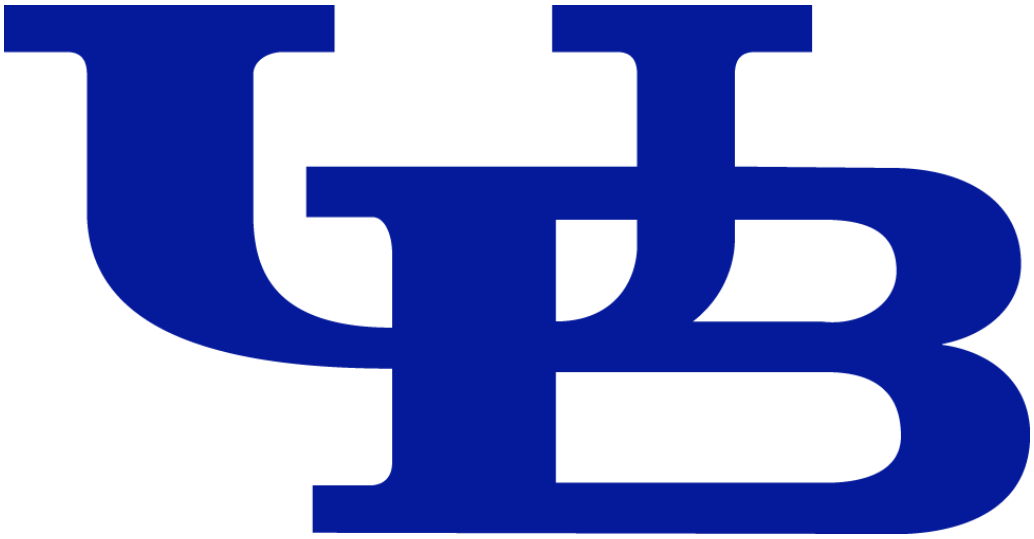
University at Buffalo

Department of Industrial Engineering



School of Engineering & Applied Sciences

Industrial Engineering Major

IE 420 - System Engineering Practicum

Lab Report 3 - Scooter Production

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Executive summary

The Dange 'R' Us Scooter Company recently decided they wanted a new production line to manufacture their most recent scooter design, the Blazer. The employees at the company work a typical 8 ½ hour day with an unpaid 30 minute lunch and two paid 15 minute breaks. This leaves 7 ½ labor hours to produce a goal of 1000 scooters. The company wanted to spare no expense on their Blazer, so 16 components were necessary with at least three power tools being used to assemble them. The goal was to develop a streamlined manufacturing process of producing these scooters using ergonomics, line balancing, and a little bit of intuition.

The ergonomic analysis was a component the Dange 'R' Us Scooter Company emphasized because safety is one of their major concerns. The analysis consisted of a RULA (Rapid Upper Limb Assessment) calculation for the 6 biggest potential problem areas and HAL TLV analysis of each station. The 6 tasks analyzed with RULA required either the most dexterity or strength which have a major impact on this assessment. If these tasks are acceptable it is fair to assume the entire process is acceptable as far as RULA is concerned. The highest score calculated was a 4; on the RULA scale this indicates that although some change may be needed the score is acceptable. A further investigation to get this score down could be a potential project for the future. The HAL TLV analysis initially returned some alarming numbers with only 5% of the tasks being under the Action Limit and 81% of the tasks being over the Threshold Limit Value. The manufacturing process was revisited and some fixtures were added to lighten the load on the employees. Recalculation of the HAL TLV score indicated that 15% of the tasks were now under the Action Limit and only 62% were over the Threshold Limit Value. Although these scores are far from perfect, major progress was made to improve the process and future analysis may be able to move these scores to an even safer range.

Before getting to line balancing, the number of work stations needs to be determined. The constraints used to determine the optimal number of stations were the amount of parallel assembly lines, the production of 1000 scooters per shift, and the work content time (time needed to build a scooter from start to finish). The optimal number of work stations was calculated to be 16 with 1 worker at each stations (4 parallel rows of 4 stations). Using the largest candidate rule, the 37 tasks to assemble a scooter were divided evenly among the stations. Each station ended up taking about 110 seconds to complete and transfer to the next sequential station. This layout ensures that 1000 scooters will be produced per 7 ½ hour shift with the minimal number of workers.

The manufacturing process proposed was able to guarantee hitting the target goal of 1000 scooters per shift for the Dange 'R' Us Scooter Company. Although the ergonomic analysis left plenty of room for improvement, overall the process met the company's needs and created a wonderful product for customers to enjoy.

1. Problem Statement and Product Description

A scooter manufacturer, Dange 'R' Us, is interested in building a new model called "The Blazer". They would like to create an efficient manufacturing process to produce 1000 scooters per shift.

Figure 1.1: The Blazer

The main components of each scooter are a plank with four individually-mounted wheels, and a mounted T-bar to act as a support for the rider. The complete bill of materials for a scooter is outlined below.

