utilized in the assembly process. Details regarding the reduced RPN values can be seen in Table VI located in the Failure Modes and Effects Analysis provided in Appendix A.





Num	Name	Material	Quantity	Weight(g)	Description
5	LH Suspension Fixture Body	ABS	2	1433.80	Left hand side suspension fixture body
4	Fixture Handle	ABS	2	204.271	Fixture Handle
3	1902-0405	HSS	24	4.37	M18 Lock Washer
2	1903-0781	HSS	16	47.898	M18 Nut
1	1901-2286	HSS	8	199.67	M18 X 1.5 X 70

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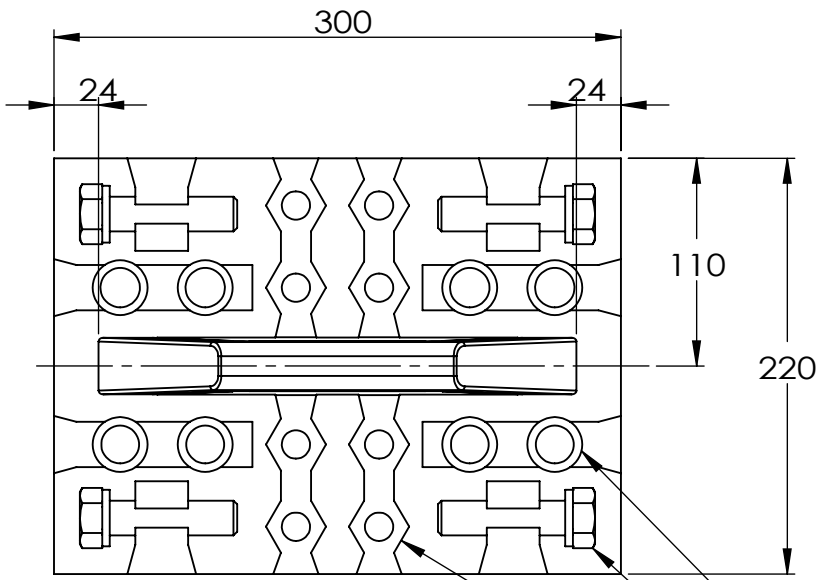
MATERIAL ASSEMBLY	CHECKED	D.D.	2015/12/5
FINISH AS ASSEMBLED			

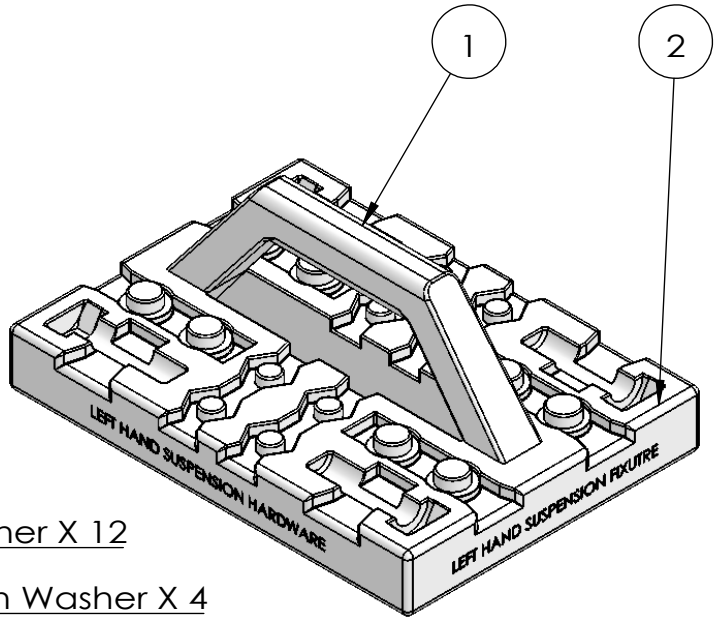
TITLE: **LEFT HAND SIDE SUSPENSION FIXTURE**

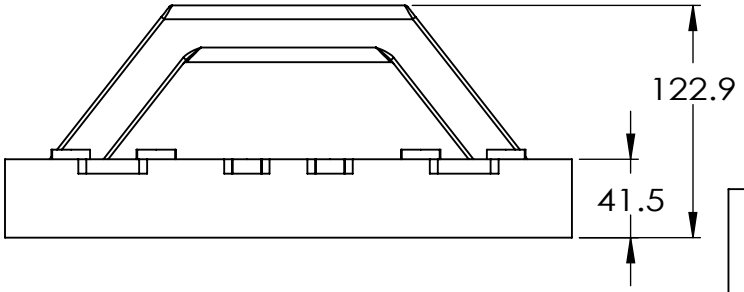
SIZE	DISCRIPTION:	REV
A	LEFT HAND SIDE SUSPENSION FIXTURE WITH STACKING	4

SCALE: 1:4 | WEIGHT: 6832.86 | SHEET 1 OF 3

5 4 3 2 1







Num	Name	Material	Quantity	Weight(g)	Description
2	LH Suspension Fixture Body	ABS	1	1433.80	Left hand side suspension fixture body
1	Fixture Handle	ABS	1	204.271	Fixture Handle

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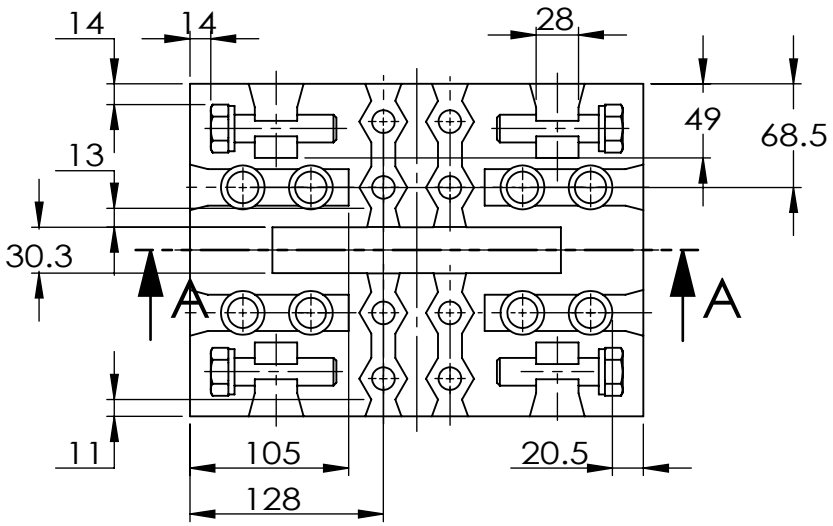
INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14. 5M-1994		NAME	DATE
DO NOT SCALE DRAWING	DRAWN	B.J.	2015/11/22
MATERIAL ABS	CHECKED	D.D.	2015/12/5
FINISH ADDITIVE MANUFACTURING			

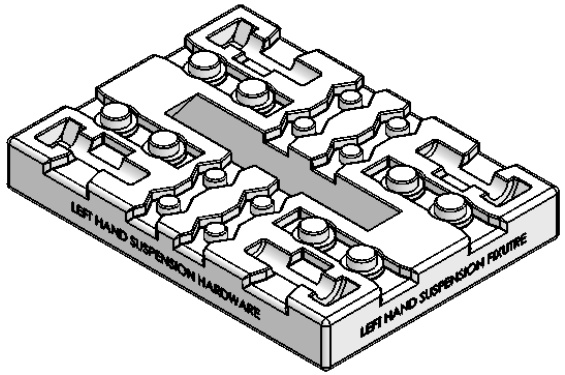
TITLE: **LEFT HAND SIDE SUSPENSION FIXTURE**

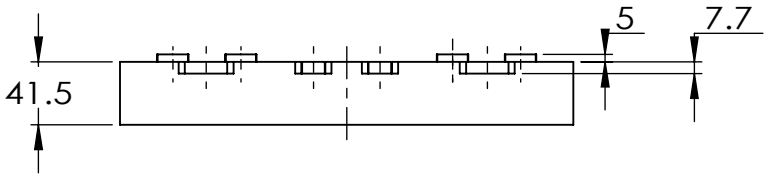
SIZE	DISCRIPTION:	REV
A	LEFT HAND SIDE SUSPENSION FIXTURE WITH HANDLE	4

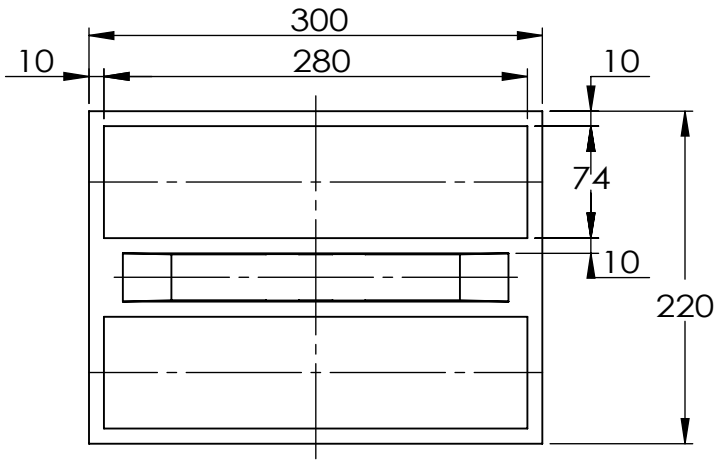
SCALE: 1:4 | WEIGHT: 1638.07 | SHEET 2 OF 3

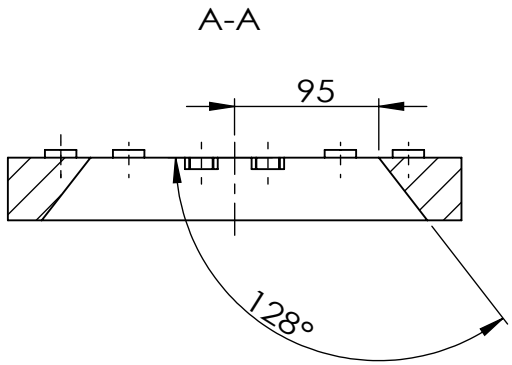
5 4 3 2 1











Note:
1. All Edges Fillet: 1.5 mm
2. For Additive Manufacturing Only (3D Printer)

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MATERIAL ABS	CHECKED	D.D.	2015/12/5
FINISH ADDITIVE MANUFACTURING			

TITLE: **LEFT HAND SIDE SUSPENSION FIXTURE**

SIZE	DISCRIPTION:	REV
A	LEFT HAND SIDE SUSPENSION FIXTURE BODY	4

SCALE: 1:5 | WEIGHT: 1638.07 | SHEET 3 OF 3

5 4 3 2 1

8.4 Right-Hand Suspension Hardware Fixture

The purpose of the right-hand suspension hardware fixture is to provide organization of the hardware required for the installation of the right suspension assembly and improve upon the existing methods used to keep the bolts, washers, and nuts within reach of the assembly operator during the assembly process. Previously, the required hardware was handpicked from hardware bins located within the workstation and set loosely upon the flat top surface of the right front suspension cart. The suspension cart is used to maneuver and lift the entire right-hand wheel hub and A-arm assembly into place underneath the J-coach. Assembly operators were then responsible for ensuring that the correct quantity and the correct part numbers were installed in their respective locations according to the provided work instructions.

The assembly process was then improved by MCI through the use of a basic tray that held only the correct number of hardware components required for the right hand side of the front suspension assembly. The hardware tray can also be carried to the work area and placed on the suspension cart. However, due to the relatively small (dimensional) differences in some of the hardware used within the workstation, this fixture design allows the possibility for incorrect hardware to be loaded into the fixture, specifically the lock washers and nuts for the steering gear installation process. Assembly operators also outlined the difficulty of lifting and carrying the triangle shaped fixture with no handle, as well as the difficulty they were experiencing removing hardware from the tray due to tight tolerances. To address the existing problems, a new right-hand suspension fixture, as seen in Figure 30, was created to organize and track hardware as it is installed, improve handling of the hardware fixture, and ultimately error proof the assembly process.

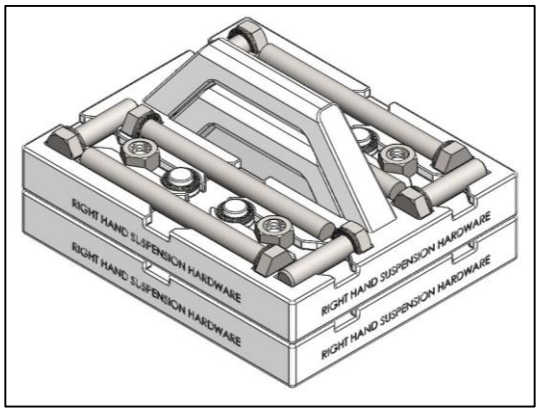


Figure 30: Fully assembled and stacked right-hand suspension fixture [61].

The right-hand suspension hardware fixture is designed around the handle, which addresses the need for ergonomic handling of the fixture during movement within the workstation.

Additionally, the handle serves a second function as a stacking feature, allowing multiple fixtures to be stored vertically, centered on the handle. A total of 24 components are placed within the right hand suspension fixture, as seen in Table XXVII. The layout of the hardware is symmetrical across the centerline of the handle, creating a near neutral weight balance, and allowing for easy verification of all hardware during the installation process. Washers are preloaded onto all eight bolts before being placed in the fixture, and the fixture has been designed to accommodate this to eliminate the sub assembly process while underneath the bus. Figure 31 illustrates the overall layout of the fixture. General dimensions and hardware locations can be seen on the right suspension hardware fixture drawings provided immediately following Section 8.4.

TABLE XXVII: FRONT INDEPENDENT SUSPENSION HARDWARE - RIGHT

Part Number	Description	Weight (g)	Amount
1901-2287	M18X 1.5X70 Screw	187	4
1902-0404	Lock washer M18; inner diameter: 19.5mm, outer diameter: 29 mm; thickness = 3.4mm.	9	12
1903-0781	M18 Nut; outside diameter: 27mm; thickness 15mm	48	4
1901-2286	M18X1.5X200 Screw	465	4
Total Mass of Right Hand Suspension Hardware		2908	

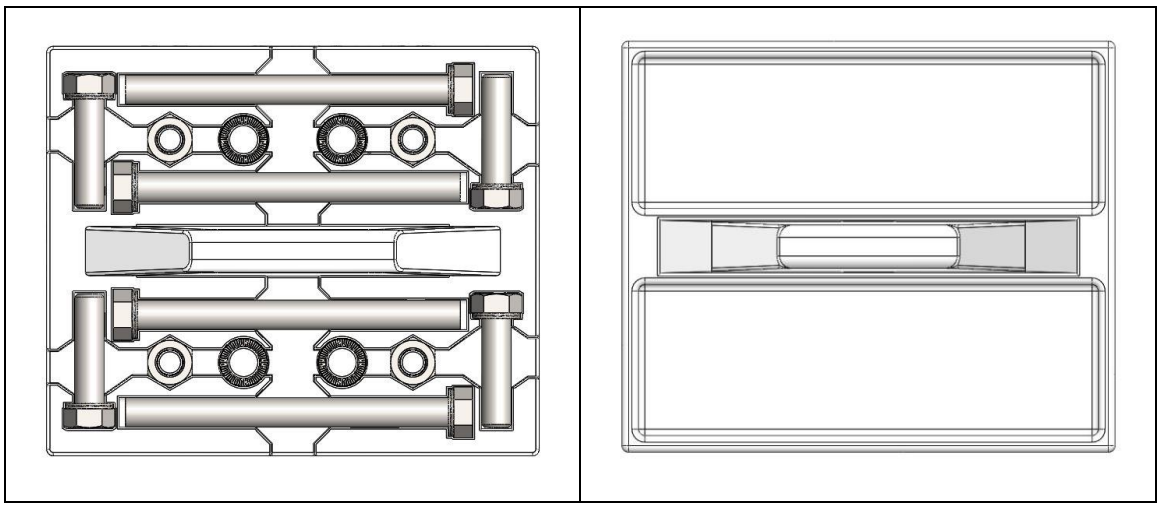


Figure 31: Top view (left) and bottom view (right) of right-hand suspension hardware fixture [62].

In addition to presenting the steering gear in an organized, easy to follow manner, the design of the right hand suspension fixture must also ensure that only the correct parts, and correct quantity of parts, can be placed into the fixture. The hardware contained in the suspension fixture is

dimensionally similar to the steering gear hardware, and thus the design of the suspension fixture must prevent the possibility that the similar steering gear hardware is placed into the suspension fixture.

In order to achieve this design requirement, the specific components which are prone to user error in the right suspension fixture had their features modeled to a precise tolerance. The affected components most likely to be installed by mistake is the steering gear lock washer, part number 1902-0414, and suspension nut, part number 1903-0775; these are highlighted in Figure 32. As such, these parts must not be able to be placed into the suspension fixture.

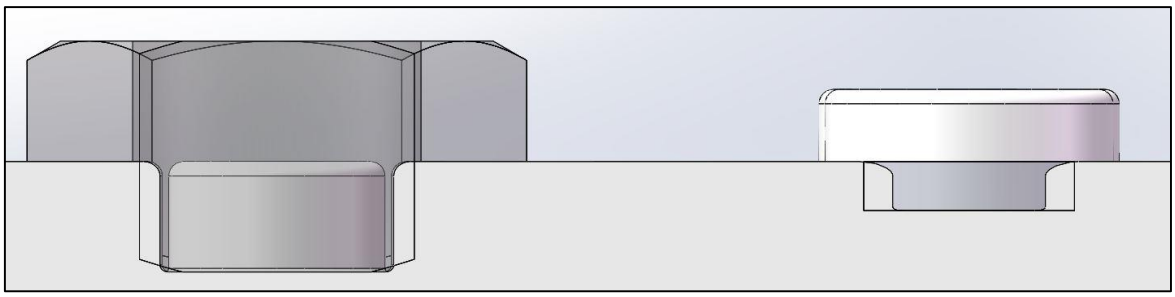


Figure 32: Interference occurs when steering gear washer (left) and steering gear nut (right) is inserted into the right hand suspension hardware fixture [63].

As with the left hand suspension hardware fixture, the lock washers used in the right hand suspension hardware fixture are prone to erroneous installation, stemming from the unique, two piece design bonded together by adhesive. Due to the supplier's large scale of manufacturing and storage of the components, it is easy to find washers that have split apart and formed a set of three halves. This creates a problem as locking mechanism only function with two halves, that when torqued, crush the adhesive and interlock teeth. If a third washer halve is introduced, the washer would essentially fail to perform its required design function. In order to address this issue, the washer feature is designed in a way that only when the correct washer is placed into the fixture, the top surface of the washer will sit flush with the top surface of the hardware fixture. This can be verified both visually and also physically by the assembly operator as they pass their finger over the feature. An illustration of this can be seen in Figure 33.