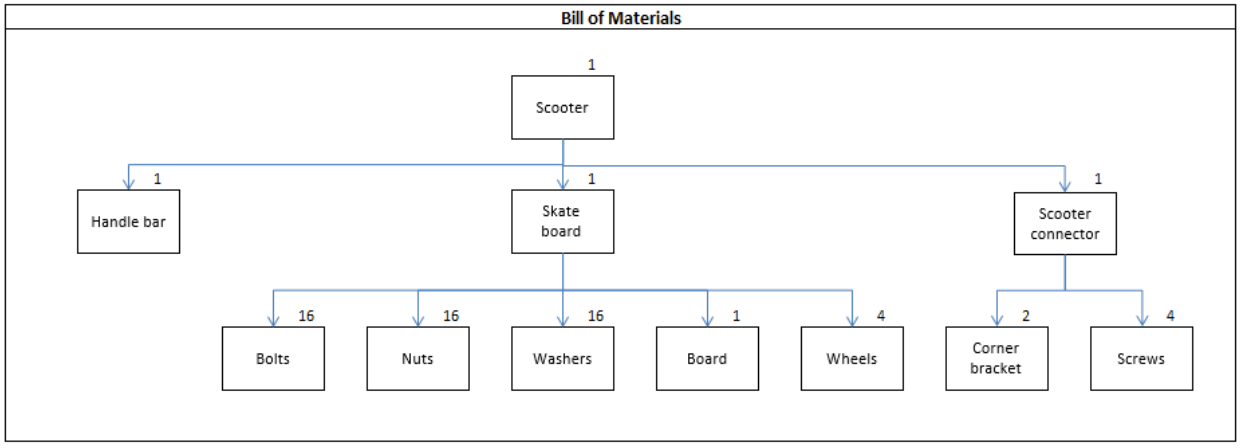

Figure 1.2: Bill of Materials

In order to completely assemble a scooter, certain fixtures and tools are required. Complete tooling and fixtures for the process is outlined in table 1.1. Pictures of specialty fixtures can be found in figure 1.3. An outline of assembly steps with corresponding standard times can be found in appendix 7.3.

Tooling	Fixtures
Pneumatic Drill	Riser
Pneumatic Screwdriver	Clamps
Pneumatic Sander	Drill Template
5/16th Manual Wrench	T-Bar Stand
	Flipping Board

Table 1.1: List of Tooling and Fixtures

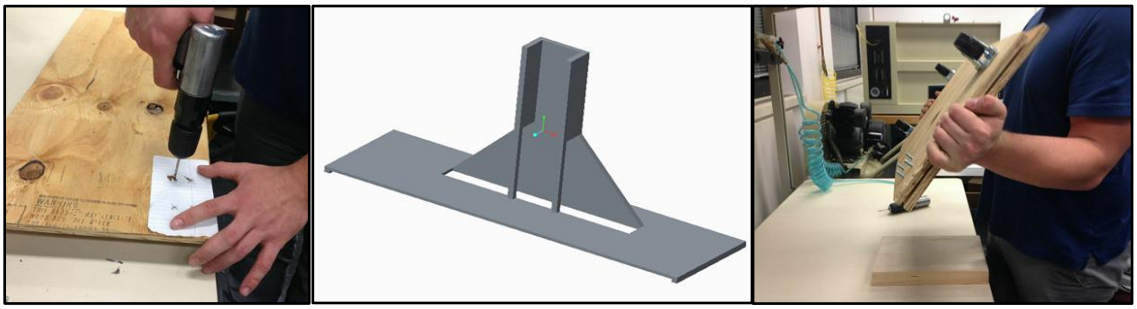

Figure 1.3: (From left) Drilling Template, T-Bar Stand, Flipping Board

2. Methodology and Assumptions

The methodology of this project requires multiple steps and techniques. First, a bill of materials, list of tooling needed, and list of fixtures were compiled to outline all of the resources needed throughout production. Then, a time study was conducted through video to record times and positions of the worker for each task in assembly. This will aid in line balancing and ergonomic analysis.

After initial ergonomic analyses using RULA, HAL TLV, and hand balancing, an iteration was made to address appropriate issues. Further explanation and details can be found in Section 3. A second time study was conducted with these process improvements. The corresponding normal and standard times were calculated to be used for line balancing and

development of a standard operating procedure (SOP).Further explanation of line balancing can be found in Section 4, and the SOP can be found in the appendix 7.3.

The times taken were compared with values given in the predetermined motion time system (PMTS) for accuracy. Validation with the given times for each task determined that our time study results were accurate and representative.

To complete this project, the following assumptions are made:

- 1000 scooters must be completed each 8-hour shift.

- Employees have two 15-minute breaks during the 8-hour shift, and an unpaid 30-minute lunch break that is added on to the 8-hour shift. This means that there is an available production time of 7.5 hours per worker per shift.

- All workers are right handed. Because the majority of the world population is right handed, this will be considered when completing hand-balancing analysis.

- An allowance factor of 0.1 is applied to the times in the time study to obtain the standard times. This was decided amongst the analysts to be representative of a real-world application.

- A performance rating of 1.0 was applied to the times in the time study to obtain the normal times. Because the subject of the time study was one of the participating analysts, steps were taken to ensure appropriate pacing. This eliminates any behavioral effects or Hawthorne Effect on the operator.

- The most repetitive and strenuous tasks act as the constraint for ergonomic analysis. If these are considered safe, so are the smaller, less strenuous tasks.

3. Ergonomics

3.1. Rapid Upper Limb Assessment (RULA)

This project called for an ergonomic analysis to ensure the work would be safe for employees. The most demanding and repetitive parts of the work were analyzed with the assumption that the rest of the tasks would be safe if these were. The tasks analyzed were drilling the holes in the board, clamping the board to the table, attaching the