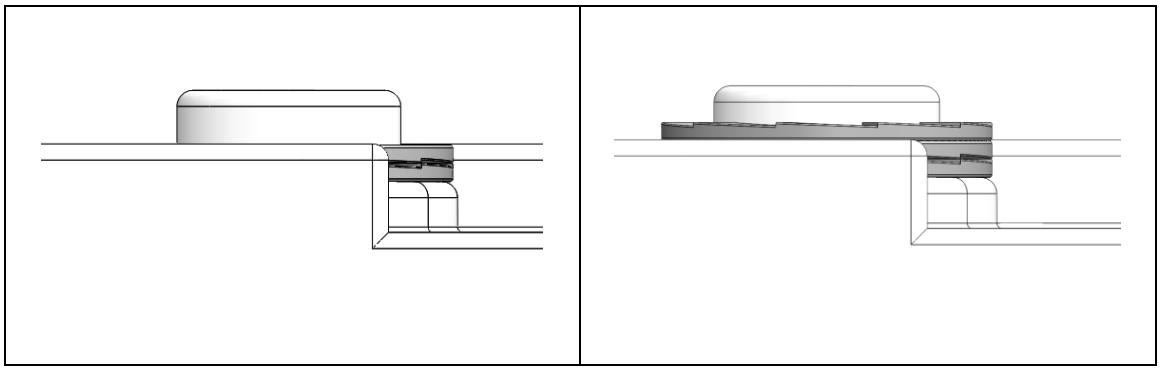
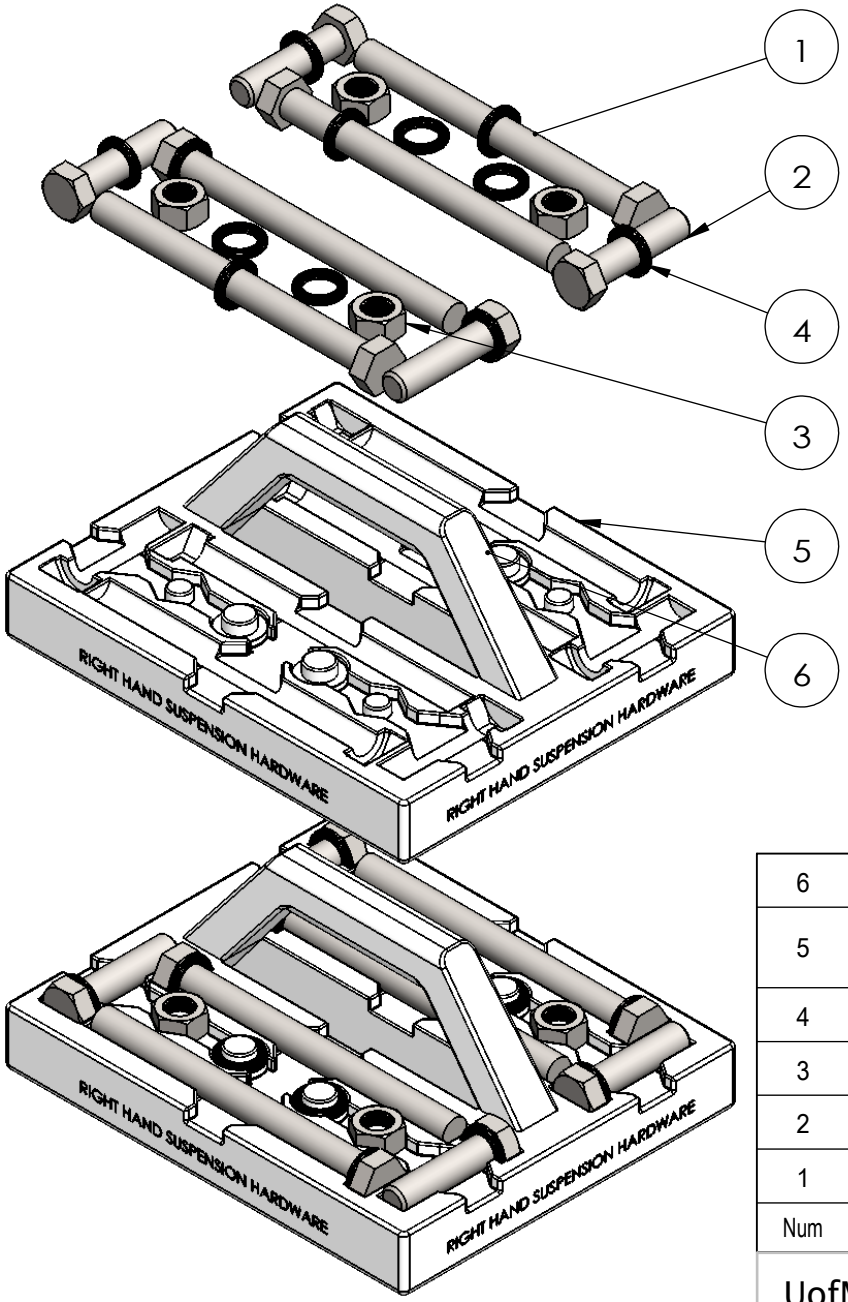
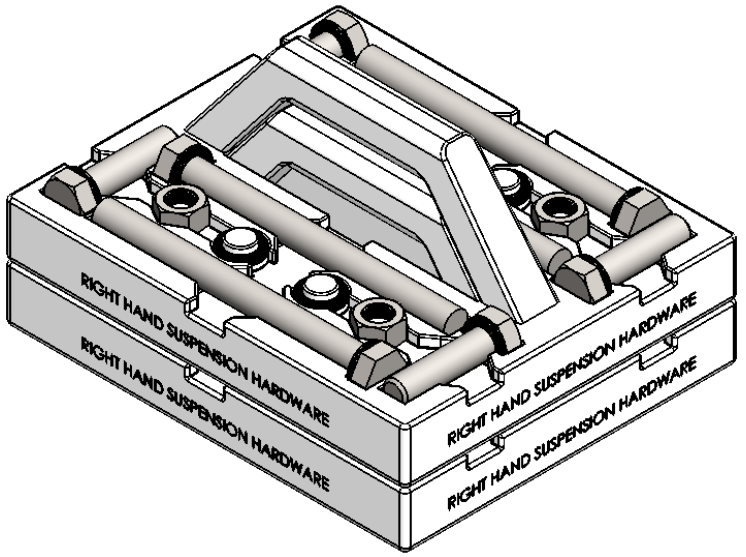


Figure 33: Suspension lock washer (1902-0405) thickness can be verified visually, and by touch [64].

With the above design considerations in mind, the Design Team is confident that the right hand suspension fixture meets the needs of the client by addressing the current issues that exist within the assembly process in Station 19 of the J-coach line at MCI. The design specifically addresses the need for a completely new hardware fixture that is ergonomic for the assembly operators, stackable for easy storage, can easily be assembled within the station and reduces the possibility of assembly error by preventing the placement of incorrect hardware into the fixture during suspension assembly. Additionally, the Risk Priority Number (RPN) will also be reduced if the right-hand front suspension hardware fixture is utilized in the assembly process. Details regarding the reduced RPN values can be seen in Table VI located in the Failure Modes and Effects Analysis provided in Appendix A.





Num	Name	Material	Quantity	Weight(g)	Description
6	Fixture Handle	ABS	2	204.271	Fixture Handle
5	Right Side Suspension Fixture Body	ABS	2	1496.37	RIGHT HAND SUSPENSION FIXTURE BODY
4	1902-0405	HSS	24	4.37	M18 Lock Washer
3	1903-0781	HSS	8	47.898	M18 Nut
2	1901-2286	HSS	8	199.67	M18 X 1.5 X 70
1	1901-2287	HSS	8	465.233	M18 X 1.5 X 200

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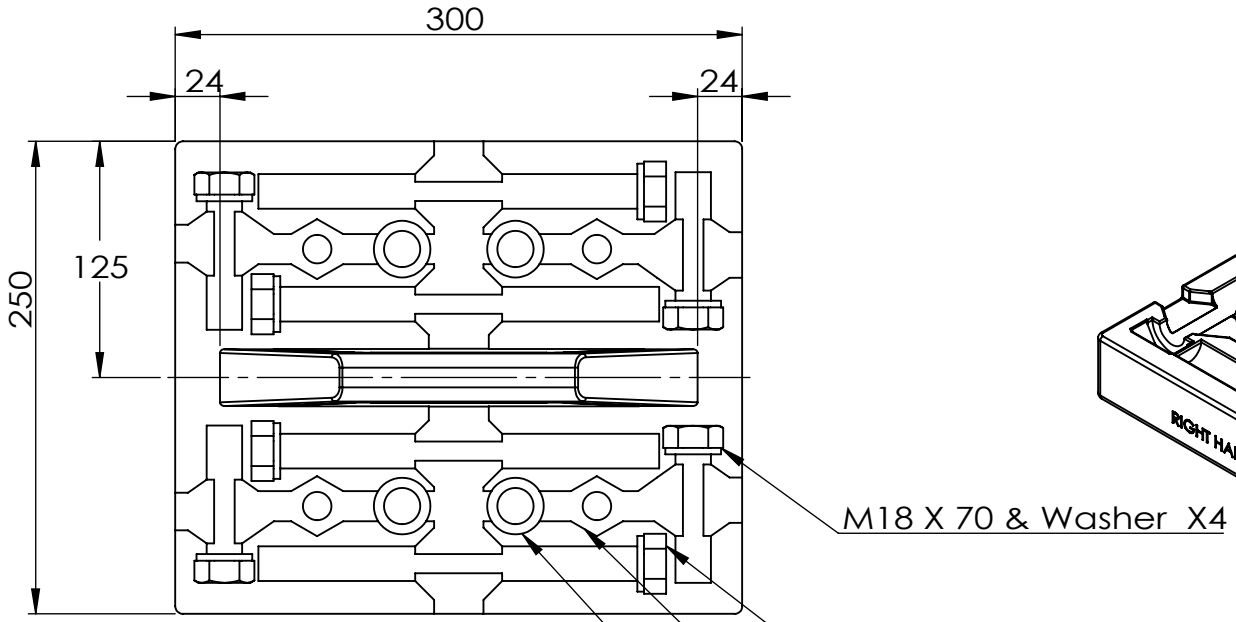
MATERIAL ASSEMBLY	CHECKED	D.D.	2015/12/5
FINISH AS ASSEMNBLED			

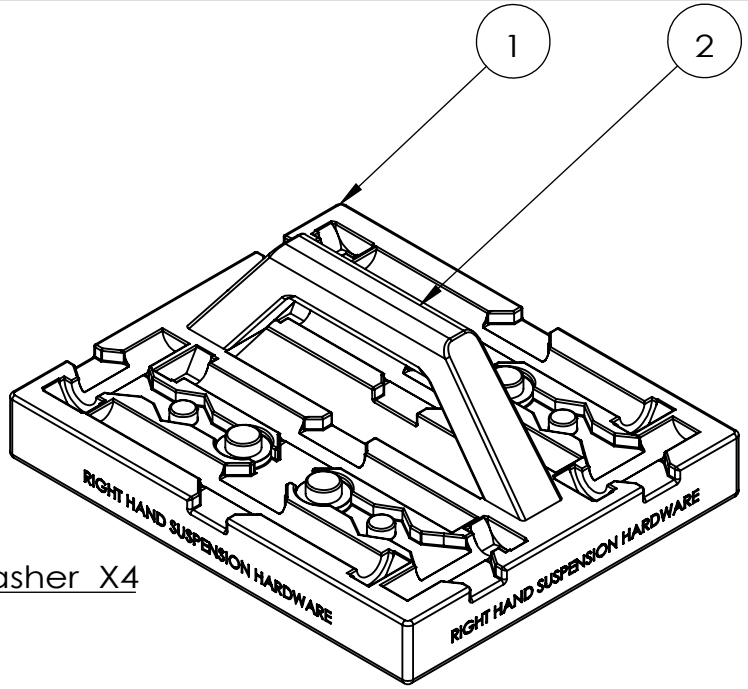
TITLE:
RIGHT HAND SUSPENSION FIXTURE

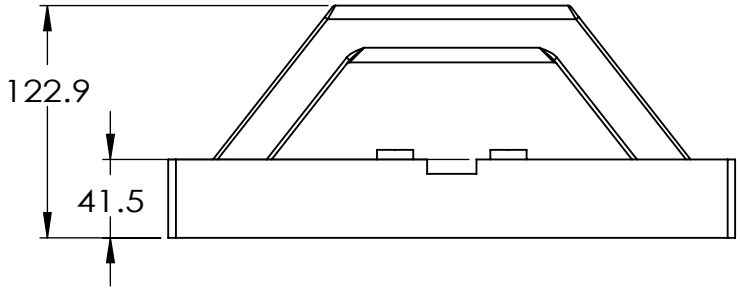
SIZE	DISCRIPTION:	REV
A	RIGHT HAND SUSPENSION FIXTURE WITH STACKING	4

SCALE: 1:4 | WEIGHT: 15225.68 | SHEET 1 OF 3

5 4 3 2 1







Num	Name	Material	Quantity	Weight(g)	Description
2	Fixture Handle	ABS	1	204.271	Fixture Handle
1	Right Side Suspension Fixture Body	ABS	1	1496.37	RIGHT HAND SUSPENSION FIXTURE BODY

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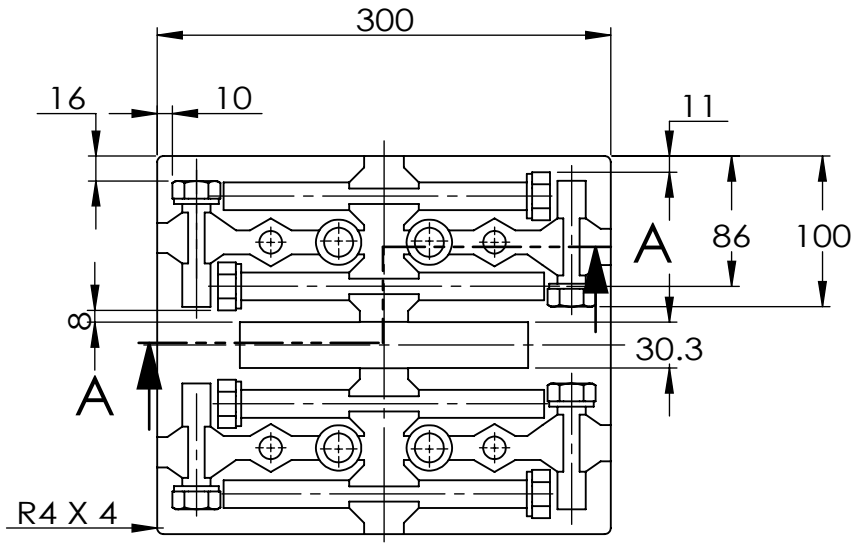
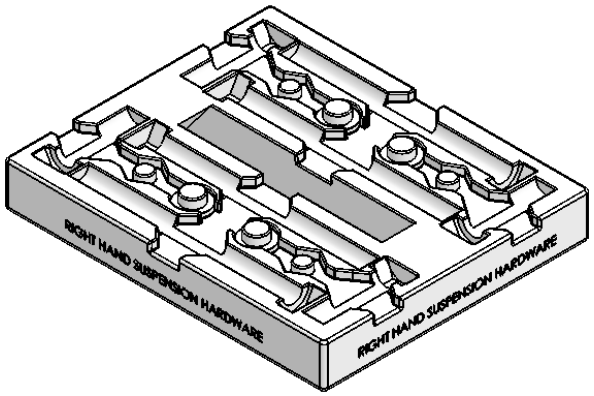
MATERIAL ABS	CHECKED	D.D.	2015/12/5
FINISH ADDITIVE MANUFACTURING			

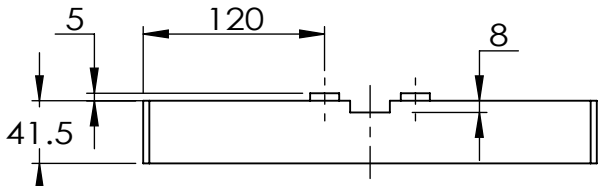
TITLE:
RIGHT HAND SUSPENSION FIXTURE

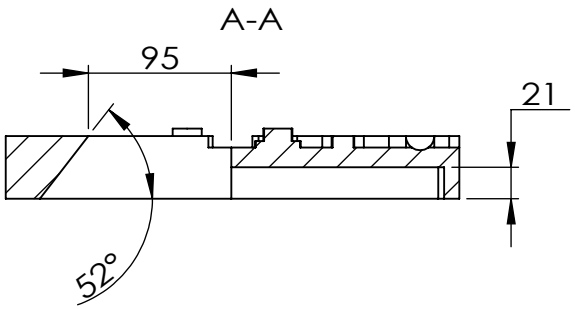
SIZE	DISCRIPTION:	REV
A	RIGHT HAND SUSPENSION FIXTURE	4
SCALE: 1:4	WEIGHT: 1700.65	SHEET 2 OF 3

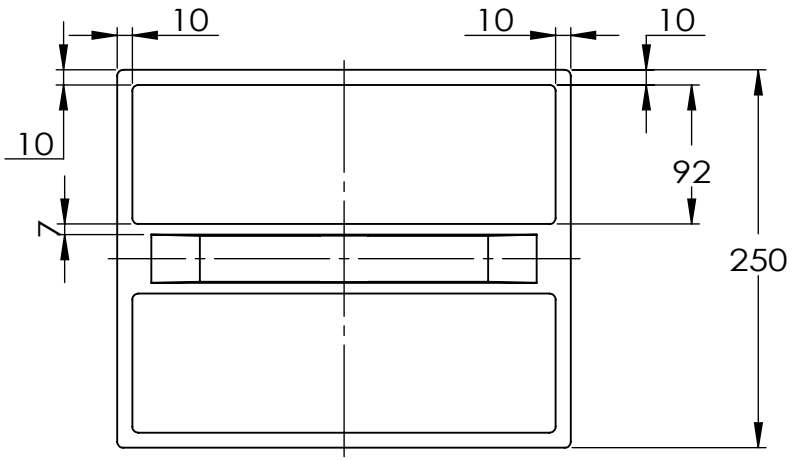
5 4 3 2 1











Note:
1. All Edges Fillets: 1.5 mm
2. For Additive Manufacturing only (3D Printer)

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INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14. 5M-1994		NAME	DATE
DO NOT SCALE DRAWING	DRAWN	B.J.	2015/11/22
MATERIAL ABS	CHECKED	D.D.	2015/12/5
FINISH ADDITIVE MANUFACUTRING			

TITLE: **RIGHT HAND SUSPENSION FIXTURE**

SIZE	DISCRIPTION:	REV
A	RIGHT HAND SUSPENSION FIXTURE BODY	4

SCALE: 1:5 | WEIGHT: 1496.37 | SHEET 3 OF 3

5 4 3 2 1

8.5 Steering Gear Hardware Fixture

In Station 19, the hardware for the steering gear installation process is placed loose on the steering gear fixture cart as it is brought to the coach for assembly. Additionally, the assembly operators have no provisions available to them that allow them to bring the steering gear hardware to the coach in an organized fashion. To address this situation, the steering gear hardware fixture was created to provide the assembly operators within Station 19 with the means to organize and track the steering gear hardware as it is installed. The steering gear hardware description can be seen in Table XXVIII while the fully assembled and stacked steering gear hardware fixture can be seen in Figure 34.

TABLE XXVIII: STEERING GEAR ASSEMBLY HARDWARE

Part Number	Description	Weight (g)	Amount
1901-2172	M20X100 Screw	311	4
1902-0414	Lock washer M20; inner diameter: 21.4mm, outer diameter: 30.7mm; thickness: 3.4mm.	9.2	8
1903-0775	M20X1.5 Nut; outside diameter: 30mm; thickness: 16mm.	65	4
Total Mass of Steering Gear Assembly Hardware		1577.6	16

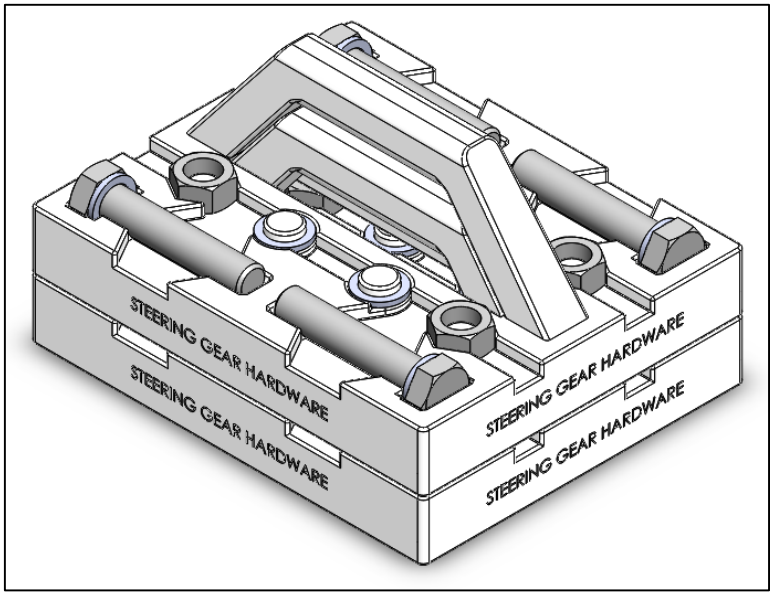


Figure 34: Fully assembled and stacked steering gear hardware fixture [65].

The detailed part numbers and their locations in the fixture can be seen in the bill of materials found in the assembly drawings for the steering gear hardware fixture immediately following Section 8.5. Note that a washer is to be placed on the bolts prior to insertion into the fixture, as

this is preferred by the assembly line operators and the fixture has been designed to accommodate this in order to eliminate the sub assembly process while underneath the coach. In addition, having the nuts placed in a horizontal fashion allows the assembly operators to place the nuts with their identification numbers visible. This reduces the amount of visual checks that the assembly operators need to perform during installation.

The steering gear fixture effectively organizes the 16 components (nuts, fasteners and washers) required to secure the steering gear onto the coach. Figure 35 illustrates the layout of the top and bottom faces of the steering gear hardware fixture and it can be seen that this fixture presents hardware in a symmetrical fashion. This means that the fixture can be stacked without concern of orienting the top fixture in an incorrect fashion.