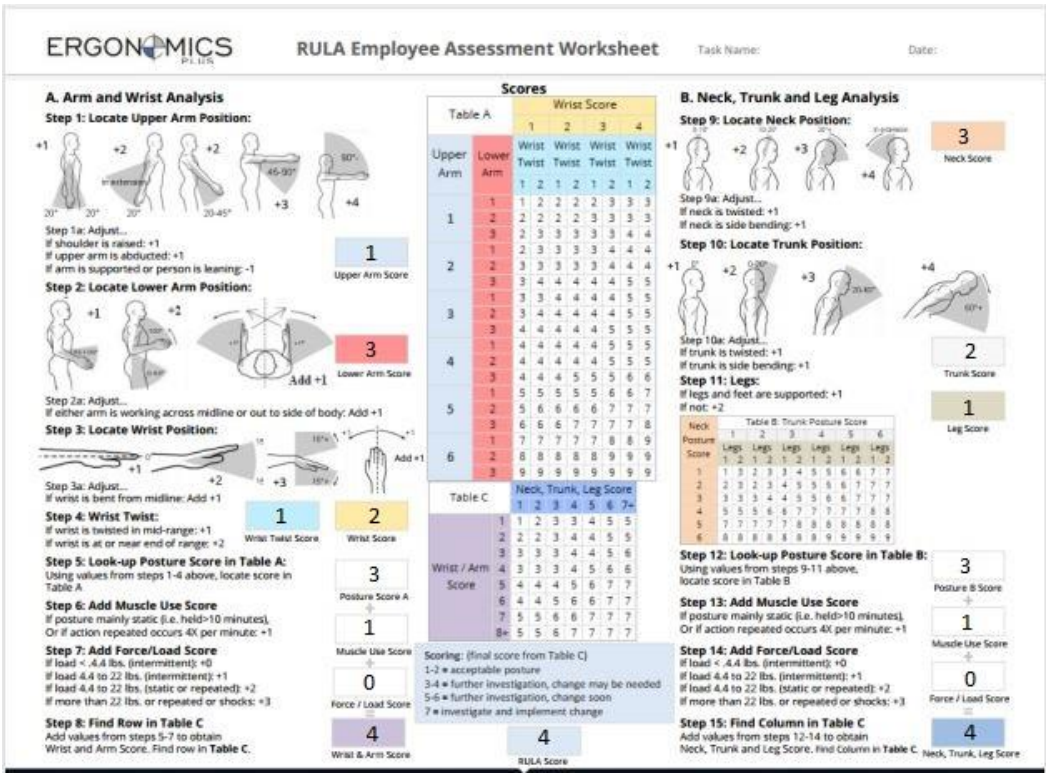

Figure 3.1: RULA Assessment for Drilling

wheels, attaching the handle bar, putting the washers and bolts together, and moving the board from station to station. These tasks are assumed to give a complete picture of the production of the scooter.

Drilling turned out to be one of the riskier tasks with a RULA score of 4. Based on this score, the task is approaching a potentially unsafe state and change may be necessary, but it is not certain. The other tasks measured received RULA scores of 3 except for moving the board, which received a 4 (see Appendix 7.4.1). These scores are not very high on the RULA scale, so change is not necessary at this time.

3.2. Hand Activity Level Threshold Limit Value (HAL TLV)

The Threshold Limit Value (TLV) is used to evaluate the job risk factors that are related with musculoskeletal disorders particularly at the hand and wrist. It takes in to account factors such as the amount of effort and frequency of activity to perform the evaluation.

The TLV categorizes hand activities into three categories

Category	**Definition**
> TLV	High risk
AL to TLV	Moderate risk
<AL	Safe

Table 3.1: TLV risk categorization

Ideally, the ratio of activities for each hand should be as close to 1:1 as possible. In addition, the activity should minimize the number of activities >TLV and maximize the number of action <AL.

As seen in figure 3.2 an assessment of the initial simulation of the assembly procedures indicate that there is a high frequency of activities in the category of >TLV. This indicates that the activity is not safe. Also, figure 3.3 shows bars representing the ratio of hand activity for each hand. Both hands have a fairly equal number of activities.