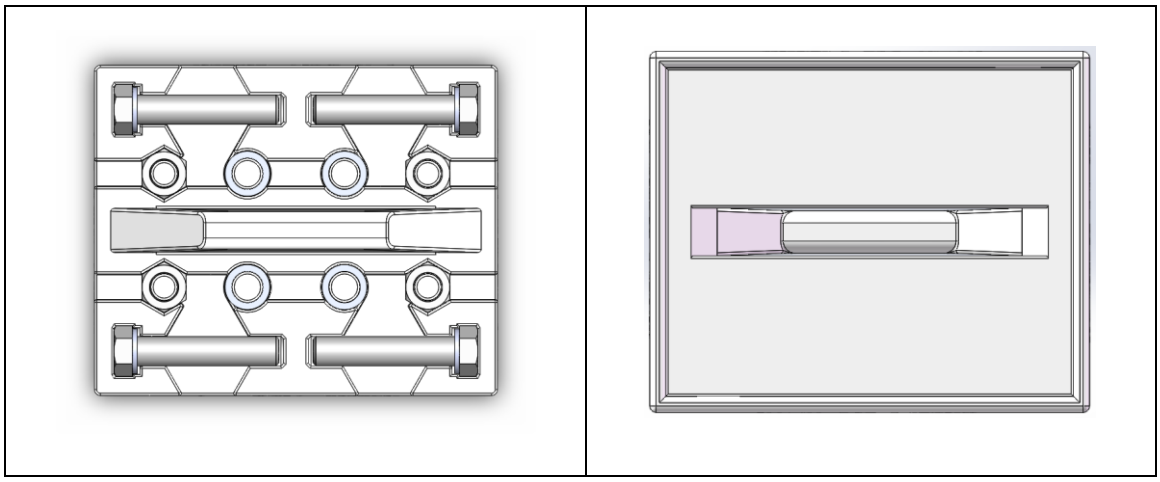


Figure 35: Top view (left) and bottom view (right) of the steering gear hardware fixture [66].

In addition to presenting the steering gear hardware in an organized fashion, the steering gear hardware fixture has to ensure that only the correct parts, and only the correct number of parts, can be installed into the steering gear fixture. As the steering gear hardware was determined to be dimensionally similar to the suspension hardware, the steering gear hardware fixture had to be created in a fashion that prevents suspension hardware from being placed into the fixture.

To address this issue, the steering gear hardware fixture contains tolerances that prevent the placement of the suspension hardware into the steering fixture. Figure 36 illustrates that part number 1902-0781 (suspension nut) and part number 1902-0405 (suspension washer) cannot be placed into the steering gear fixture due to these tolerances.

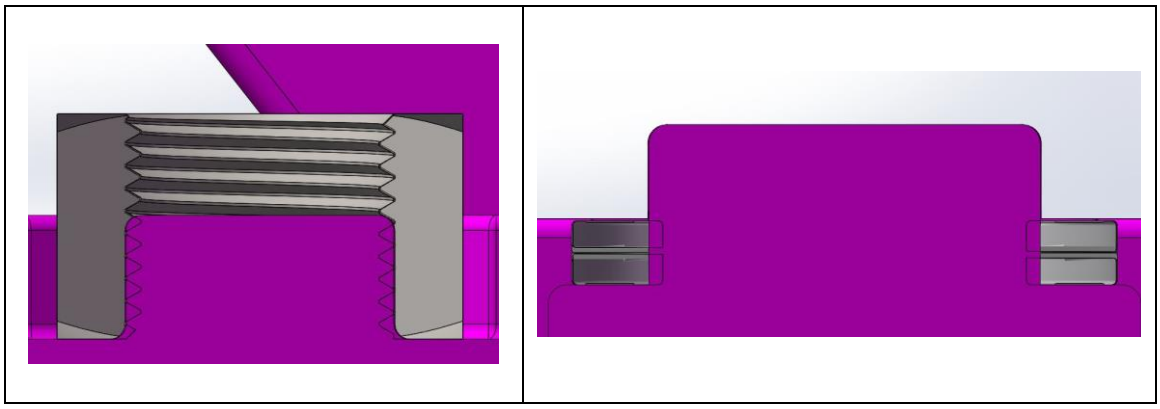


Figure 36: Internal interference occurs when suspension nut (left) and suspension washer (right) is inserted into the steering gear hardware fixture [67].

Although it is apparent that only four bolts and four nuts can be placed within the fixture, the steering gear washers are unique. This is due to the fact that the steering gear washers (part number 1902-0414) are a two-piece design. As such, there have been instances where three or more washer-halves have been installed on the coach within Station 19. To address this issue, the Design Team has established a visual check to verify that only a complete, two piece washer is placed into the steering gear fixture, as illustrated in Figure 37.

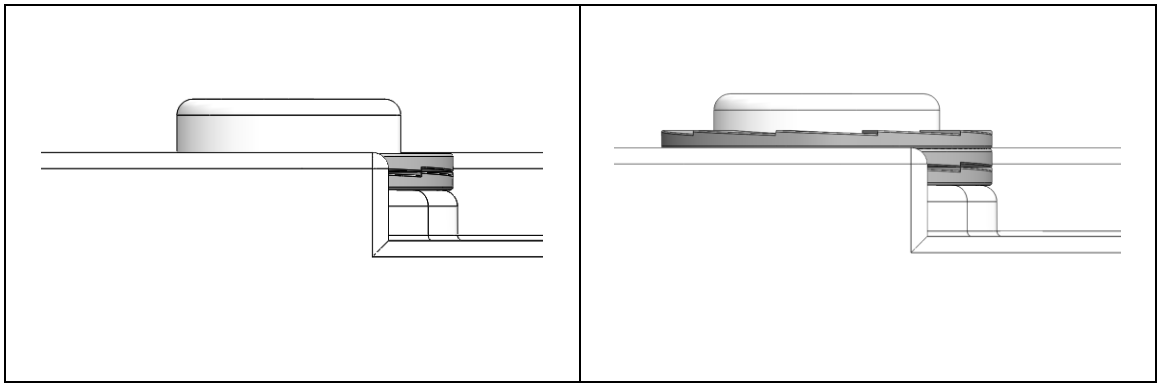
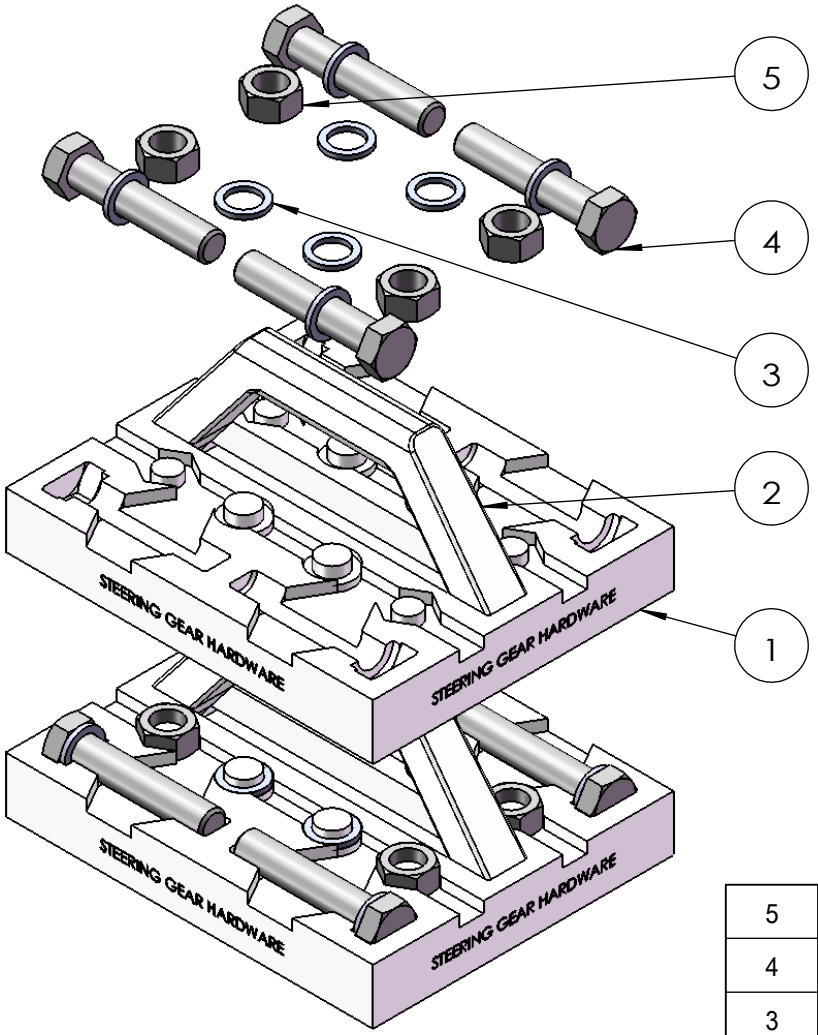
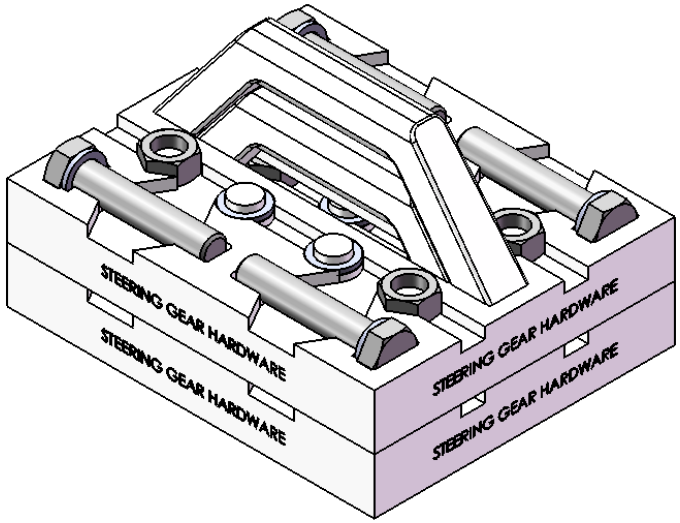


Figure 37: Thickness of two-piece suspension lock washer (1902-0414) can be verified visually, and by touch [68].

Figure 37 illustrates that when two washer halves are present, as seen on the left, the washer will be flush with the top face of the fixture, which can be verified by touch and by sight. If there are instances in which more than two washer halves are stuck together, the additional halves will be raised above the top face of the steering gear fixture and the component can be easily removed with a replacement that meets specification.

With the above considerations in mind, the Design Team is confident that the steering gear hardware fixture meets the needs of the client by organizing the steering gear hardware with a fixture design that is ergonomic to the user and stackable. Furthermore, by ensuring that the tolerances of the fixture prevents hardware from being improperly installed into the fixture itself, the risk of installing incorrect hardware onto the coach in Station 19 will be reduced, effectively error proofing the installation of the steering gear into the coach. Additionally, the Risk Priority Number (RPN) will also be reduced if the steering gear hardware fixture is utilized in the assembly process. Details regarding the reduced RPN values can be seen in Table V located in the Failure Modes and Effects Analysis provided in Appendix A.





Num	Name	Material	Quantity	Weight(g)	Description
5	1903-0775	HSS	8	7.386	M20X1.5 NUT
4	1901-2172	HSS	8	41.03	M20 X 100
3	1902-0414	HSS	16	1.29	M20 Washer
2	Fixture Handle	ABS	2	204.271	FIXTURE HANDLE
1	Steering Gear Fixture	ABS	2	1156.45	STEERING GEAR HARDWARE FIXTURE BODY

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TOLERANCES:
ANGULAR: MACH ±0° 30'
TWO PLACE DECIMAL ±.127

UofM MECHANICAL ENGINEERING

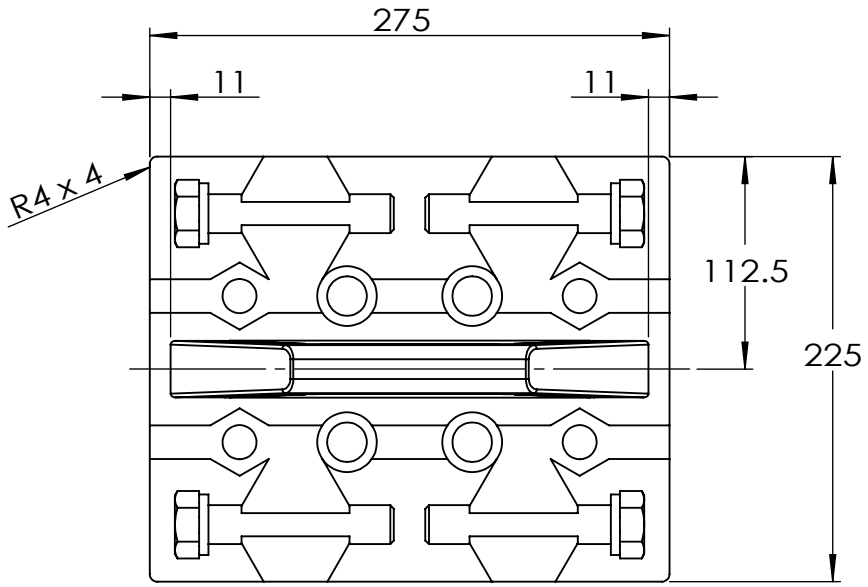
INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14. 5M-1994		NAME	DATE
DO NOT SCALE DRAWING	DRAWN	M.Y.	2015/11/21
MATERIAL ASSEMBLY	CHECKED	D.D.	2015/12/5
FINISH AS ASSEMBLED			

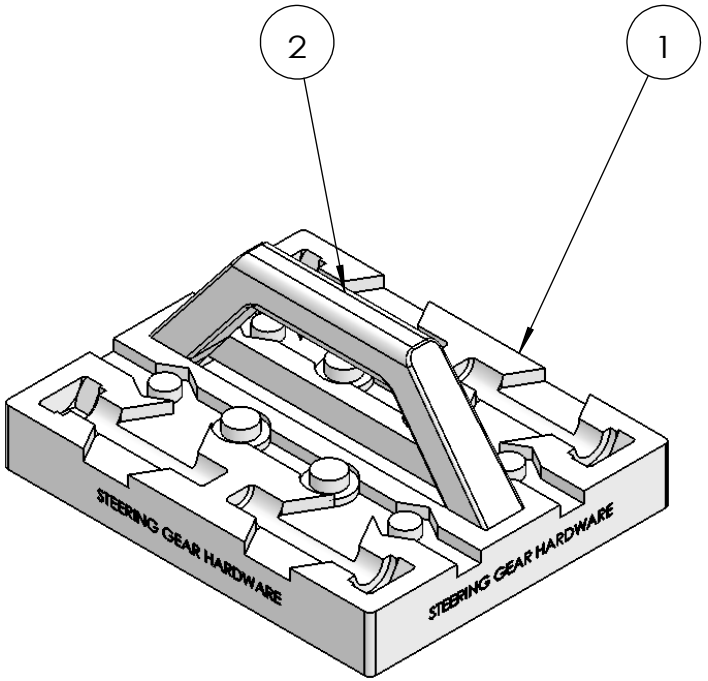
TITLE: **STEERING GEAR HARDWARE FIXTURE**

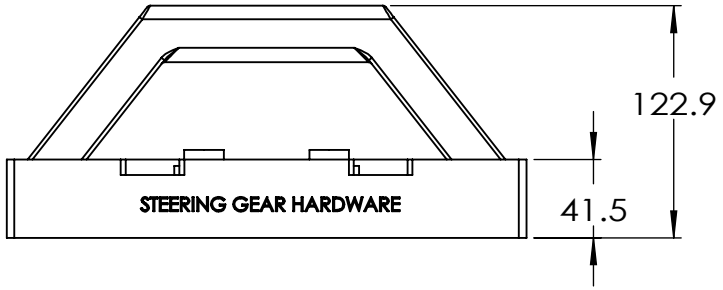
SIZE	DISCRIPTION:	REV
A	STEERING GEAR HARDWARE FIXTURE WITH STACKING	6

SCALE: 1:3 | WEIGHT: 3.129 | SHEET 1 OF 3

5 4 3 2 1







Num	Name	Material	Quantity	Weight(g)	Description
2	Fixture Handle	ABS	1	204.271	FIXTURE HANDLE
1	Steering Gear Fixture	ABS	1	1156.45	STEERING GEAR HARDWARE FIXTURE BODY

SolidWorks

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TOLERANCES:
ANGULAR: MACH ±0° 30'
TWO PLACE DECIMAL ±.127

UofM MECHANICAL ENGINEERING

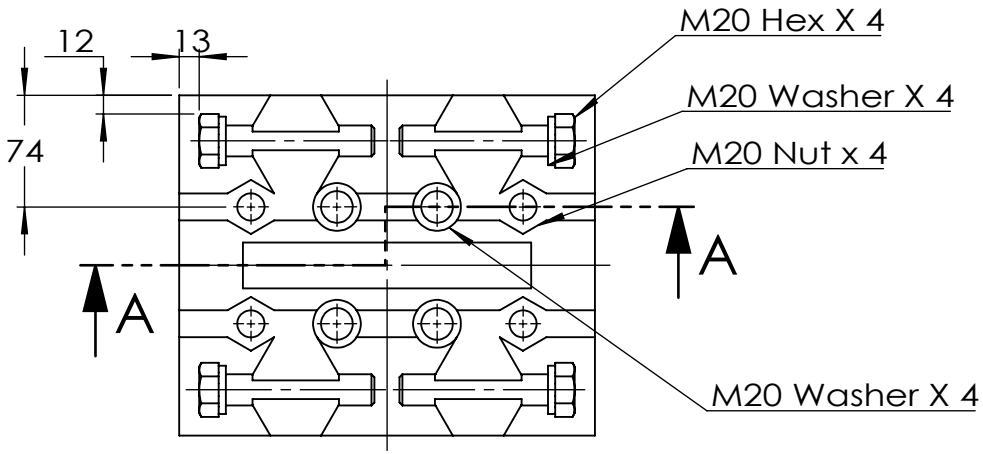
INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14. 5M-1994		NAME	DATE
DO NOT SCALE DRAWING	DRAWN	M.Y.	2015/11/21
MATERIAL ABS	CHECKED	D.D.	2015/12/5
FINISH ADDITIVE MANUFACTURING			

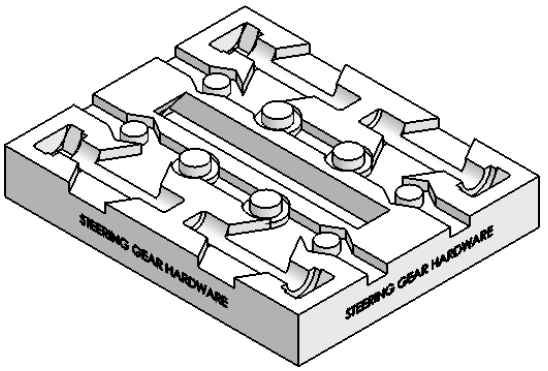
TITLE: **STEERING GEAR HARDWARE FIXTURE**

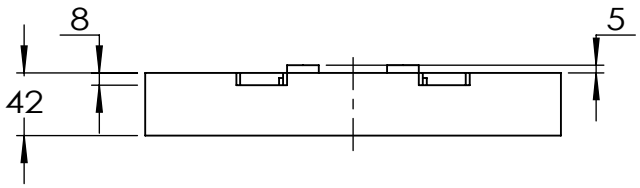
SIZE	DISCRIPTION:	REV
A	STEERING GEAR HARDWARE FIXTURE	6

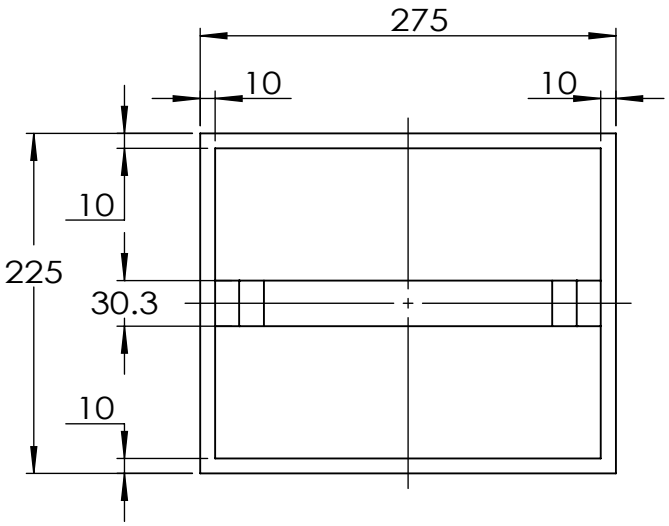
SCALE: 1:4 | WEIGHT: 1360.14 | SHEET 2 OF 3

5 4 3 2 1

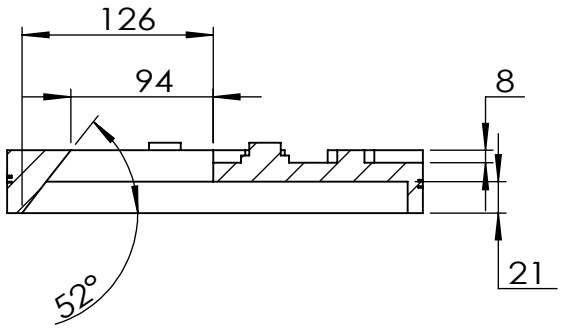








A–A



Note:
1. All Edges Fillet: 1.5 mm
2. For Additive Manufacturing Only (3D Printer)

SolidWorks	MECH 4860	UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN METRIC TOLERANCES: ANGULAR: MACH ±0° 30' TWO PLACE DECIMAL ±.127	UofM MECHANICAL ENGINEERING	TITLE: STEERING GEAR HARDWARE FIXTURE
			INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14. 5M-1994 / NAME / DATE	SIZE: A / DISCRIPTION: STEERING GEAR HARDWARE FIXTURE BODY / REV: 6
			DO NOT SCALE DRAWING / DRAWN / M.Y. / 2015/11/21	SCALE: 1:5 / WEIGHT: 1156.45 / SHEET 3 OF 3
			MATERIAL ABS / CHECKED / D.D. / 2015/12/5	
			FINISH ADDITIVE MANUFACTURING	

5 4 3 2 1

8.6 MITRE BOX HARDWARE FIXTURE

The mitre box hardware fixture serves to organize the hardware for the mitre box installation, as the current procedure for storing hardware prior to installation is to place it loosely into the access compartment on the coach. As the mitre box assembly takes places in a confined area, the operators are inconvenienced when the nuts, bolts and washers roll out of reach and as a result, the assembly operators have to reposition themselves each time that this occurs. In order to secure the mitre box hardware for the assembly workers, the team created a mitre box hardware fixture to perform this task. The mitre box hardware description can be seen in Table XXIX while the fully assembled and stacked mitre box fixture can be seen in Figure 38.

TABLE XXIX: MITRE BOX HARDWARE

Part Number	Description	Weight (g)	Amount
1901-1975	M12X50 Screw; Din 931.	60	4
1902-6004	Washer-Flat; M12	7	8
1903-6083	Lock Hex Nut; M12	20	4
Total Mass of Mitre Box Hardware		376	16

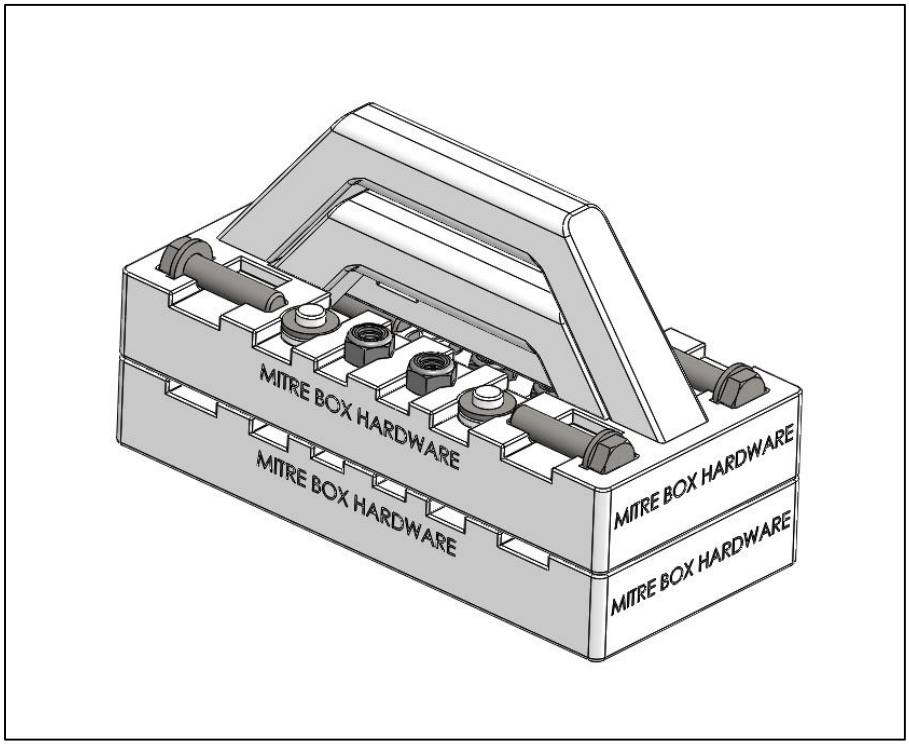


Figure 38: Fully assembled and stacked mitre box hardware fixture [69].

This fixture organizes the components identified in Table XXIX (16 components total) in a symmetrical fashion, as seen in Figure 39 and can be stacked regardless of the orientation of the topmost fixture. Detailed locations of the components, and their part numbers, can be seen in the bill of materials included with the assembly drawings for the mitre box hardware fixture, immediately following Section 8.6. It is to be noted that a washer is to be placed on the mitre box bolts prior to insertion into the fixture, this is a preferred method of the assembly line operators currently as this reduces assembly operations when under the coach.

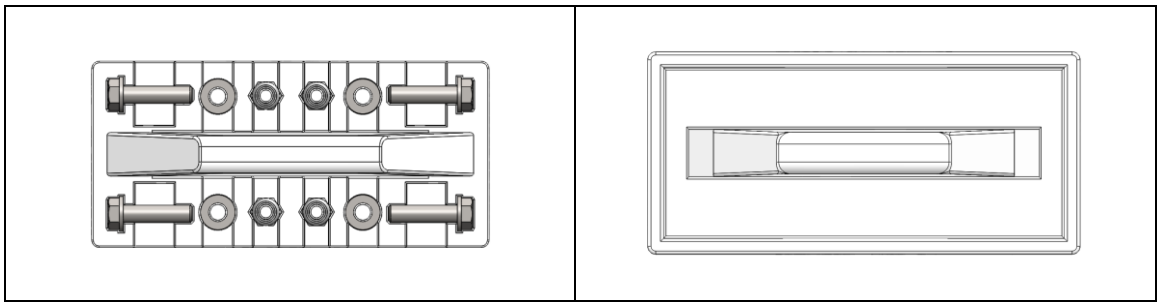


Figure 39: Top view (left) and bottom view (right) of the mitre box hardware fixture [70].

The design team has identified that part number 192-284 (½" flat washer used in the front axle cart fixture) is dimensionally similar to part number 1902-6004 (M12 flat washer) used to secure the mitre box. As such, the Design Team designed the mitre box fixture in such a way as to prevent the insertion of part number 192-284 into the mitre box fixture. Figure 40 illustrates that when part number 192-284 is placed into the mitre box fixture, interference will result, preventing the assembly operator from installing the incorrect washers into the fixture and onto the coach. It is to be noted that no other hardware was identified by the Design Team that could be mistakenly placed in the mitre box fixture.

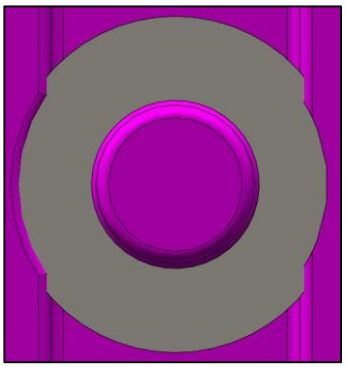
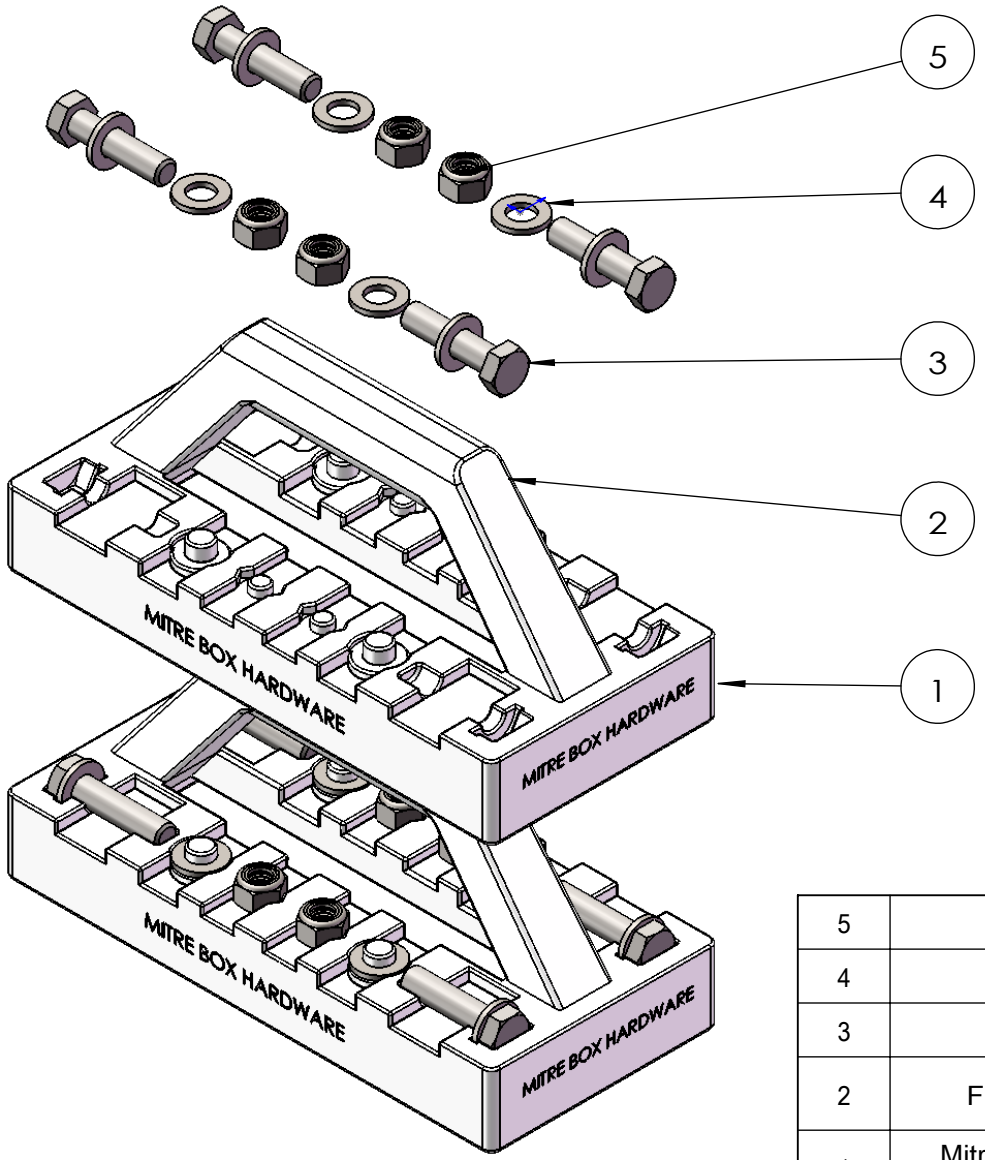
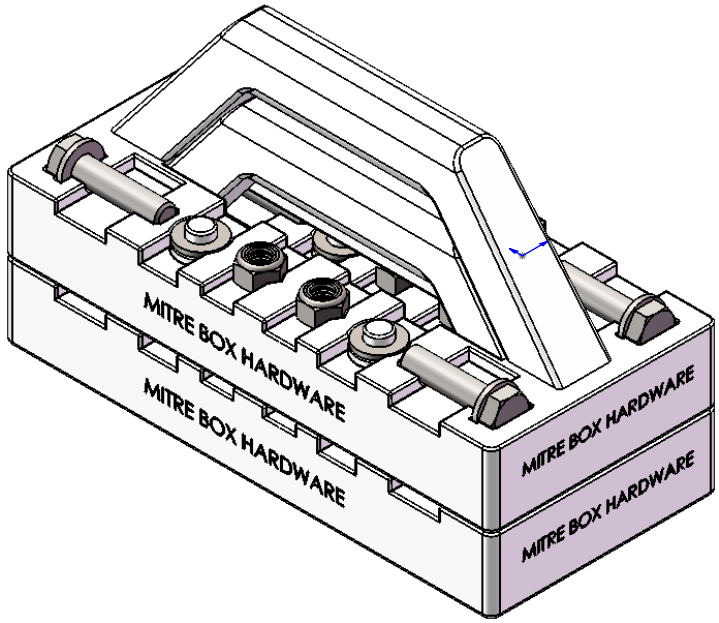


Figure 40: External interference occurs when inserting part number 192-284 into the mitre box fixture [71].

With the above considerations in mind, the Design Team is confident that the Mitre Box Hardware Fixture meets the needs of the client by organizing the mitre box hardware with a fixture design that is ergonomic and stackable. Furthermore, by ensuring that the tolerances of the fixture prevents incorrect hardware from being installed into the fixture itself, the risk of installing incorrect hardware onto the coach in Station 19 will be reduced, effectively error proofing the mitre box installation process. Additionally, the Risk Priority Number (RPN) will also be reduced if the mitre box hardware fixture is utilized in the assembly process. Details regarding the reduced RPN values can be seen in Table V located in the Failure Modes and Effects Analysis provided in Appendix A.





Num	Name	Material	Quantity	Weight(g)	Description
5	1903-6083	HSS	8	18.743	M12 LOCKNUT HEX
4	1902-6004	HSS	16	6.65	M12 WASHER
3	1901-1975	HSS	8	63.70	M12 X 50 DIN 931
2	Fixture Handle	ABS	2	204.271	Mitre Box Hardware Fxiture Handle
1	Mitre Box Hardware Fixture	ABS	2	693.7636	MITRE BOX HARDWARE FIXUTRE BODY

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TWO PLACE DECIMAL ±.127

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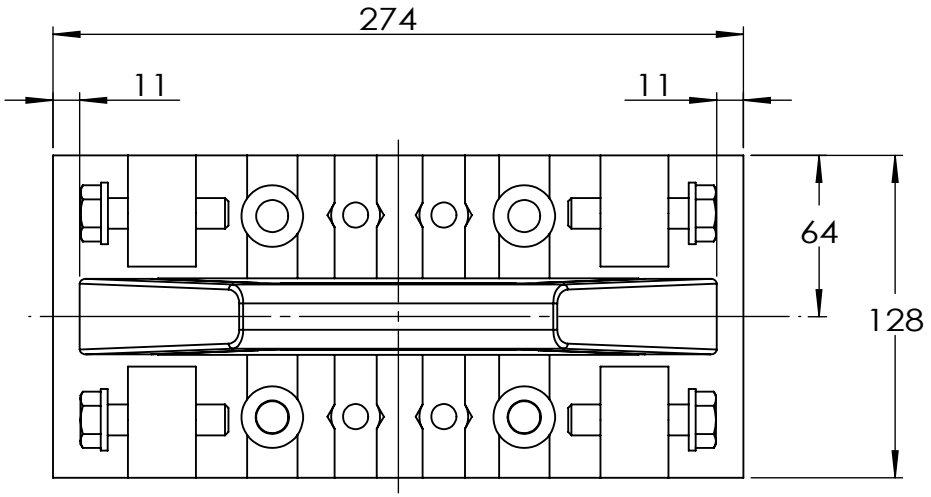
INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14. 5M-1994		NAME	DATE
DO NOT SCALE DRAWING	DRAWN	M.Y.	2015/11/21
MATERIAL ASSEMBLY	CHECKED	D.D.	2015/12/5
FINISH AS ASSEMBLED			

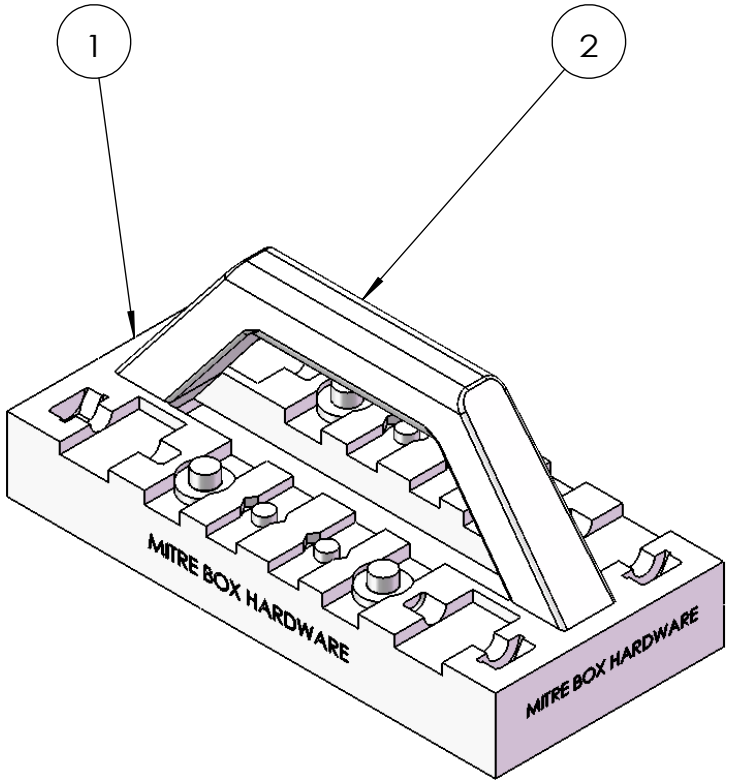
TITLE:
MITRE BOX HARDWARE FIXUTRE

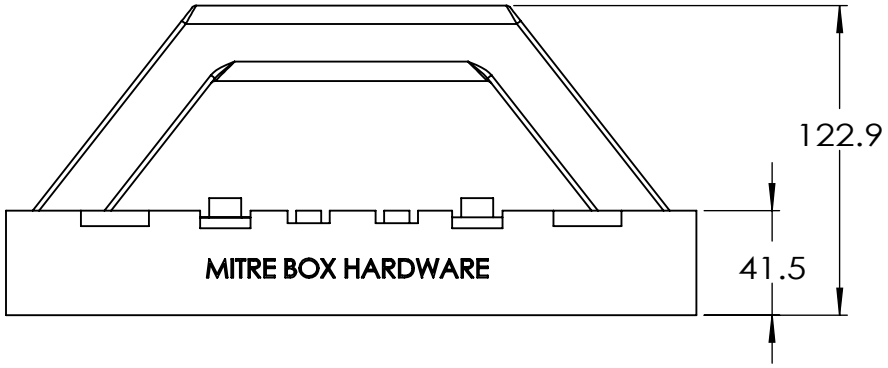
SIZE	DISCRIPTION:	REV
A	MITRE BOX HARDWARE FIXUTRE WITH STACKING	6

SCALE: 1:3 | WEIGHT: 2555.885 | SHEET 1 OF 3

5 4 3 2 1







Num	Name	Material	Quantity	Weight(g)	Description
2	Fixture Handle	ABS	1	204.271	Mitre Box Hardware Fxiture Handle
1	Mitre Box Hardware Fixture	ABS	1	693.7636	MITRE BOX HARDWARE FIXUTRE BODY

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TOLERANCES:
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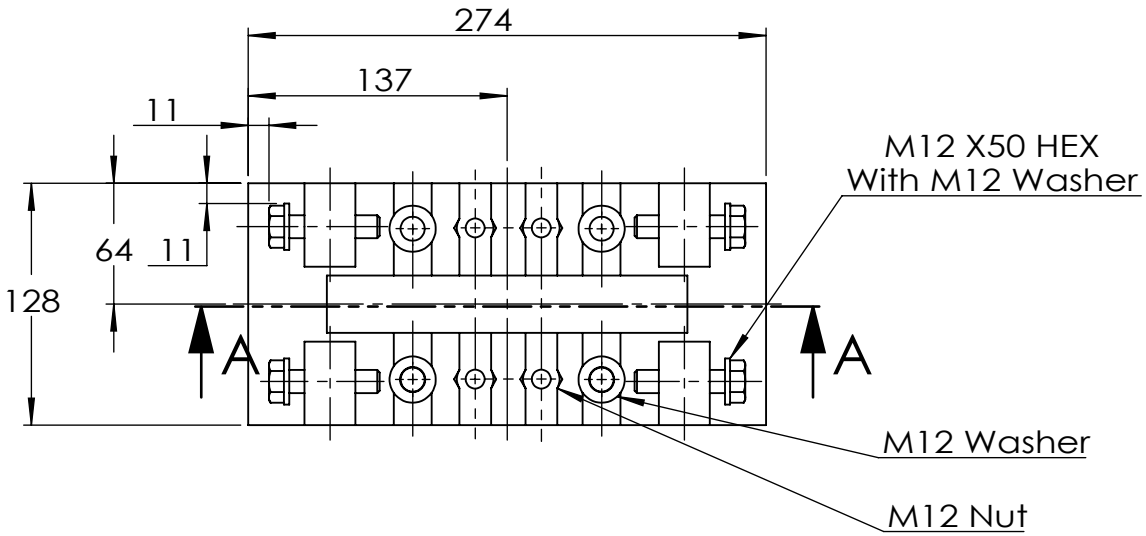
INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14. 5M-1994		NAME	DATE
DO NOT SCALE DRAWING	DRAWN	M.Y.	2015/11/21
MATERIAL ABS	CHECKED	D.D.	2015/12/5
FINISH ADDITIVE MANUFACTURING			