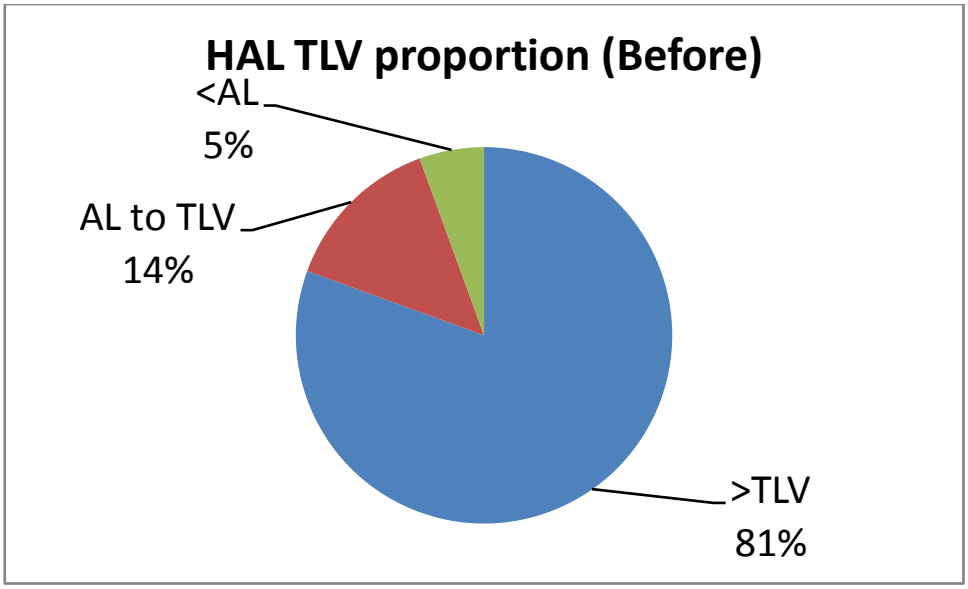

Figure 3.2: Initial hand activity level and threshold limit value

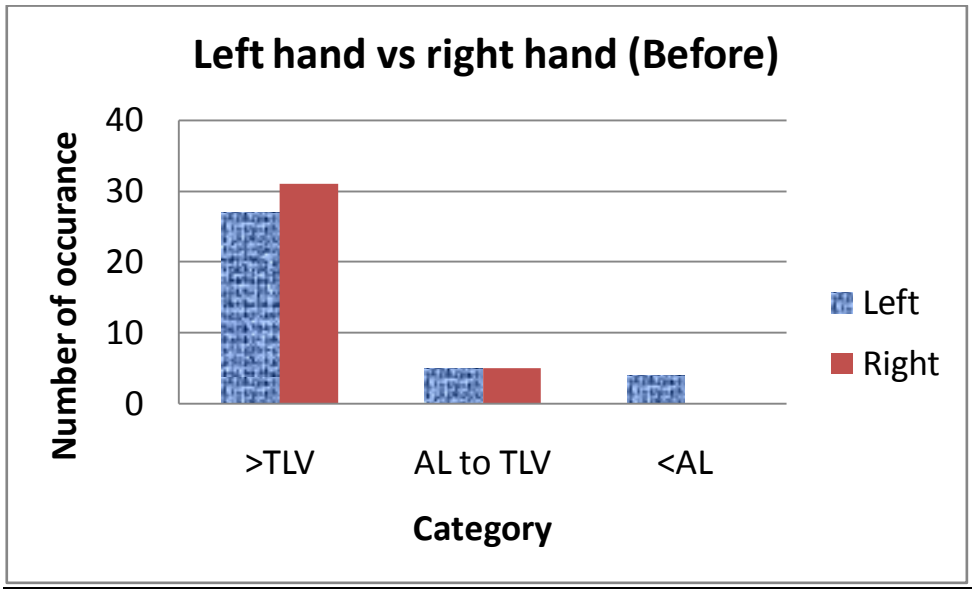

Figure 3.3: Initial number of occurrence for each hand

To minimize the number of high risk activities (>TLV), several improvements are implemented into the assembly process to either reduce the hand activity level or the normalized peak force required to perform the assembly procedure as seen in figure 3.4 which shows a reduction in the number of task categorized as >TLV.

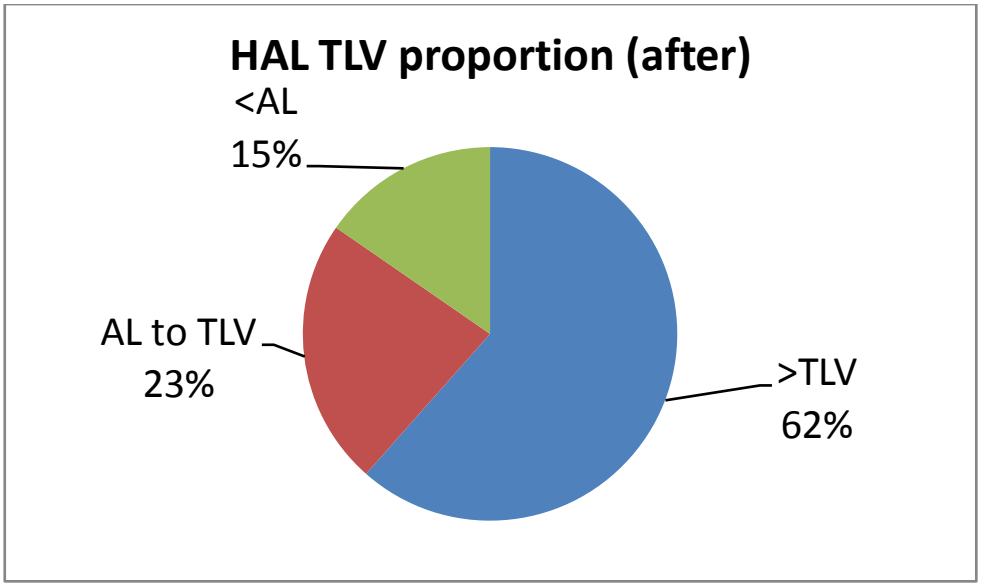

Figure 3.4: Final hand activity level and threshold limit value

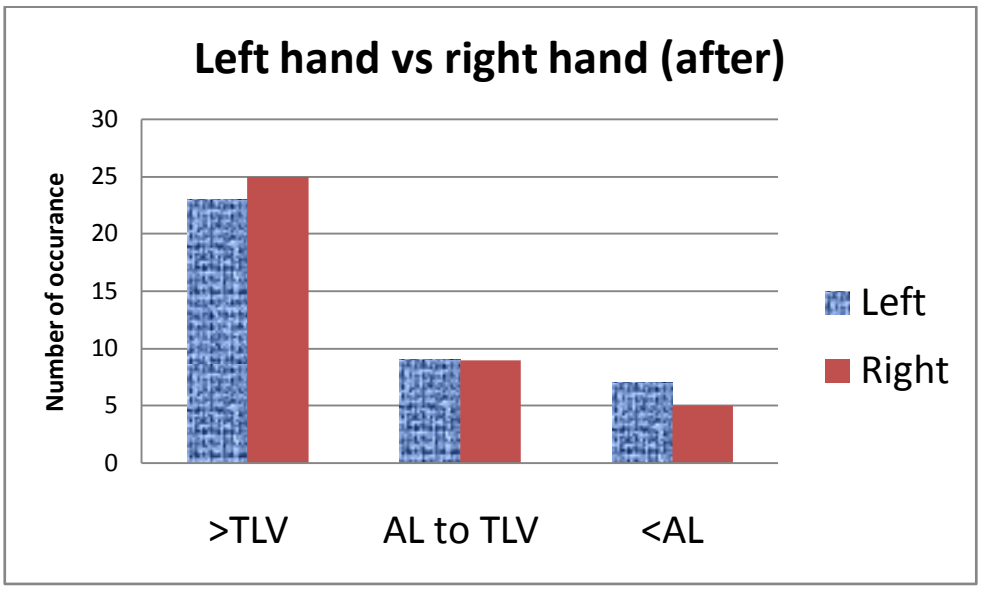

Figure 3.5: Final number of occurrence for each hand

4. Line Balancing and Organization of Work

Given the adjustments made after an ergonomic analysis and time study, the final precedence diagram is found in figure 4.1. Steps of assembly with no prerequisite steps can be found on the far right side, with no arrows going into them. The final step, 37, is found on the far right. This means that all other steps must be completed before 37 is completed.