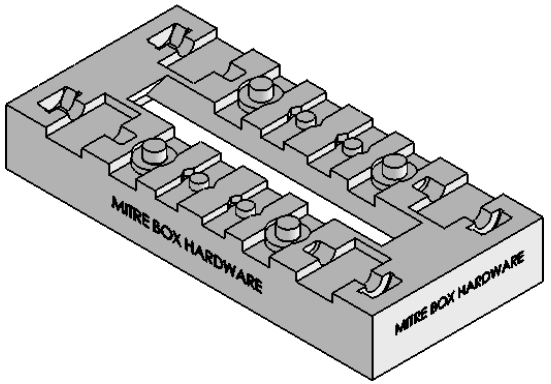
TITLE:
MITRE BOX HARDWARE FIXUTRE

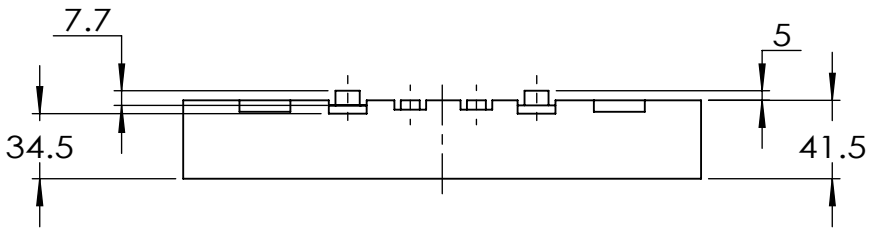
SIZE	DISCRIPTION:	REV
A	MITRE BOX HARDWARE FIXUTRE ASSEMBLY	6

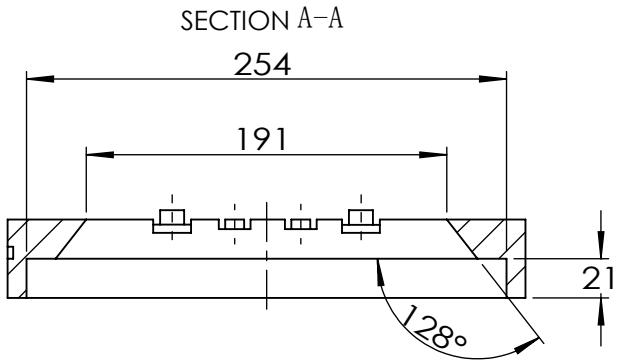
SCALE: 1:3 | WEIGHT: 0.898 | SHEET 2 OF 3

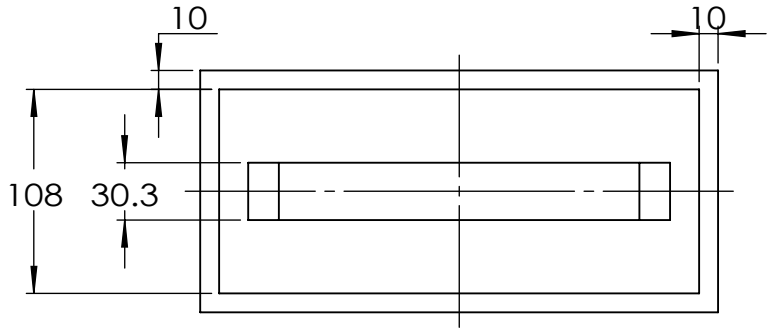
5 4 3 2 1











Note:
1. All Edges Fillet: 1 mm
2. For Additive Manufacturing Only (3D Printer)

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			INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14. 5M-1994	NAME	DATE
			DO NOT SCALE DRAWING	DRAWN M.Y.	2015/11/21
			MATERIAL ABS	CHECKED D.D.	2015/12/5
			FINISH ADDITIVE MANUFACTURING		

TITLE: **MITRE BOX HARDWARE FIXUTRE**		
SIZE **A**	DISCRIPTION: MITRE BOX HARDWARE FIXUTRE BODY	REV 6
SCALE: 1:4	WEIGHT: 693.7636	SHEET 3 OF 3

5 4 3 2 1

8.7 Front Axle Cart Hardware Fixture

The purpose for the front axle cart hardware fixture arose from the observation of how the assembly operators currently store the hardware for installing the auxiliary equipment, such as the air hoses, miscellaneous brackets and the steering shaft and the descriptions of the hardware is provided in Table XXX. The current method for storing this hardware on the front axle cart involves four soft-sided bins with an assorted amount of hardware in each bin. In this set-up, the assembly operators were responsible for tracking and installing the correct amount of hardware for the auxiliary equipment. The front axle cart hardware fixture serves to present the hardware required for the auxiliary equipment installation in an organized manner. The fully assembled and stacked front axle cart hardware fixture can be seen in Figure 41.

TABLE XXX: FRONT AXLE CART HARDWARE

Part Number	Description	Weight (g)	Amount
1901-1536	1/2-13 UNC X 1.5 screw-cap	52	4
1903-0497	Nut-FLG 1/2-13 (Yellow Zinc Plating)	22	4
1903-0641	Nut-Hex slotted, 3/4 – 16 UNF	63	2
192-284	Washer-Flat, 1/2 steel, ZN plated	9	2
193-188	NYLock Nut 1/2 – 13 UNC, ZN PL	24	2
197-26	Cotter Pin; Diameter: 1/8”; Length: 1-3/8”.	7	4
No number	Cotter pin (larger than 197-26)	8	4
1201-1303	Bushing; outer diameter: 17mm; inner diameter: 14mm; height: 28mm.	16	2
1101-1094	M10X50; steering bolt	41.2	4
1101-1083	Lock nut; M10; thickness: 9.85mm	11.3	4
Total Mass of Front Axle Cart Hardware		790	32

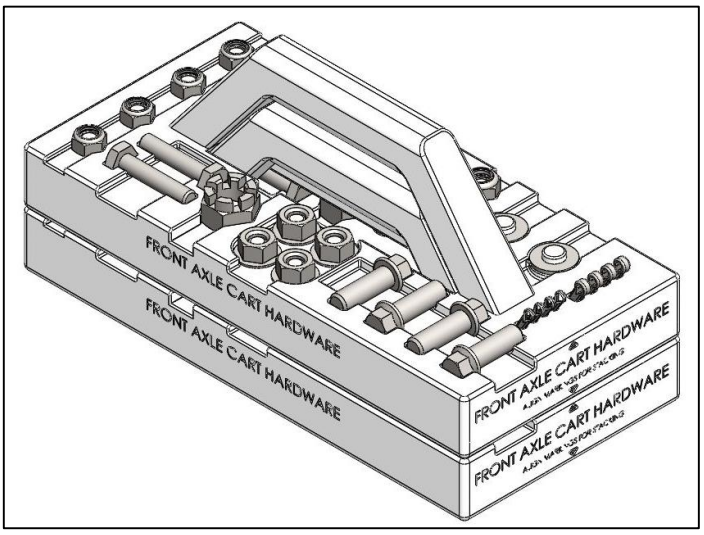


Figure 41: Fully assembled and stacked front axle cart hardware fixture [72].

This fixture organizes the components identified in Table XXX (32 components total) in a manner that is convenient for the assembly operators to ensure that they will continue to utilize the fixture during the assembly process. It is to be noted that this fixture groups like part numbers together to improve the organization and tractability of the hardware as the hardware is installed. Figure 42 illustrates the layout of the front axle cart hardware fixture and detailed part numbers and their locations can be seen in the bill of materials found in the assembly drawings for the front axle cart fixture located immediately following section 8.7.

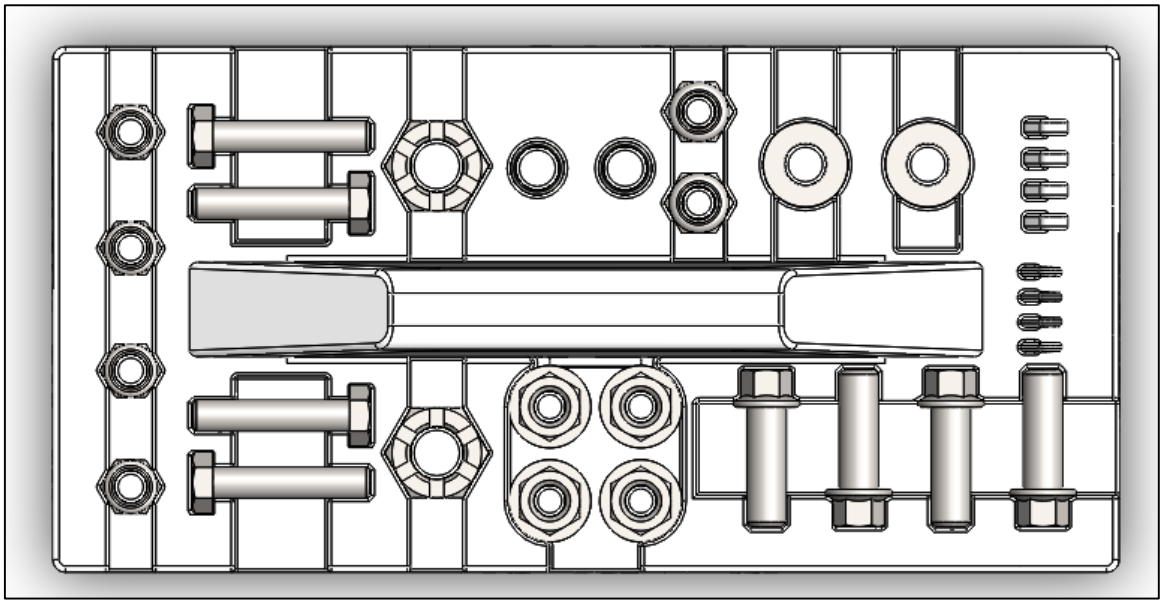


Figure 42: Top view of the front axle cart hardware fixture [73].

From Figure 42, it can be seen that the front axle cart hardware fixture is organized in an unsymmetrical fashion. The reasoning for this is to ensure that similar components were organized in the most logical way possible and due to the low combined mass of the hardware contained in this fixture, the unbalance of the weight distribution was found to be insignificant (120 grams max).

This arrangement allows the assembly operators to remove like hardware from a specific area of the fixture, as required. However, this unsymmetrical arrangement requires that this fixture be stacked in a specific manner in order to eliminate interference during stacking as the large cotter pins will contact the steering shaft bolts if stacked incorrectly. Figure 43 illustrates the interference between the large cotter pins and the steering shaft bolts.

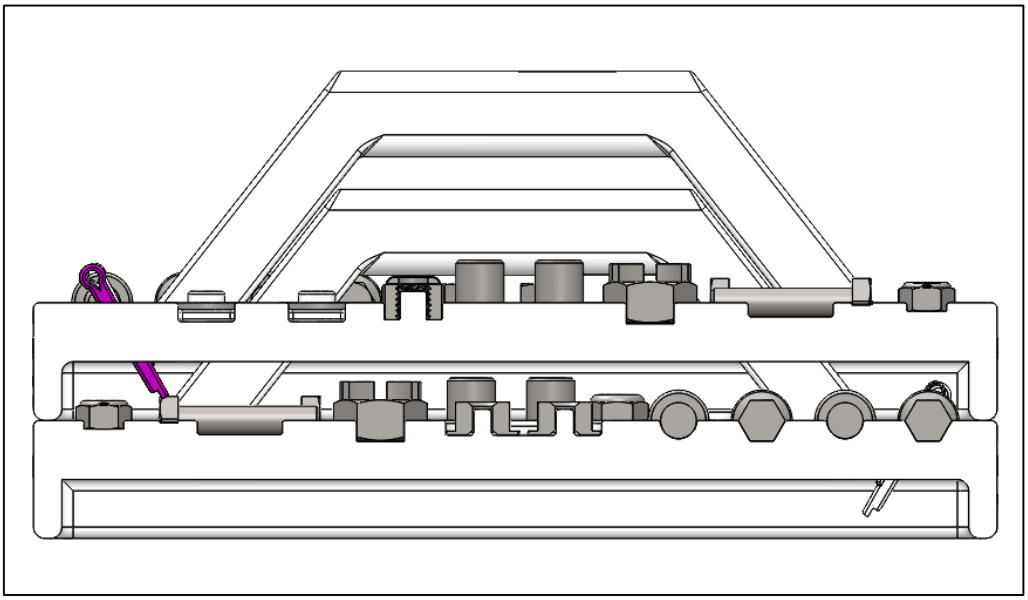


Figure 43: Interference between large cotter pins and steering shaft bolts if fixtures are stacked in reverse [74].

To remedy this, alignment markers have been provided to ensure that this fixture will be stacked correctly. These alignment markings can be seen on the left of Figure 44. These markings ensure that the Front Axle Cart Fixture is stacked correctly and that there is adequate clearance for the large cotter pins and no stacking interference will result (as illustrated on the right of Figure 44).

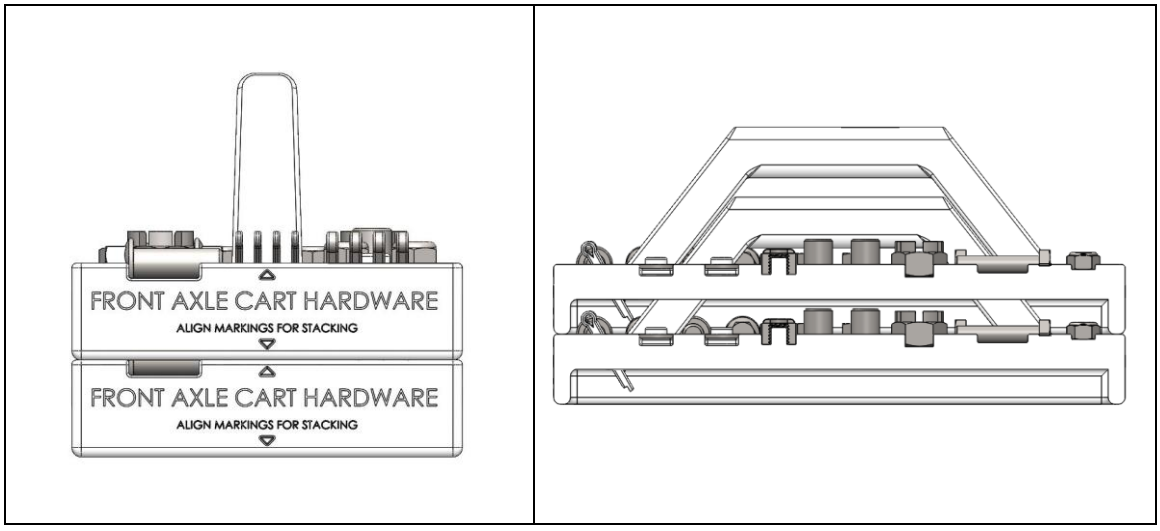


Figure 44: Front axle cart hardware fixture alignment markings (left) ensure no interference (right) [75].

The tolerances of the Front Axle Cart Fixture ensure that only the correct components fit into their intended location. As part number 193-188 (NYLock Nut ½ - 13 UNC ZN PL) is very similar to part number 1101 – 1083 (M10 Lock Nut) the fixture tolerances are of extreme importance in order to ensure that only the correct hardware (and correct amount of hardware) is installed into the fixture. Figure 45 illustrates that when either part 193 – 188 or part 1101 – 1083 is placed in the incorrect position on the fixture, interference will result and that those components will not be able to be placed into the incorrect positions on the fixture.

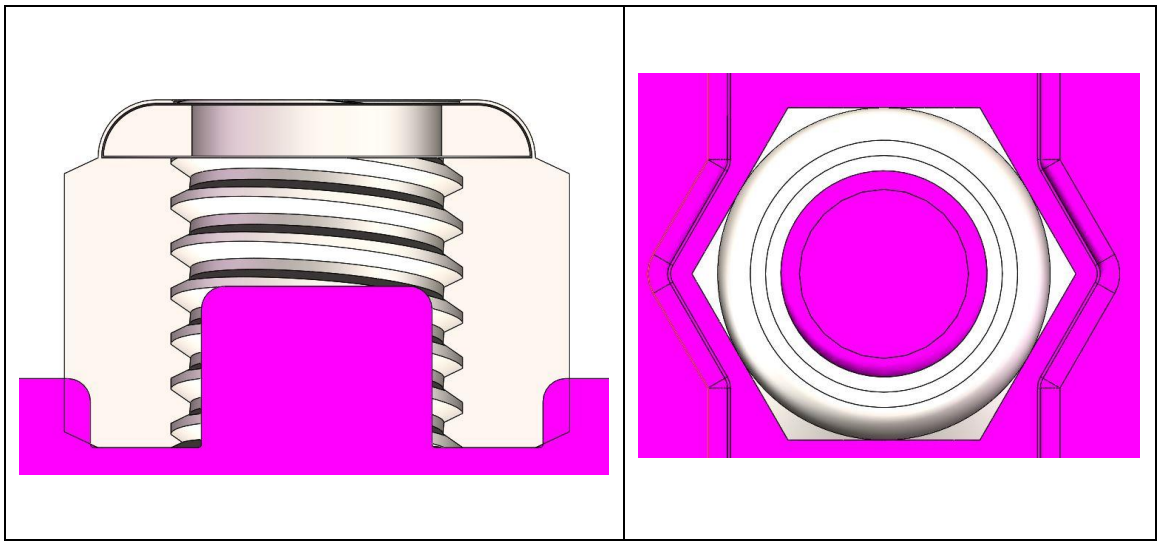
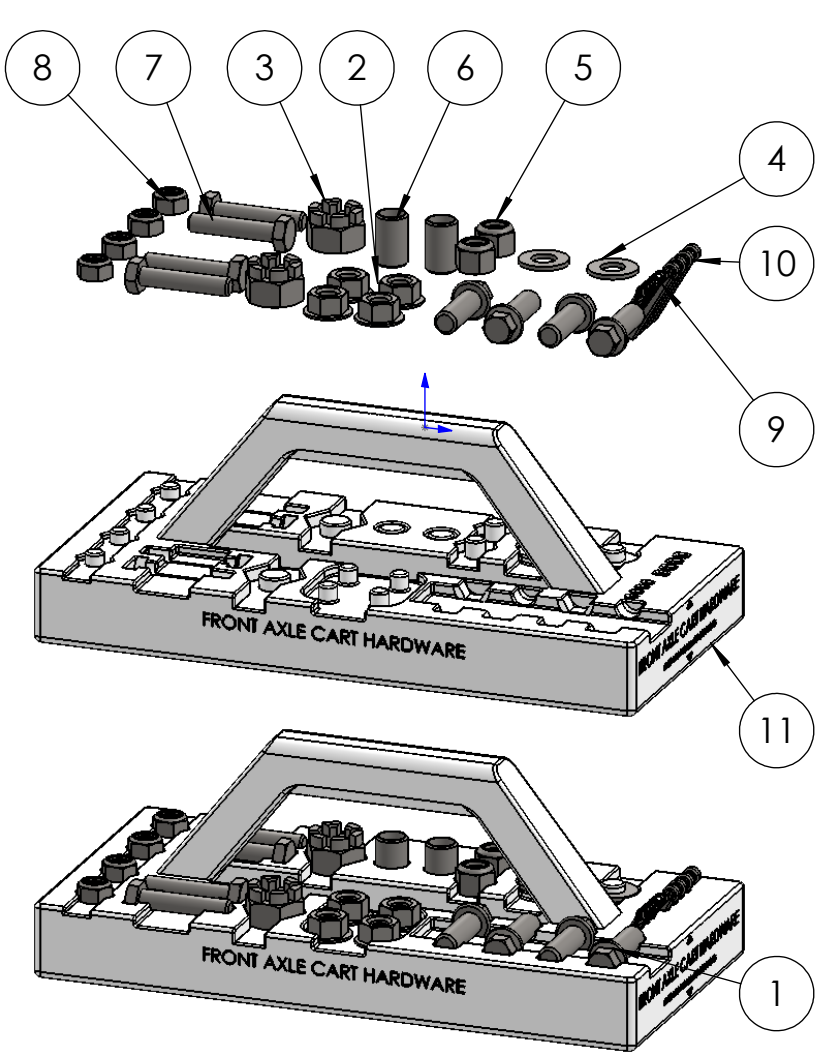


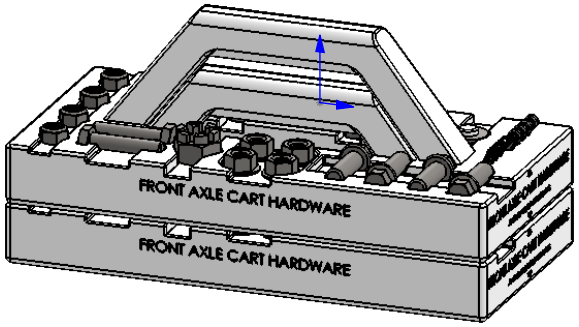
Figure 45: External interference occurs on part 193-188 (left) and internal interference occurs on part 1101-1083 (right) if placed in the incorrect position on the front axle cart fixture [76].

Furthermore, it is to be noted that the large cotter pin cannot fit into the location for the small cotter pin. As for the small cotter pin, if it is placed into the location for the large cotter pin, the eye of the small cotter pin will rest on the top face of the fixture, visually indicating that the small cotter pin is in the incorrect location.

With the above considerations in mind, the Design Team is confident that the Front Axle Cart Hardware Fixture meets the needs of the client by organizing the front axle cart hardware with a fixture design that is ergonomic and stackable. Furthermore, by ensuring that the tolerances of the fixture prevents hardware from being incorrectly installed into the fixture itself, the risk of installing incorrect hardware onto the coach in Station 19 will be reduced, effectively error proofing the auxiliary equipment installation process. Additionally, the Risk Priority Number (RPN) will also be reduced if the front axle cart hardware fixture is utilized in the assembly

process. Details regarding the reduced RPN values can be seen in Table VII located in the Failure Modes and Effects Analysis provided in Appendix A.





Num	Name	Material	Quantity	Weight(g)	Description
11	FRONT AXLE CART HARDWARE FIXTURE	ABS	2	1350.69	FRONT AXLE CART FIXTURE
10	Miss part number	Steel	8	11	Big pin
9	197-26	Steel	8	3	small pin
8	1101-1083	HSS	8	11.311	M10 nut
7	1101-1094	HSS	8	44.04	M10 steering bolt
6	1201-1303	HSS	4	16	Bushing
5	193-188	HSS	4	23.346	NYLOCK Nut 1/2 - 13, ZN PL
4	192-284	HSS	4	8.27	Washer-Flat, 1/2 steel, ZN Plated,
3	1903--0641	HSS	4	66.89	Nut hex slotted 0.75 - 16 UNF
2	1903-0497	HSS	8	23.04	Nut-FLG 1/2 – 13 YELLOW ZINC PLATING
1	1901-1536	HSS	8	58.71	Flage bolt 0.5-13 UNC X 1.5

SolidWorks

MECH 4860

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN METRIC
TOLERANCES:
ANGULAR: MACH ±0° 30'
TWO PLACE DECIMAL ±.127

UofM MECHANICAL ENGINEERING

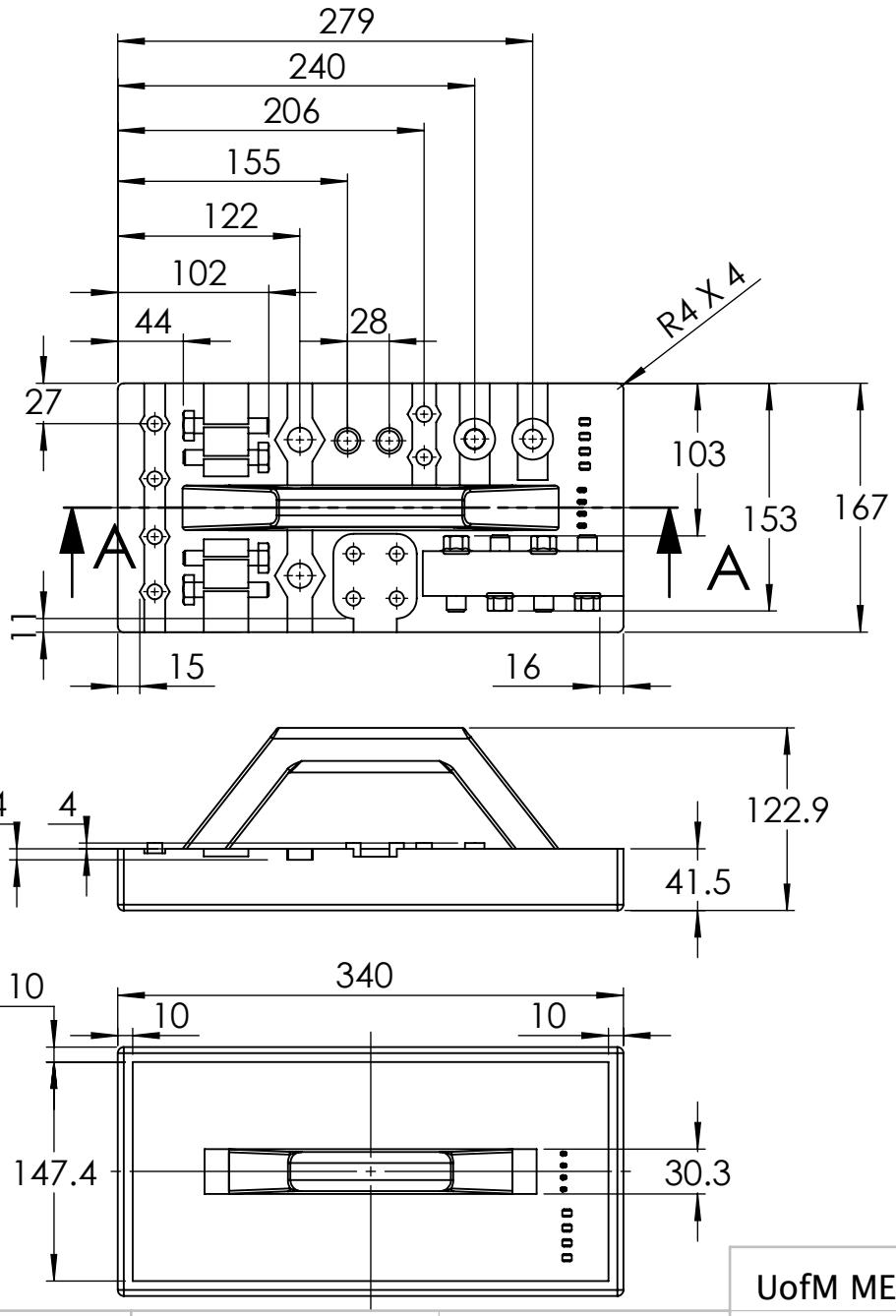
INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14. 5M-1994		NAME	DATE
DO NOT SCALE DRAWING	DRAWN	D.D.	24/11/2015
MATERIAL ASSEMBLY	CHECKED	M.Y.	05/12/2015
FINISH AS ASSEMBLED			

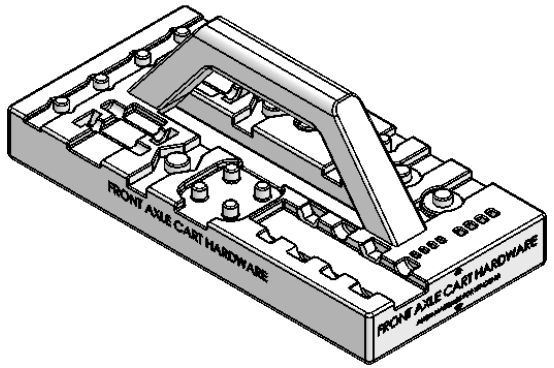
TITLE: **FRONT AXLE CART FIXTURE**

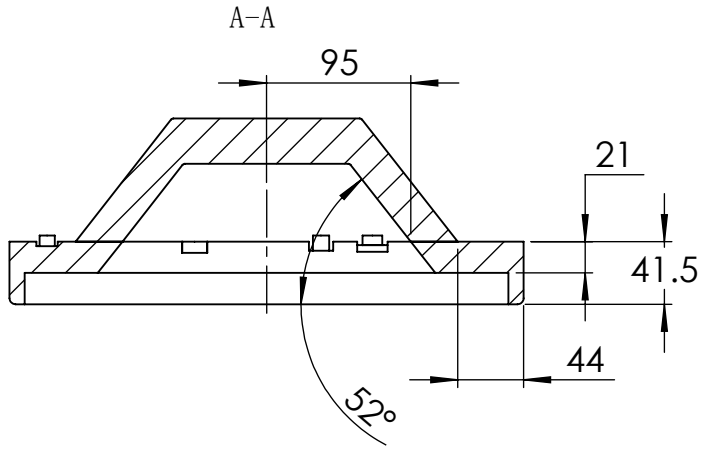
SIZE	DISCRIPTION:	REV
A	FRONT AXLE CART FIXTURE WITH STACKING	4

SCALE: 1:4 | WEIGHT: 4370.14 | SHEET 1 OF 2

5 4 3 2 1







Note:
1. All Edges Fillet: 1 mm
2. For Additive Manufacturing Only (3D printer)

SolidWorks

MECH 4860

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN METRIC
TOLERANCES:
ANGULAR: MACH ±0° 30'
TWO PLACE DECIMAL ±.127

UofM MECHANICAL ENGINEERING			
INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14. 5M-1994		NAME	DATE
DO NOT SCALE DRAWING	DRAWN	D.D.	24/11/2015
MATERIAL ABS	CHECKED	M.Y.	05/12/2015
FINISH ADDITIVE MANUFACTURING			

TITLE: **FRONT AXLE CART FIXTURE**

SIZE	DISCRIPTION:	REV
A	FRONT AXLE CART FIXTURE	4
SCALE: 1:5	WEIGHT: 1355.28	SHEET 2 OF 2

5 4 3 2 1

9.0 MANUFACTURING, MATERIAL ANALYSIS AND COSTING

The Industrial Technology Centre (ITC) located in Winnipeg Manitoba is currently in a working partnership with Motor Coach Industries and has been selected by the Design Team as the manufacturer for the fixtures. ITC currently possesses a FORTUS 400mc 3D printer from Stratasys with a build envelope of 16 x 14 x 16 inches that is capable of producing manufacturing tolerances of +/- 0.127 mm, which is sufficient for the fixtures. Figure 46 depicts the FORTUS 400mc.

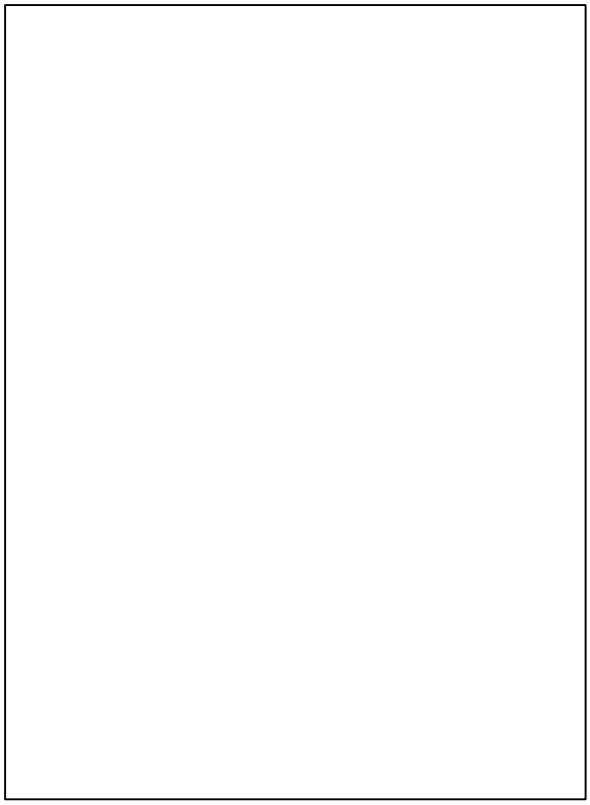


Figure 46: FORTUS 400mc 3D printer [77]

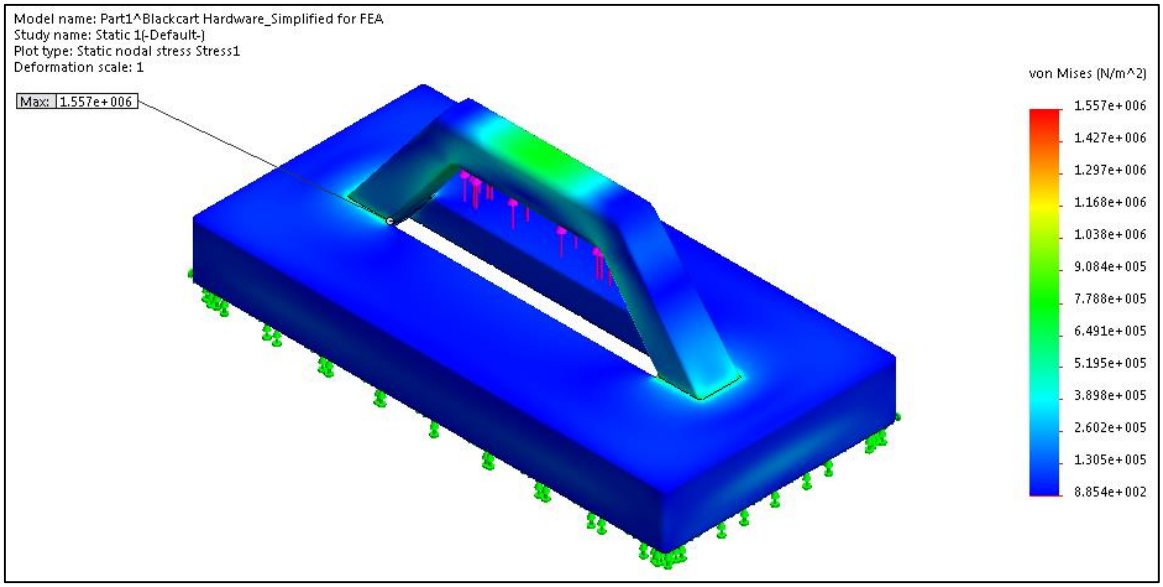
For the construction of the fixtures, ITC has recommended the use of ABS-M30 as this material is stronger than standard Stratasys ABS and is suitable for functional prototyping. The mechanical properties of ABS-M30 can be seen below in Table XXXI [78].

TABLE XXXI: MECHANICAL PROPERTIES OF ABS-M30

Mechanical Properties	Test Method	English	Metric
Tensile Strength, Ultimate	ASTM D638	5,200 psi	36 MPa
Tensile Strength, Yield	ASTM D638	3,750 psi	26 MPa
Tensile Modulus	ASTM D638	350,000 psi	2,400 MPa
Tensile Elongation	ASTM D638	4%	4%
Flexural Strength	ASTM D790	8,800 psi	61 MPa
Flexural Modulus	ASTM D790	336,000 psi	2,300 MPa
IZOD Impact, notched	ASTM D256	2.6 ft-lb/in	139 J/m
IZOD Impact, un-notched	ASTM D256	5.3 ft-lb/in	283 J/m

9.1 Material Analysis

As all five fixtures utilize the same handle design, and have equivalent tray height and thickness, a Finite Element Analysis (FEA) was conducted on a simplified front axle cart hardware fixture to verify the performance of the fixtures under an extreme loading scenario. The analysis displayed in Figure 47 indicates a simulated 20 Kg vertical load (200 N) on the fixture handle, while the base is fixed. This loading scenario is much greater than the maximum expected load that any of the fixtures will see as the largest expected load is 2.9 Kg (28.45 N), equivalent to the combined mass of the hardware for the right front suspension.



• Mesh Type: 10 Node Tetrahedral • Constraint: Fixed at Base (Green Arrows) • Load: Applied Force on underside of handle (200N)	• Maximum von Mises Stress: 1.577 MPa • Material: ABS-M30 • Tensile Strength (Yield) 26 MPa • No face features (simplified for analysis)

Figure 47: Simplified front axle cart hardware fixture FEA results [79]

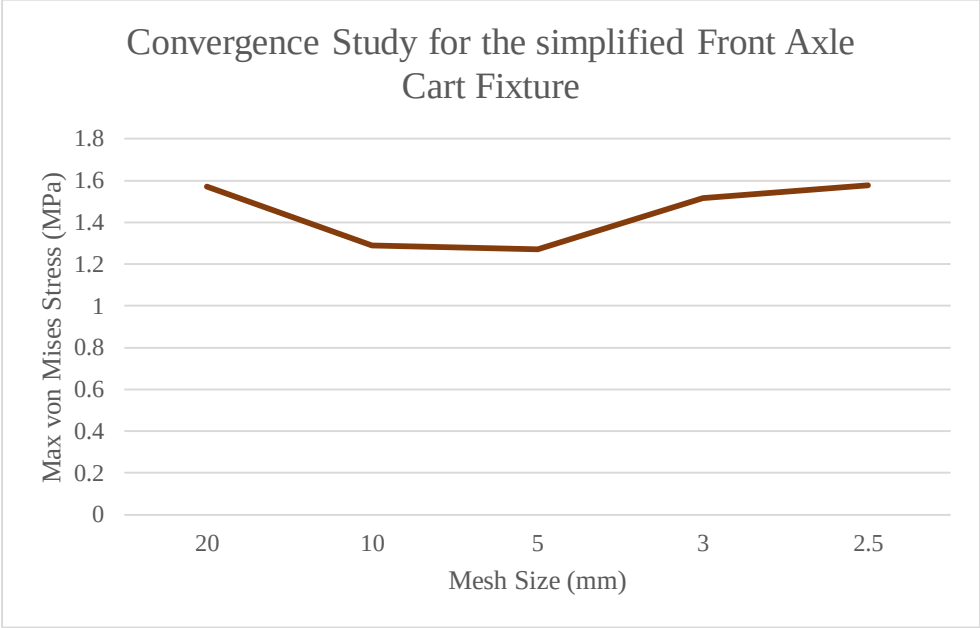


Figure 48: Convergence plot for the simplified front axle cart fixture [80].

Figure 48 illustrates that the FEA study for the simplified fixture converges with a maximum von Mises stress of 1.577 MPa. As the yield strength for the ABS-M30 material is 26 MPa, the loading scenario depicted above indicates that the fixtures are over designed for their intended

application; and a factor of safety of 16.48, at nearly seven times the expected loading scenario was determined. This will ensure that the all five fixtures are robust and will withstand repeated use in Station 19 and the Design Team is confident that ABS-M30 will provide the required longevity that our client requires.

Additionally, it is understood by the design team that the fixtures may be dropped on occasion. However, due to the robust nature of the fixture design, the design team is confident that the fixtures will withstand prolonged usage in Station 19. It is to be noted that the Design Team cannot guarantee the performance of the fixtures if they are intentionally mistreated, used outside of their intended application or in extreme environments.

9.2 COSTING

ITC has produced a lump sum price estimate for the fixture set, incorporating the material costs, machine time and labour costs. It is to be noted, that on request of the client, the fixtures must be solid construction, meaning there will be no voids in the body of the fixture. Although this will raise manufacturing costs, the durability of the fixtures will not be a concern when comparing to a sparsely filled fixture. The manufacturing costing summary can be seen in Table XXXII [81]. Additional information regarding the quote is provided in Appendix C.

TABLE XXXII: MANUFACTURING COSTING SUMMARY

Layer Thickness	0.010 in (Solid Fill Construction)
Material Cost (ABS-M30)	$5700 (Total, for 5 Fixtures)
Printing Time	142 Hours (Total, for 5 Fixtures)
Turnaround	Two Weeks

Although $5700 is a significant sum of money, the Design Team is confident that the hardware fixtures will be a cost effective investment that serves to organize the hardware within Station 19. It is to be noted that 3D printing does not require unique manufacturing fixtures or an operator to watch the printer during the manufacturing process. If the Design Team were to be limited to a CNC milling process, the centre handle design and the complexity of the trays would be extremely difficult to manufacture in a timely, and cost effective manner.

10.0 INSTRUCTIONS

The following instruction set outlines the assembly location of the fixtures and the placement of the fixtures when in use.

10.1 ASSEMBLY

All hardware fixtures are to be assembled on the hardware prep table. As stated in Section 5.0, the hardware bins are currently located at this table but the bins located on the face of the table will be relocated to the steering prep table, shown in Figure 49. This will provide a sufficient amount of space for the assembly line operators to prepare the hardware fixtures. Note that fixture assembly drawings are provided in detail within in Section 8.0 for all fixtures.

Figure 49: Relocate hardware bins to steering prep table to provide adequate assembly space for fixtures [29].

NOTE: At the completion of assembling a given hardware fixture, all components must be verified for correct installation into the fixture, particularly the washers. Figure 50 below indicates the check that must be performed in order to identify that only two lock washer halves are present in the fixture.

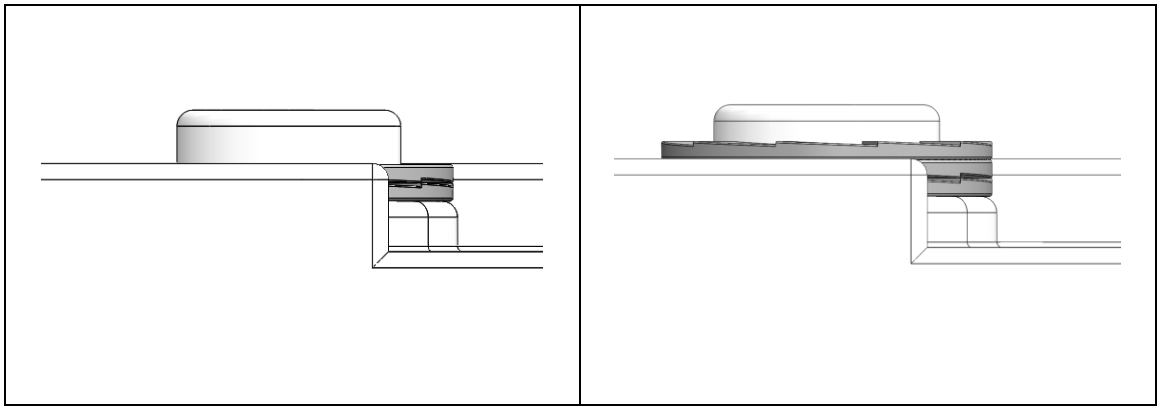


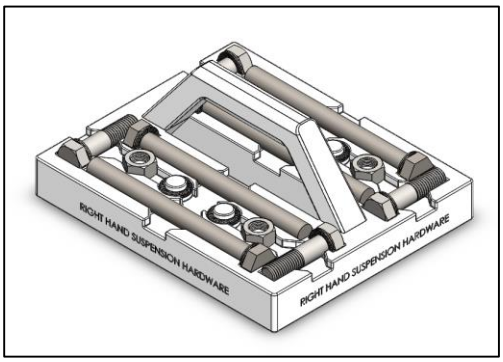
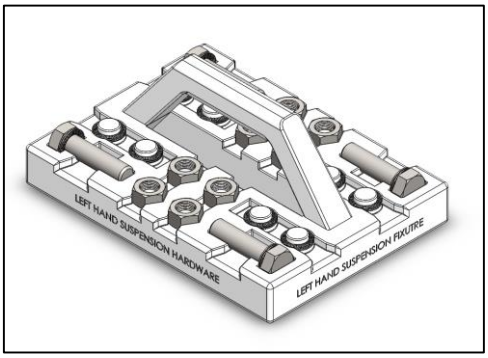
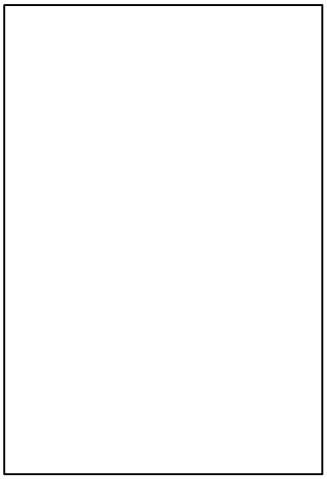
Figure 50: Check that the correct washer sits flush with fixture (left) (incorrect washer will be above surface of fixture) [69].