A table with each numbered task and the associated standard times and prerequisite steps can be found in Appendix 7.6.

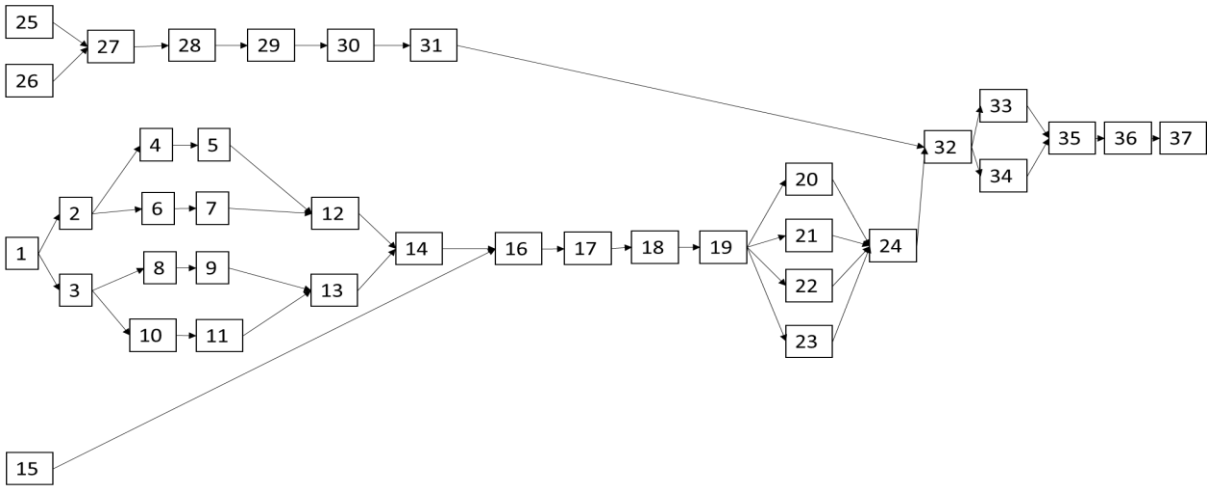

Figure 4.1. Precedence Diagram

Before line balancing can be completed, the number of stations needs to be calculated. The number of stations takes the following into consideration:

- Demand constraint of 1000 scooters per shift
- Work content time, or the time needed to build a scooter from beginning to end
- The number of parallel assembly lines

Using these parameters, the corresponding production rate, cycle time, and the total number of workers can be calculated. The work content time is the required time to complete a scooter based on the cumulative standard times of each task. Hourly production rate is the amount of scooters each assembly line needs to produce in an hour. The cycle time is how long each station has to build their portion of the product, assuming all stations have equal assigned assembly times. Finally the number of single-worker stations needed is the work content time divided by the cycle time. The total workers needed is rounded to the nearest integer. Table 4.1 summarizes the results.

Number of Lines	Work Content Time (min)	Hourly Production Rate (units/hr)	Cycle Time (min)	Stations	Total Workers
1	6.98	133.33	0.43	17	17
2	6.98	66.67	0.86	9	18
3	6.98	44.44	1.3	6	18
4	6.98	33.33	1.73	4	16

Table 4.1: Total Stations and Workers given Number of Lines

These calculations show that having four parallel assembly lines with four single-worker stations in each is most efficient for production. Now, the 37 tasks in production can be distributed over four stations using the largest candidate rule line balancing method. The largest candidate rule consists of assigning tasks to stations based on the following parameters:

- Time in each station
- Feasibility of task order shown in the precedence diagram
- Time for each task

The sum of task times at each station must not exceed the calculated time of 1.73 minutes (104 seconds) per station. Because it is infeasible to divide the tasks perfectly into 104-second stations, 110 seconds will be used as the new work station time. This allows for a slight buffer in balancing the tasks. In other words, the product will spend exactly 110 seconds at each of the four stations, and move on in a linear fashion. Figure 4.2 outlines the balanced process. Figure 4.3 illustrates the entire process, with four identical lines of four stations each and the basic material flow. Gantt Charts and SOPs for each of the four stations can be found in the appendix.

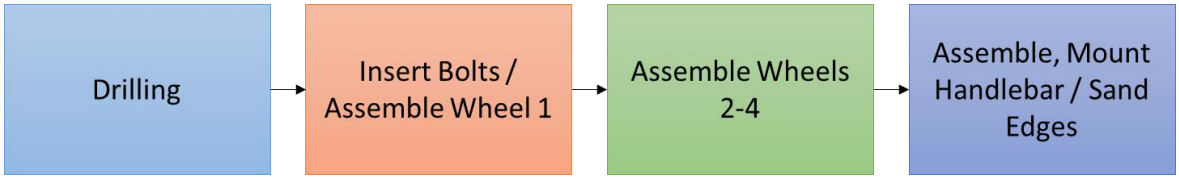

Figure 4.2: Four Balanced Stations

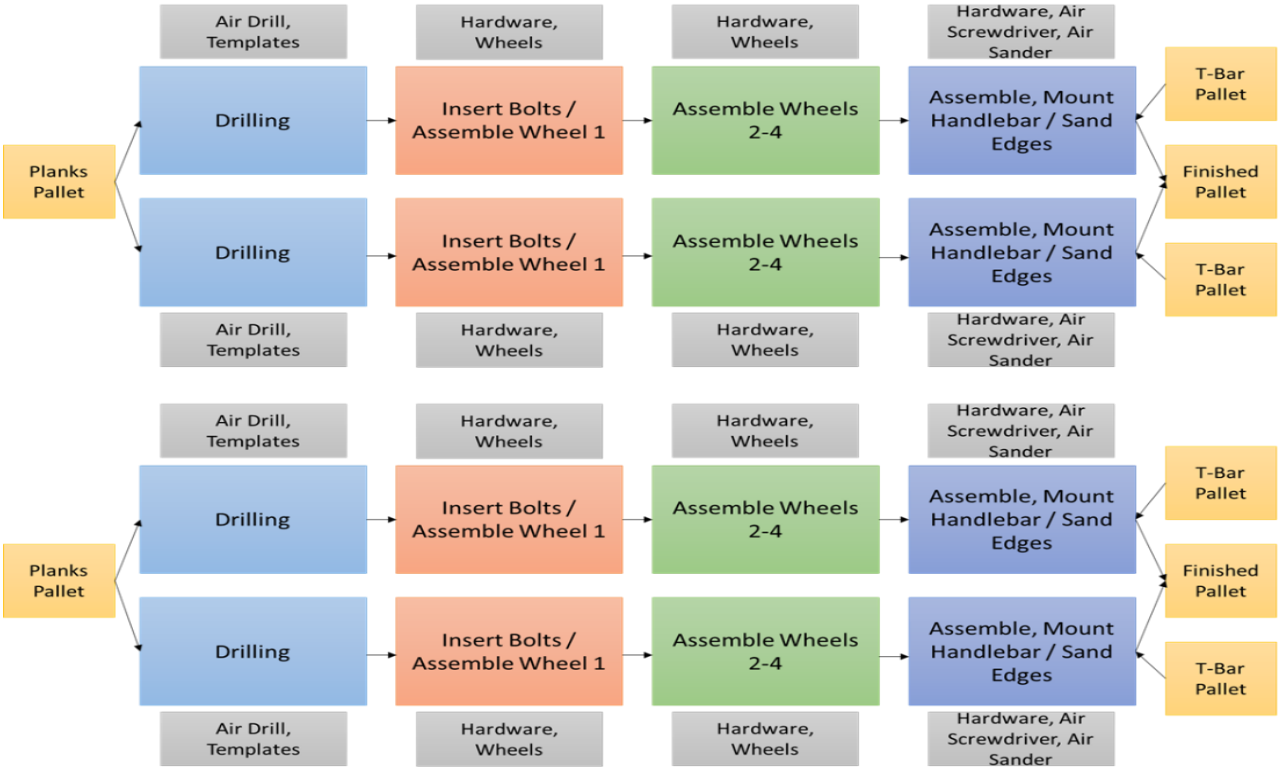

Figure 4.3: Four Identically Balanced Assembly Lines

With this layout, 16 stationary workers are able to produce 1000 scooters per shift, where each shift consists of 7.5 hours of work time for each worker.

5. Recommendations and Conclusion

The purpose of this project was to design and analyze a manufacturing process which would produce 1000 scooters in 7 ½ working hours. By designing the process with 16 stations overall in 4 rows of 4, this goal was met with the use of only 16 employees. Each of the 4 stations in each row was balanced to take no more than 110 seconds. The tasks were broken down evenly to ensure that each employee was given a fair amount of work and there were no bottlenecks.

The ergonomic analysis consisted of a RULA calculation and a HAL TLV score for the procedure. The RULA calculation was done on the 6 tasks which required the most dexterity or strength to perform, as these factors weigh heavily on the RULA score. If these tasks returned an acceptable score, it is fair to assume the entire process would be safe as well.

The highest calculated RULA score was a 4 which is in the middle of the road as far as RULA is concerned. This is definitely not a perfect score, but considering the sensitivity of the RULA calculation it is in an acceptable range. Further analysis may be considered in the future, but for the sake of this project the score is fair. The HAL TLV analysis initially returned some alarming number with only 5% of the tasks being under the Action Limit and 81% being above the Threshold Limit Value. After implementing some modifications, these numbers were greatly improved to 15% of tasks being under the Action Limit and only 62% being over the TLV. Although these numbers are far from perfect, they are a major improvement and pave the way for future ergonomists.

In the end the project was a success and the Dange 'R' Us Scooter Company was very pleased with the process laid out for them.

6. References

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Sorby, S. and Bulleit, W. (2005). An Engineer's Guide to Technical Communication. Prentice Hall, Upper Saddle River, NJ.