NOTE: Erroneous hardware installation into the fixtures themselves is prevented due to the design tolerances of the fixtures themselves, as illustrated in Section 8.0.

10.2 USAGE

When in use within Station 19, the hardware fixtures are to be placed in specific locations. The intended location for each of the five hardware fixtures when assembled is provided in Table XXXIII.

TABLE XXXIII: LOCATIONS OF HARDWARE FIXTURES WITHIN STATION 19

Fixture	Location
 Figure 51: Right hand front suspension fixture [61]	 Figure 52: Right hand front suspension fixture Cart [25]
 Figure 53:Left hand front suspension fixture [57]	 Figure 54: Left hand front suspension fixture cart [25]

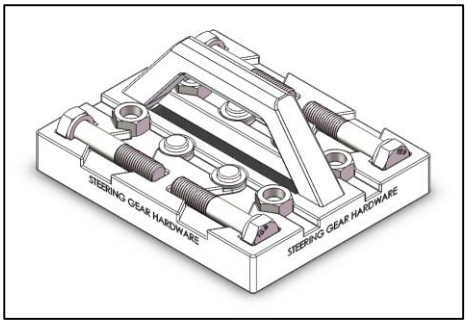


Figure 55: Steering gear hardware fixture [65]

Figure 56: Steering gear fixture cart [27]

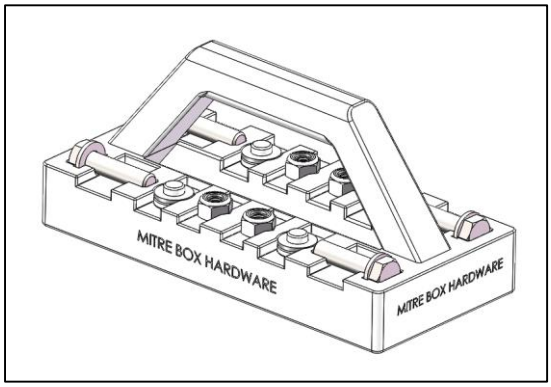


Figure 57: Mitre box hardware fixture [69]

Figure 58: Driver's side access compartment [82]

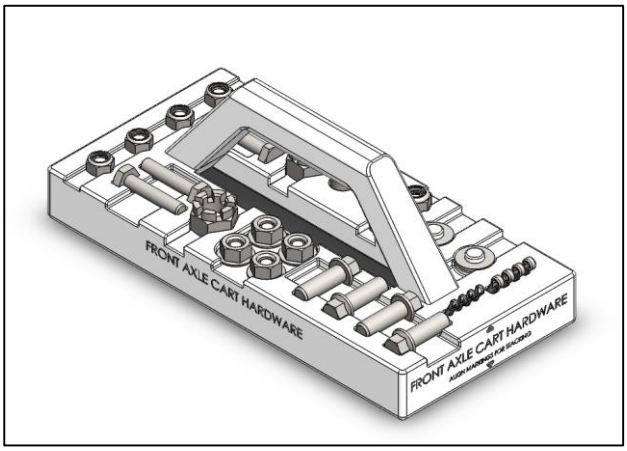


Figure 59: Tool cart hardware fixture [72]

Figure 60: Front axle took cart [83]

11.0 RECOMMENDATIONS

MCI requested two recommendations based on results from our process Failure Modes and Effects Analysis, provided in Appendix A. It is important to note that these recommendations only provide an initial concept and final designs and specifications are not required.

11.1 FIXTURE STORAGE

As part of the deliverables for the design project, the client requested a conceptual design and recommendation for a designated area for fixtures to be stored within the workstation using the existing infrastructure within Station 19. Based off the average takt time for Station 19, the suspension assembly process for a single bus takes approximately two hours and fifty minutes [17]. For a normal workday of eight hours, this means that a maximum of three fixtures may be required per day, per fixture type. Thus, a total of fifteen fixtures will need to be stored within the workstation on a daily basis. Additionally, empty fixtures are to be placed in storage until the assembly operator has time to reload the correct hardware into the fixture.

MCI's internal department responsible for custom cart and jig configuration uses a pre-fabricated, modular mounting plate that is welded to carts and fixtures. A custom sized sheet metal shelving unit can then be created with mounting tabs that are compatible with the mounting pattern on the cart. As such, the design team based the design of the new storage cart concept off of these modularized features and created a shelving unit for the hardware prep cart. A rendering of the complete prototype cart modification can be seen in Figure 61.

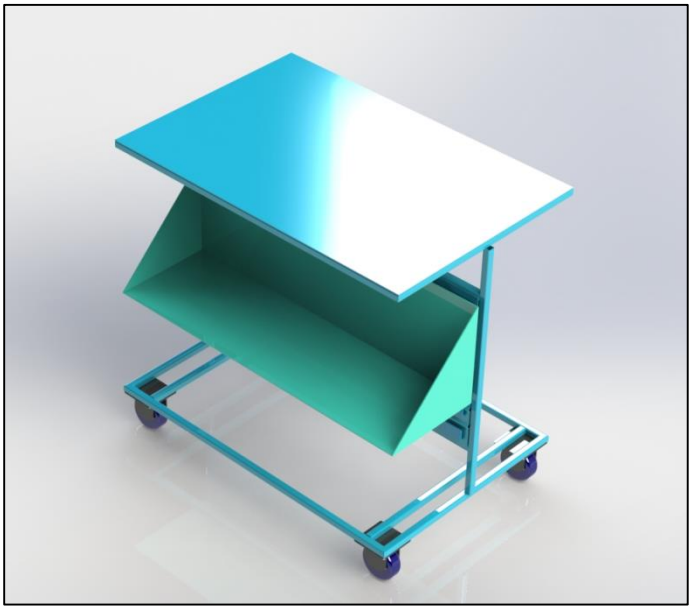


Figure 61: Isometric view of the conceptual hardware prep cart shelving modification [84].

The main structure of the cart is based off of the existing steering gear prep cart, and hardware prep cart. Both of these carts are currently located within Station 19. Materials consist of one inch square tube steel for the main structure, sheet metal for the table top surface and shelving structures, casters, and the pre-fab mounting plate. The shelving unit is newly designed around the dimensional requirements for the storage of the hardware fixtures.

For mounting, the back side of the shelving unit is designed to fit in to the slots located on the pre-fab plate that is welded on to the cart structure. On the shelf side, the lips are welded to the backside structure, spaced accordingly to align with cart side slots. An illustration of the mounting interface can be seen in Figure 62.

Figure 62: Conceptual shelving modification mounting interface. [85]

Design of the shelving focuses on presenting the hardware fixtures in a manner that they are easy to identify and recognize by the assembly operators without having to bend down. Each of the fixtures is labeled with its specific application, and when placed on the shelves, the labels are fully visible to the operator. An illustration of the fixtures stacked on the cart can be seen in Figure 63 and Figure 64.

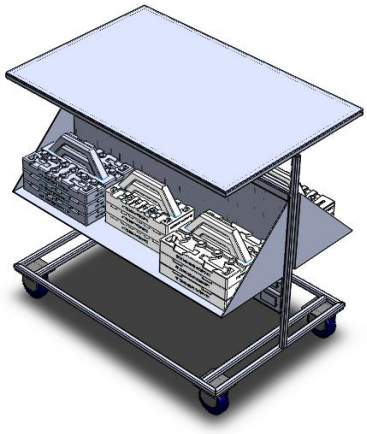


Figure 63: Fixtures stored on front side of cart [86].

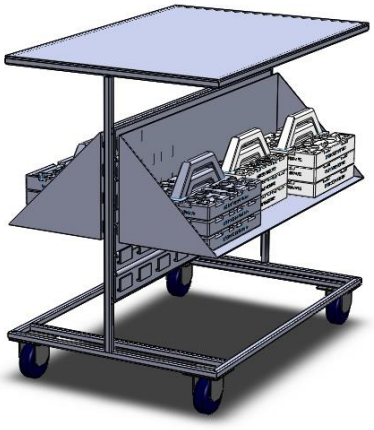


Figure 64: Fixtures stored on backside of cart [87].

Given the size of the fixtures, the fixtures must be stored between two shelves. Three of the five types of fixtures must be placed on one shelf while the remaining two are place on the second shelf.

11.2 Front Axle Cart

There is room for improvement for the current layout of the front axle cart as the client is not satisfied with the organizational effectiveness of the cart, as indicated in the interview results located in Appendix B. The front axle cart is not easily adjustable and difficult to modify because it is welded together, which constrains the manner in which the tools are organized and laid out on the cart. The Styrofoam cut-out is also not being utilized properly because the tools are not being placed back in there designated spots and there are several tools without a designated area. This results in tools and hardware being randomly placed on the top shelf and bottom shelf of the cart. The current front axle is displayed in Figure 65 below.

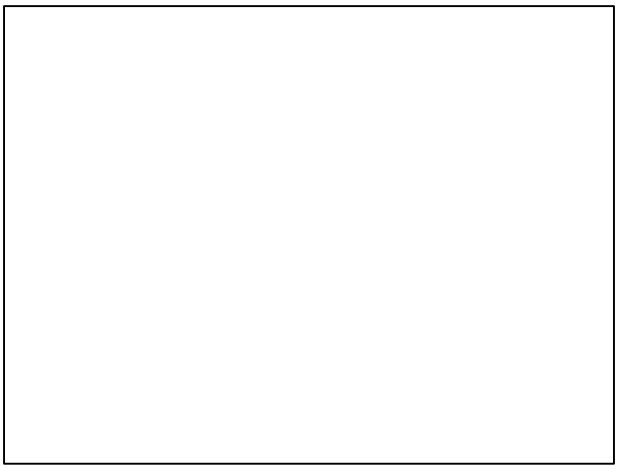


Figure 65: Front Axle Cart [9].

The loose hardware placed in the soft rubber bins, displayed in Figure 65 is addressed with the front axle cart hardware fixture design the design team has supplied to the client, therefore the recommendation for the front axle cart would improve the tool organization within Station 19.

The design team is recommending to the client the use of Aluminum Structural Tubing from the Rexroth Bosch Group [30]. This type of aluminum tubing will allow for the implementation of an adjustable front axle cart that will allow for the proper reorganization of all the required tools. The Rexroth Bosch tubing has several different aluminum profile configurations and connectors suitable for diverse applications. They also have adjustable and completely modular material

shuttles, as illustrated in Figure 66, where an example of a heavy-duty material shuttle and a heavy duty bin shuttle is provided.

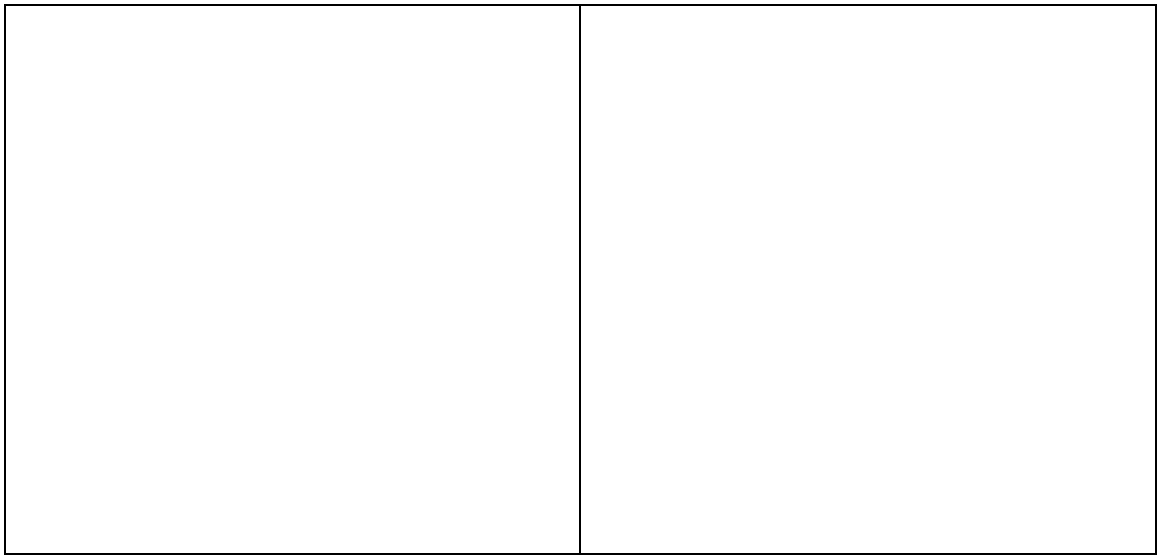


Figure 66: A modular heavy-duty material shuttle (left) and a heavy duty material shuttle (right) available from Rexroth Bosch Group [88].

The ability to adjust the cart height would allow for the addition of extra shelves, if needed, for and would allow the assembly line operators to raise the cart for easier access to the bottom shelf components. Examples of the different aluminum profile configurations can be viewed in Figure 67 below, which includes profiles for light duty, light to medium duty, and heavy duty construction from left to right, respectively.

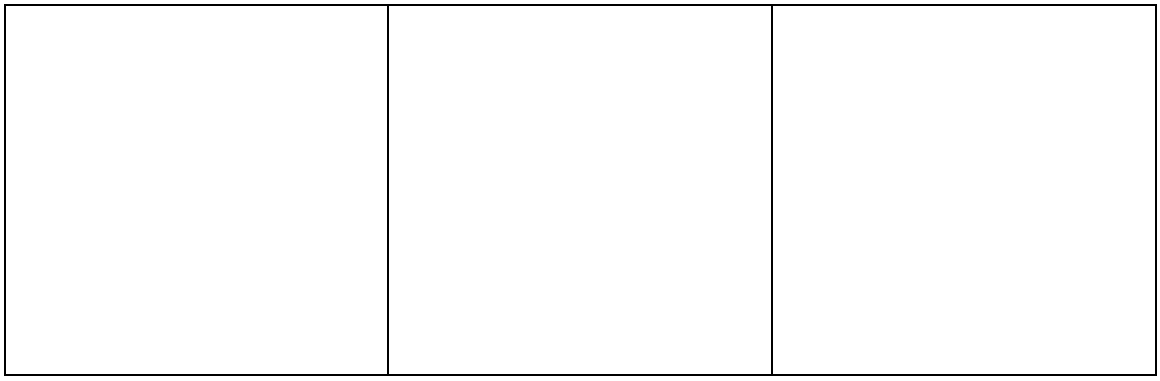


Figure 67: Extruded aluminum tubing profiles available from Rexroth Bosch Group [89].

Another useful apparatus that can be purchased from the Rexroth Bosch Group is a tool hanger, which could be used to locate tools on the side of the cart, providing more space for the other required tools on the top and bottom shelves of the cart. An example of the tool hanger can be

viewed in Figure 68 below. The company also offers a program called MTpro, which allows for proper planning and designing of the cart to ensure all the appropriate Bosch Rexroth products are ordered [30].

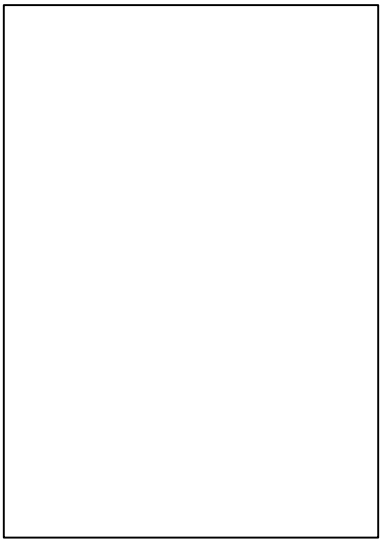


Figure 68: 180º/360º Tool Hanger from Rexroth Bosch Group [90].

The implementation of these products from the Rexroth Bosch Group would improve the organization of the front axle tool cart tremendously, and ensure there is a spot for each tool on the cart. It should be noted that the use of the Styrofoam cut-outs for the tools would still be very useful for the non-hanging tools, and these cut-outs may even be 3D printed in future applications to provide additional rigidity and longevity. The adjustable height, and the ease of adding additional shelves to the cart will ensure that there will be enough room to store all required tools in a designated location for the front axle assembly process.

Although the design team is not able to access prices of the aluminum tubing, we are suggesting that our client explore the option of using this supplier for the re-construction of the front axle cart and compare these products with the current layout and effectiveness of the cart currently used in house. It is to be noted that these modular aluminum products available from Rexroth Bosch can be applied to applications other than the front axle cart. The front axle cart was merely used to provide an example in which the Rexroth Bosch products would significantly improve Station 19.

12.0 CONCLUSION

Group 15 was tasked with the design of hardware fixtures for the front suspension assembly process in Station 19 at Motor Coach Industries. The need for a hardware fixture design arose from assembly errors stemming from the current presentation of hardware and the lack of a hardware tracking system within the workstation. The design team was tasked with analyzing/determining areas within Station 19 that would benefit from the use of hardware fixtures as a means of organization and tracking hardware. We were also tasked with the final design of the hardware fixtures including CAD models for each hardware fixture identified for the use of 3D printing.

The client specified that the goal for the hardware fixture designs is to ensure the correct number of hardware is installed on the coach as well as the correct type. The client also specified that the hardware fixtures were to be stackable for ease of storage. Following these guidelines the design team designed five hardware fixtures for the following applications:

- Right Independent Front Suspension Assembly
- Left Independent Front Suspension Assembly
- Steering Gear Assembly
- Mitre Box Installation
- Front Axle Cart Hardware

Each individual hardware fixture pertains to the hardware used for each of the processes listed above and ensures only the hardware for its certain application can be placed in the fixture; additionally each fixture is labeled with its specific application. Each fixture follows the same layout, with hand reliefs inserted for easy removal of the hardware as well as a handle to allow for easy transportation. The weight of the hardware is equally distributed throughout the fixture to ensure it will not tip over, and each fixture was designed so it would fit in a designated location outlined in the instruction set. The total cost of all five hardware fixtures, with a turn around time of two weeks was approximated to be $5700 including material, labour and machine time.

The design team also provided the client with recommendations upon their request. The first recommendation was completed for tool organization for the front axle cart, where the design team recommended using products from Rexroth Bosch Group for the complete rebuild of the cart. The aluminum tubing products from the Rexroth Bosch Group will allow for the addition of

adjustable shelves, provide hanging capabilities for tools to provide more space, and will allow the client to make modifications to the cart whenever needed as the aluminum tubing does not need to be welding together like the current front axle cart.

The second recommendation is for the storage location for the hardware fixtures. The design team recommended that the hardware fixtures be stored on the existing steering prep table and be fabricated using existing methodology that is currently used throughout Station 19. The storage area will be constructed from a pre-fabricated modular mounting plate already used within the workstation and will be welded to existing steering prep table and will allow for adequate space to store all fixtures when not in use.

Finally, with the design of the five hardware fixtures for the applications listed above, the design team was successful in reducing the Risk Priority Numbers (RPN) calculated in the preliminary FMEA shown in Appendix A. As the five hardware fixtures reduced the RPN values, it can be said that the hardware fixtures reduce the process errors and adequately organize the hardware for the assembly line operators.

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APPENDICES

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APPENDIX A: FAILURE MODES AND EFFECTS ANALYSIS

A Failure Modes and Effects Analysis (FMEA) is *"a systematic method by which potential failures of a product or process are identified, analyzed and documented [1]."* Specifically, an FMEA serves to identify performance or safety issues present within a product or process and once recognized, appropriate actions can be taken to mitigate the effects of any identified failures. An FMEA is also a useful brainstorming tool and was utilized by the Design Team to aid in the identification of the deliverables for this design project. The following Appendix outlines the FMEA conducted by the Design Team and serves to define the Severity Rating, Frequency Rating and Detection Rating Scales utilized to calculate the Risk Priority Numbers (RPNs) of problem areas identified within Station 19.