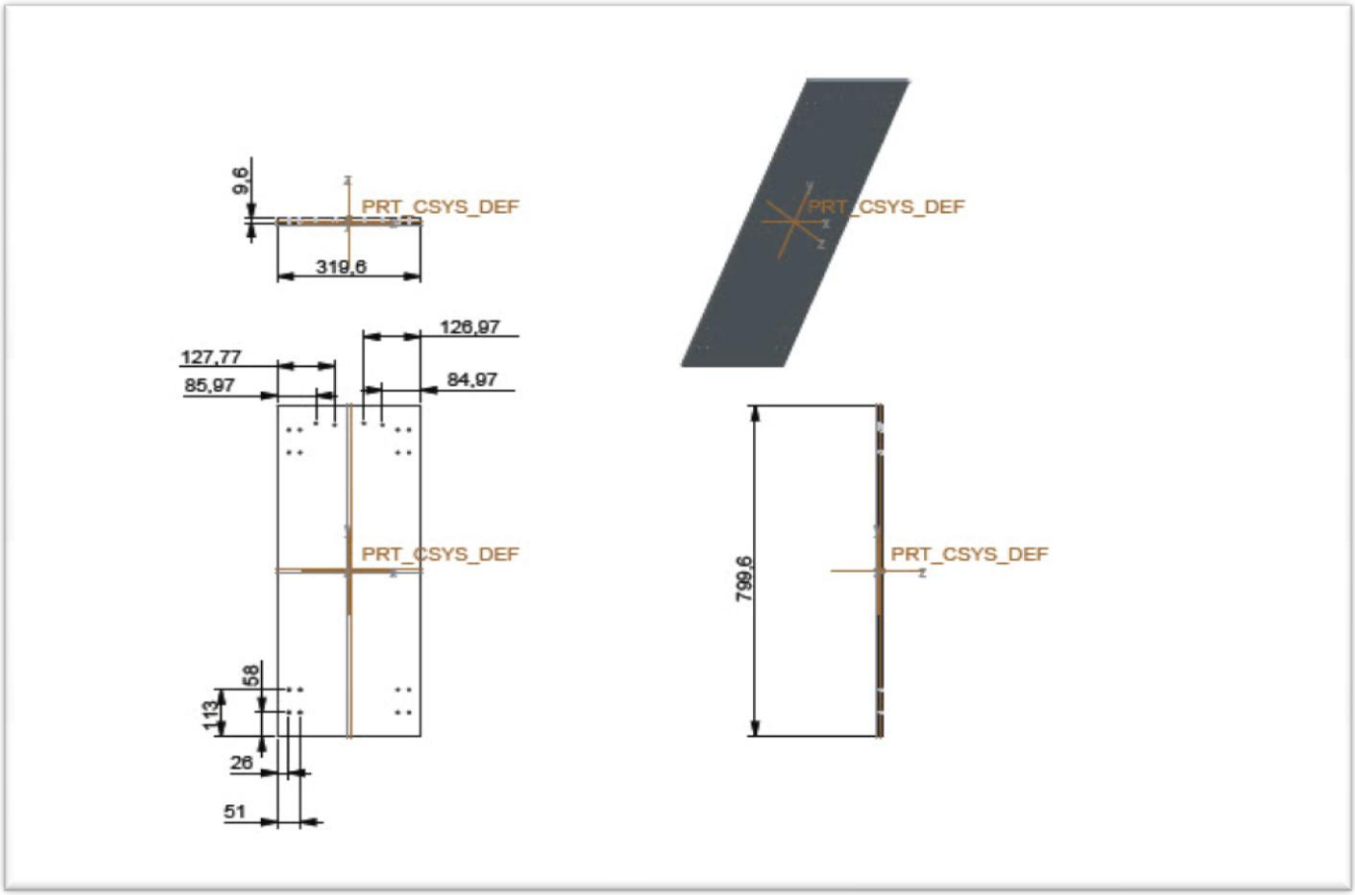
Hillier and Lieberman (2010). "Introduction to Operations Research". 9th edition. New York City (NY): McGraw-Hill Higher Education. 1047 p.

J. Steven Moore and ArunGarg, The Strain Index: A proposed method to analyze jobs for risk of distal upper extremity disorders; Am. Ind. Hyg. Assoc. J. 56:443-458, 1995.