SEVERITY RATING SCALE

The Severity Rating Scale presented in Table I outlines the effect of the process failure, should it go undetected, and be passed on to the end customer [1]. The Severity Rating Scale serves to illustrate that a ranking of 10 refers to a high level of severity if failure was to occur and a ranking of 1 refers to a minor level of severity if failure was to occur. The Severity Rating Scale is represented by the abbreviation SEV in the Station 19 FMEA presented in Table V through Table VII.

TABLE I: SEVERITY RATING SCALE

Severity Rating Scale		
Severity of Effect		**Ranking**
Minor	Effect of failure insignificant.	**1**
Low	At most, effect of failure will cause annoyance.	**2**
Moderate	Failure will cause customer dissatisfaction. Rating dependent on the reduced level of performance of the product.	**4,5,6**
High	Causes high degree of customer dissatisfaction. Failure causes product to be unusable. Requires repairs.	**7,8**
Very High	Failure causes serious safety hazards. Noncompliant with government regulations.	**9,10**

FREQUENCY RATING SCALE

The Frequency Rating Scale presented in Table II, outlines the rate at which a given process may produce a failure that may be passed on to the end customer [1]. The Frequency Rating Scale utilizes a ranking of 10 to indicate a very high possibility of failure while a ranking of one denotes a very low possibility of failure. The Frequency Rating Scale is represented by the abbreviation FREQ in the Station 19 FMEA presented in Table V through Table VII. Note that for the purposes of the FMEA, the Possible Failure Rates were assumed and determined following initial discussions with MCI, and acts as a reasonable estimate that allows comparisons of the frequency of process failures.

TABLE II: FREQUENCY RATING SCALE

Frequency Rating Scale		
Probability of Failure	**Ranking**	**Possible Failure Rates**
Failure highly unlikely	**1**	**<1 in 10,000**
Occurrence of failure very low.	**2**	**1 in 10,000**
Occurrence of failure low. Past failures have been isolated.	**3**	**1 in 5,000**
Occurrence of failure moderate. Occasional failures have been documented, but not in major proportions.	**4** **5** **6**	**1 in 1,000** **1 in 400** **1 in 80**
High occurrence of failure. Failures are repetitive in nature.	**7** **8**	**1 in 40** **1 in 20**
Very high failure occurrence.	**9** **10**	**1 in 8** **1 in 2**

DETECTION RATING SCALE

The likelihood of detecting a possible failure before the failure is passed to the end customer is defined by the Detection Rating Scale, presented in Table III [1]. A detection rating of one indicates that the current control methods utilized in the process in question are very likely to prevent failures, while a detection rating of 10 indicates a low likelihood of preventing failures being passed to the end customer. The Detection Rating Scale is represented by the abbreviation DET in the Station 19 FMEA presented in Table V through Table VII.

TABLE III: DETECTION RATING SCALE

Detection Rating Scale		
Likelihood of Detection		**Ranking**
Very High	Procedures will likely prevent the failure.	**1,2**
High	Procedures most likely to prevent the failure.	**3,4**
Moderate	Procedures may prevent the failure.	**5,6**
Low	Procedures have a low likelihood of detecting the failure.	**7,8**
Very Low	Procedures likely to not detect the failure.	**9**
Absolute Certainty of Non-Detection	Procedures will not prevent failure.	**10**

Dynamics of the Risk Priority Number

The Risk Priority Number, denoted by the abbreviation RPN, is used to prioritize the action recommendations for the identified process failures [1]. The RPN itself is calculated by multiplying the SEV by FREQ by DET. Thus, addressing the process failure becomes more urgent as the RPN increases. An action baseline can be seen in Table IV.

TABLE IV: DYNAMICS OF THE RISK PRIORITY NUMBER

Dynamics of the RPN				
SEV	**FREQ**	**DET**	**Result**	**Actions**
1	**1**	**1**	Ideal Scenario	Monitor
1	**1**	**10**	Non-issue	Monitor
10	**1**	**1**	Failure detected	Monitor
10	**1**	**10**	Failure not detected	Act
1	**10**	**1**	Freq. failure but detectable	ACT
1	**10**	**10**	Freq. failures not detected	ACT!
10	**10**	**1**	Freq. major failures detected	*ACT!*
10	**10**	**10**	Major Concern	***ACT!***

FMEA Results

The FMEA conducted on Station 19 by the Design Team can be seen in Table V through Table VII on the following pages. The Design Team observed four specific assembly processes and calculated the RPN for the process failures that may occur, as indicated by MCI during the observation of the installation of the front suspension components. It is to be noted that the Design Team focused on reducing the processes with the highest RPN values. Action recommendations indicated that five hardware fixtures were required to provide the necessary process improvements to the areas of interest as required by the client. The recalculated RPN values determined by the Design Team when utilizing the five hardware fixtures can be seen in Table V through Table VII. As the five hardware fixtures reduced the RPN values, the hardware fixtures effectively reduce the process errors and adequately organize the hardware for the assembly operators, as requested by the client.

TABLE V: STATION 19 FMEA (1 OF 3)

Station 19 FMEA										
Item	**Process Step/Input (X)**	**Potential Failure Mode**	**Potential Effect**	**SEV**	**Potential Causes**	**FREQ**	**Current Controls**	**DET**	**RPN**	**Action Recommendations**
1	**Steering Gear Installation**	Incorrect Hardware and Assembly Procedures	• Loose Fasteners • No Steering • Injuries • Loctite not used • Injuries	10	• Incorrect Number of Washers • Incorrect Washer Size • No Hardware kit	8	• No Hardware Fixture • Digital Torque Tool • Final Inspection	7	560	Create Hardware Fixture
	Steering Gear Hardware Fixture	Prevents incorrect hardware installation	Locates and organizes hardware installation	10	Only the correct amount of hardware fits in fixture	1	Visual check for washers & tolerances prevent incorrect installation	1	**10**	RPN is reduced by utilization of Steering gear hardware fixture
2	**Mitre Box + Steering Shaft Installation**	Unaccounted or Incorrect Hardware	• Loose Hydraulic Fittings • Loosening of fasteners • No Steering	10	• Incorrect Number of Washers • Incorrect Washer Size •	8	• No Hardware Fixture • Digital Torque Tool • Final Inspection	7	560	• Create Organized Hardware fixtur5e • Organize Steering Prep Table
	Mitre Box Hardware Fixture	Prevents incorrect hardware installation	Locates and organizes hardware installation	10	Only the correct amount of hardware fits in fixture	1	Visual check for washers and tolerances prevent incorrect installation	1	**10**	RPN is reduced by utilization of Mitre box hardware fixture

TABLE VI: STATION 19 FMEA (2 OF 3)

Station 19 FMEA										
Item	**Process Step/Input (X)**	**Potential Failure Mode**	**Potential Effect**	**SEV**	**Potential Causes**	**FREQ**	**Current Controls**	**DET**	**RPN**	**Action Recommendations**
3	**Front Suspension Assembly Installations**	Incorrect Hardware	• Loss of Vehicle Control • Loss in Ride Quality • Loss in Vehicle Stability • Loose Fasteners	10	• Incorrect Number of Washers • Incorrect Washer Size • Missing Shock Sleeve	8	• Hardware Fixture • Digital Torque Tool • Final Inspection •	6	480	• Improve Existing Fixture
	Left Suspension Hardware Fixture	Prevents incorrect hardware installation	Locates and organizes hardware installation	10	Only the correct amount of hardware fits in fixture	1	Visual check for washers and tolerances prevent incorrect installation	1	**10**	RPN is reduced by utilization of Left side suspension hardware fixture
	Right Suspension Hardware Fixture	Prevents incorrect hardware installation	Locates and organizes hardware installation	10	Only the correct amount of hardware fits in fixture	1	Visual check for washers and tolerances prevent incorrect installation	1	**10**	RPN is reduced by utilization of Right side suspension hardware fixture

TABLE VII: STATION 19 FMEA (3 OF 3)

Station 19 FMEA										
Item	**Process Step/Input (X)**	**Potential Failure Mode**	**Potential Effect**	**SEV**	**Potential Causes**	**FREQ**	**Current Controls**	**DET**	**RPN**	**Action Recommendations**
4	**Sway bar Installation**	Incorrect Hardware	• Loose Fasteners • Loss in Ride Quality • Loss in Vehicle Stability	10	• Incorrect Number of Washers • Incorrect Washer Size • No Hardware kit	6	• Items come on warehouse cart • Digital Torque Tool • Final Inspection	4	240	• Create Hardware Fixture • Create Location for Swaybar on Front Axle Cart • Organize Hardware Prep Table
	Brake Line Installation	Rubs on tire after installation or too short	• Line Failure Causing no Brakes • Fail Safety Inspection	10	• Brake line too short • Incorrect Installation	5	• Items come on the warehouse cart • Jig is used to verify bracket placement • Final Inspection • Operator Pre-Trip	3	150	• Organize Hardware Prep Table • Create Fixture for Brake line length verification on Hardware Prep Table • Create Location for brake line on Front Axle Cart
	Front Axle Cart Hardware Fixture	Prevents incorrect hardware installation	Locates and organizes hardware installation	10	Only the correct amount of hardware fits in fixture	1	Visual check for washers and tolerances prevent incorrect installation	1	**10**	RPN is reduced by utilization of Front Axle cart hardware fixture

STATION 19 ACTION PLAN

Following the completion of the Failure Modes and Effects Analysis, the Design Team updated the station 19 action plan. The action plan served to identify the parties deemed responsible for completing the action recommendations. The action plan and the competed tasks can be seen in Table VIII.

TABLE VIII: STATION 19 ACTION PLAN

	Process	Recommendation	Responsible	Complete
1	Steering Gear Installation	Create Hardware Fixture	Design Team	YES
2	Mitre Box & Steering Gear Installation	Create Hardware Fixture for Mitre Box Hardware	Design Team	YES
		Create Hardware Fixture for Steering Gear Hardware	Design Team	YES
3	Front Suspension Installation	Organize Steering Prep Cart	Design Team (Recommendation Only)	YES
4	Front Suspension Installation Sway bar Installation	Create Hardware Fixture	Design Team	YES
		Create Hardware Fixture	Design Team	YES
		Locate Sway bar on Front Axle Cart	MCI	N/A
		Modify Front Axle Cart	Design Team (Recommendation Only)	YES
		Organize Hardware Prep Table	Design Team (Recommendation Only)	YES
5	Brake Line Installation	Organize hardware prep table	Design Team (Recommendation Only)	YES
		Create fixture for brake line length	MCI	N/A
		Create location for brake line on Front Axle Cart	MCI	N/A

The completion of the action plan outlined in Table VIII allowed the Design Team to track the deliverables required by the client in order to satisfy their needs and to ensure that the project was completed successfully.

APPENDIX A: REFERENCES

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APPENDIX B: QUESTIONNAIRE RESULTS

MECH 4860 – Group 15 – Questionnaire M. Yarovoy - 9-Oct.-2018

Please fill out this brief form as Group 15 from the University of Manitoba seeks your input in order to develop concepts for the purposes of completing our project involving process improvements within Station 19.

1. Existing Space

Group 15 is currently investigating ways to improve the following items within Station 19, shown below.

Are you satisfied with the organization and layout of the following items within your existing workspace? If not, in relation to the existing area, what would be ideal?

A) Front Suspension Hardware Fixture: Not satisfied. It is hard to remove hardware from the fixture. It is possible to insert wrong washer. Ergonomics. Not stockable.

B) Steering Gear Hardware Fixture: Does not exist. See above.

C) Steering Gear Hardware Fixture: Does not exist.

D) (Black) Front Axle Tool Cart: Part and hardware and tools are not organized, just lay loose on the cart.

E) Hardware Prep Table: Limited space, not well organized.

F) Hardware Storage in general: Satisfied.

2. Future Space

Can you think of any features that would benefit the organization of tools and hardware in Station 19 that could potentially be incorporated into the items listed above? (Feel free to use all available space on front and back of the page).

A)

B)

C)

MECH 4860 – Group 15 – Questionnaire M. Yarovoy - 9-Oct.-2018

Please fill out this brief form as Group 15 from the University of Manitoba seeks your input in order to develop concepts for the purposes of completing our project involving process improvements within Station 19.

1. Existing Space

Group 15 is currently investigating ways to improve the following items within Station 19, shown below.

Are you satisfied with the organization and layout of the following items within your existing workspace? If not, in relation to the existing area, what would be ideal?

A) Front Suspension Hardware Fixture: Not satisfied. It is hard to remove hardware from the fixture. It is possible to insert wrong washer. Exponomics. Not stockable.

B) Steering Gear Hardware Fixture: Does not exist. See above.

C) Steering Gear Hardware Fixture: Does not exist.

D) (Black) Front Axle Tool Cart: Part and hardware and tools are not organized, just lay loose on the cart.

E) Hardware Prep Table: Limited space, not well organized.

F) Hardware Storage in general: Satisfied.

2. Future Space

Can you think of any features that would benefit the organization of tools and hardware in Station 19 that could potentially be incorporated into the items listed above? (Feel free to use all available space on front and back of the page).

A)

B)

C)

Notes.

1) I would suggest to limit the scope of the project to hardware fixtures, leaving other improvement ideas or recomendations for future improvements.

2) As a result of the project I would like to have an instruction on how to use the fixtures.

3) It ~~was~~ would be nice to have the hardware fixtures stackable.

4) I would like to note that the team is doing a great job communicating with operators and acquiring their feed back.

MECH 4860 – Group 15 – Questionnaire (Interview) - Assembly Line
9-Oct.-2015

Please fill out this brief form as Group 15 from the University of Manitoba seeks your input in order to develop concepts for the purposes of completing our project involving process improvements within Station 19.

1. Existing Space

Group 15 is currently investigating ways to improve the following items within Station 19, shown below.

Are you satisfied with the organization and layout of the following items within your existing workspace? If not, in relation to the existing area, what would be ideal?

A) Front Suspension Hardware Fixture: Tight, Wrong washers, hardware need split
- Assemble kits themselves, washers on bolts, two kits

B) Steering Gear Hardware Fixture: - Need a fixture, Non-existent
- Spot for loctite.

C) Steering ~~Gear~~ arms mitre Hardware Fixture:
- Mitre box - 3 coaches → steering arm castle nuts

D) (Black) Front Axle Tool Cart: - integrate tool (Hardware) fixture for assorted hardware placed on tool cart. Provide for 3 coaches

E) Hardware Prep Table: - Relocate bins / under coat.

F) Hardware Storage in general: Satisfied - Want to creat wire hiding
- Not to be fixed to work tables

2. Future Space

Can you think of any features that would benefit the organization of tools and hardware in Station 19 that could potentially be incorporated into the items listed above? (Feel free to use all available space on front and back of the page).

A) Two, Stake able kits, three, four

B) Additional Shelving on blue cart

C)

APPENDIX C: 3D PRINTING QUOTATION

Industrial Technology Centre

200-78 Innovation Drive | Winnipeg, MB | R3T 6C2

3D Printing Quotation

Prepared for: Devin Draward
Team 15, University of Manitoba
15 Gillson Street – Dept. of Mechanical Engineering
Winnipeg MB R3T 5V6

Project Number: 16082-1
Proposal Date: December 1, 2015
Prepared by: Daniel Godin, C.E.T.

Work Description:

- The part(s) listed will be printed using a Fortus 400mc 3D printer.
- The files provided to ITC are to be printed as-is with no further processing.
- Production support material will be removed.
- Part surface finishing will NOT be performed.
- Part conformance to the provided file will NOT be checked.
- The client retains ownership of the designs which are considered confidential.
- The client is responsible for shipping arrangements and costs.

Qty	File Name	Material	Layer Thickness	Bead Width	Fill
1	Front Axle Cart HDWE Fixture	ABS or PC	0.010 in	0.020 in	Solid - Normal
1	Mitre Box Rev 5				
1	Suspension 2				
1	Right Hand Fixture				
1	Steering Gear				

Cost: The total cost is $6,000 for PC and $5,700 for ABS (plus applicable taxes)

Schedule: The 3D printer is booked on a first-come, first-served basis. The delivery schedule can be set upon receiving your Authorization. The part(s) require 14 days to produce.

Authorization

We hereby accept this agreement along with the attached ITC General Terms & Conditions (Rev B). NOTE: Any Purchase Orders received from the client are subject to these GT&C.

If you wish to proceed with the agreement as written, please EITHER complete the Authorization section and return that page to ITC by original, fax, or scan / email OR send an email or purchase order confirmation indicating authorization to this document's quote and revision numbers.

Signature _____ Date _____

Title _____ Purchase Order Number _____

An Agency of the Province of Manitoba

QUALITY SYSTEM REGISTERED ISO 9001

ITC General Terms and Conditions (Rev B)

The parties agree to the following terms and conditions:

1 *Payment Schedule Conditions*

1.1 Terms of Payment:
- a) Payment is due upon receipt of invoice
- b) Interest on overdue accounts is chargeable after 30 days at a rate of 18% per annum of unpaid account balance.

1.2 ITC reserves the right to obtain credit checks on the Client.

2 *Confidentiality*

2.1 All project results and reports shall be considered confidential. No results may be published without the prior written agreement of the Client and ITC except as required by law. Any publication made with ITC's prior written consent shall, at ITC's option, contain a disclaimer, the contents of which shall be acceptable to ITC.

2.2 Without limiting the rights of section 2.1, the name of ITC or the Government of Manitoba or any of its departments shall not be used or implied, directly or indirectly in any way in connection with the sale, offer, advertisement or promotion whatsoever of any articles, processes or services provided by the Client without ITC's prior written consent, which consent maybe withheld at ITC's sole discretion.

3 *Disclosure Of Progress*

3.1 As may be prearranged, the Client may have its representatives at ITC for any activity relating to the project.

3.2 The client agrees to accept reports transmitted by fax or e-mail.

4 *Client Responsible For Materials, Etc*

4.1 The Client shall be responsible for all materials, parts, components, and information provided by or on behalf of the Client.

4.2 The Client shall supply all necessary instructions, drawings, specifications, information, and materials necessary for the completion of the Services in a timely, orderly, and integrated manner. Any failure to do so shall constitute a fundamental breach of this agreement and ITC, in such event, at its option, may cancel this agreement, in which event, the Client shall remain liable for the total costs of the Services contemplated herein.

5 *Work Complies With Laws*

5.1 The Client expressly warrants and represents that the work contemplated by the parties, and the worksite, complies with all laws, including without limitation, environmental, workplace, safety, and health laws and will not infringe any patent or trademark.

6 *Force Majeure*

6.1 ITC shall not be liable for any delays resulting from causes beyond its reasonable control including but not limited to strikes, slow-downs, lock-outs, errors in manufacture, fire, failures, or delays of sources of supply of material, government orders or requests, and ITC shall not be liable in any event for any consequential, economic, special, or any other losses or damages incurred by the Client or any third party on account of such delay.

7 *Entire Agreement*

7.1 This agreement and attached Service Description contain the complete agreement between the Parties with respect to the Services. There are no other agreements, representations, or warranties, either expressed or implied. Without limiting the generalities of the foregoing, ITC shall not be responsible for market acceptance of any materials or thing associated with the project, nor does it offer any guarantees or warranty that the results of the said project may be duplicated elsewhere or on other equipment, or that any products produced hereunder will be safe for use unless specified elsewhere in this agreement.

8 *Limitation Of ITC's Liability*

8.1 Liability for any claim that the Client or any officers, employees, or agents of the Client may have against ITC for personal injury, bodily injury (including death) or property damage, arising in any way under this Agreement whether in contract law or in tort, shall be limited to two times the total cost of the Services provided hereunder.

8.2 Similarly, ITC's liability for any claim that the Client or any officers, employees, or agents of the Client may have against ITC for special, incidental, consequential, indirect, financial or economic loss arising in any way under this agreement whether in contract law or in tort, shall be limited to two times the total cost of the Services provided hereunder.

8.3 ITC's total liability for all claims under this Agreement shall not exceed two times the total cost of the Services provided hereunder.

9 *Termination*

9.1 ITC may immediately cancel this agreement at any time by giving notice in writing to the Client in any of the following events:
- a) ITC deems the project dangerous for the staff or facilities;
- b) The Client is dissolved or becomes bankrupt or insolvent; or
- c) In the opinion of ITC the Client has failed to comply with any term or condition of this Agreement.

10 *General*

10.1 The provisions hereof shall be binding upon each of the Parties, including their respective successors, and assigns.

10.2 This agreement shall be performed, interpreted, and enforced according to the laws of the Province of Manitoba. The invalidity of any provision of this agreement shall not affect any other provisions and the agreement shall be construed as if such invalid provision had never been included.