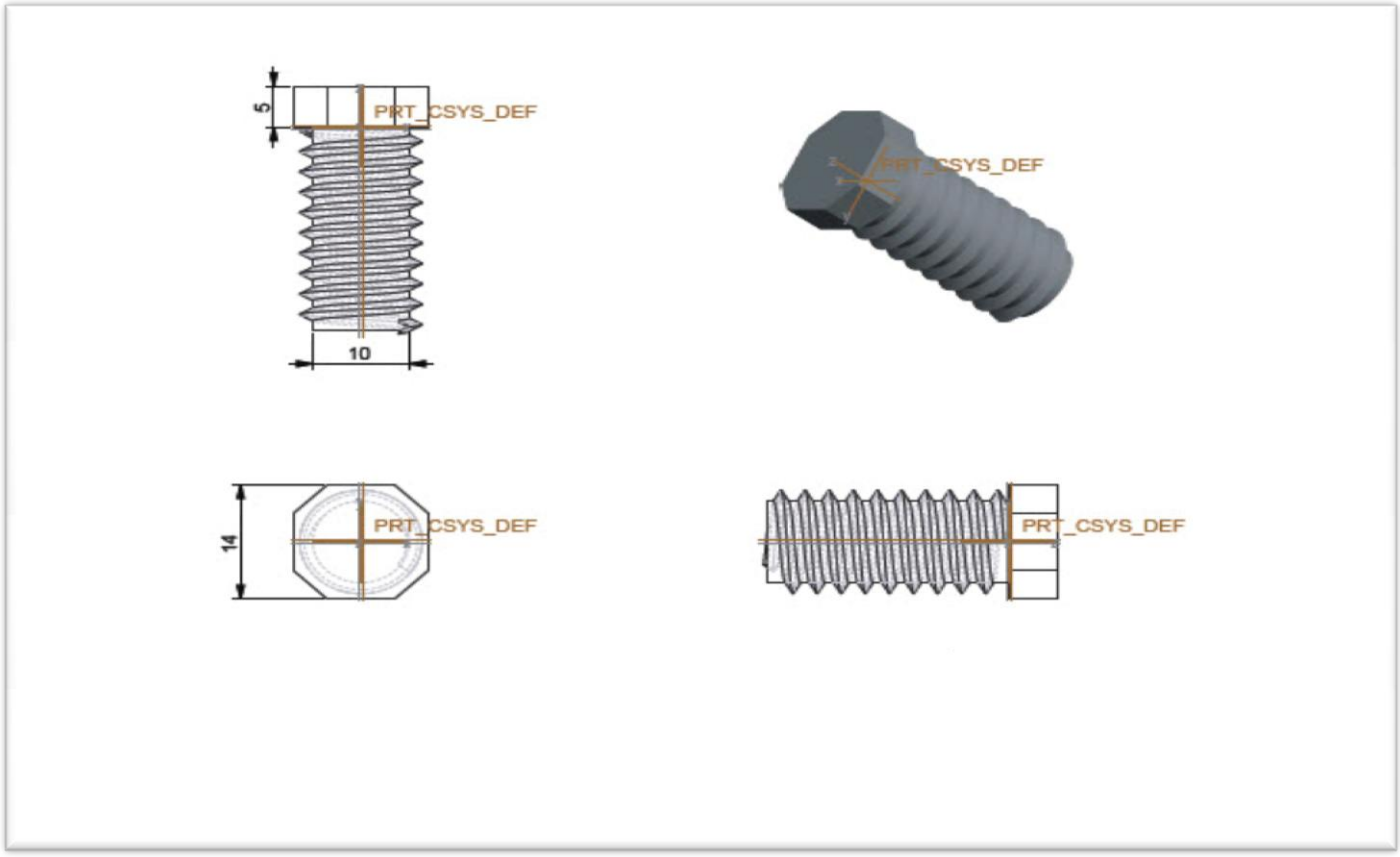
7. Appendices

7.1. Drawings

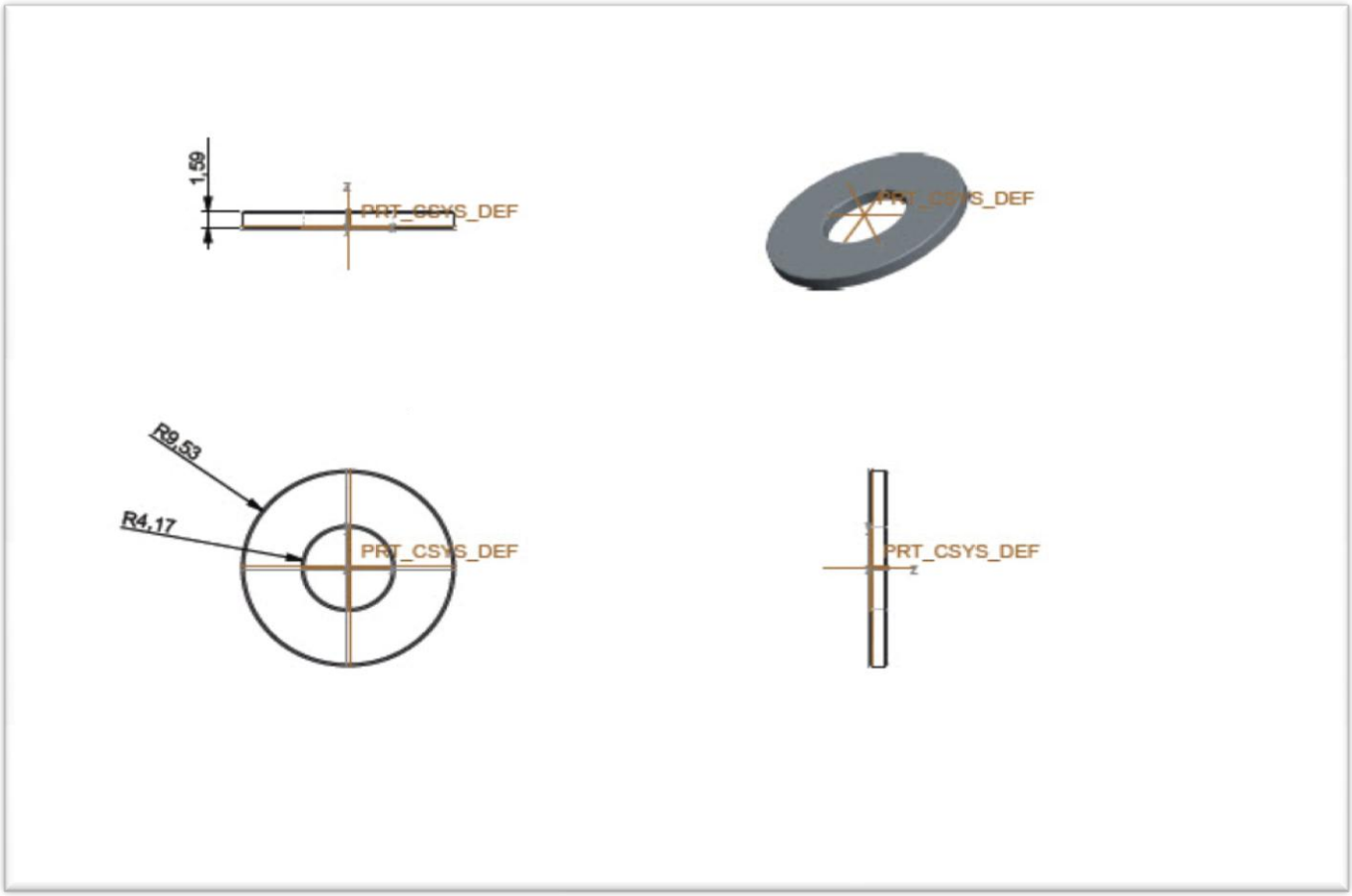
7.1.1. Drawing - Board



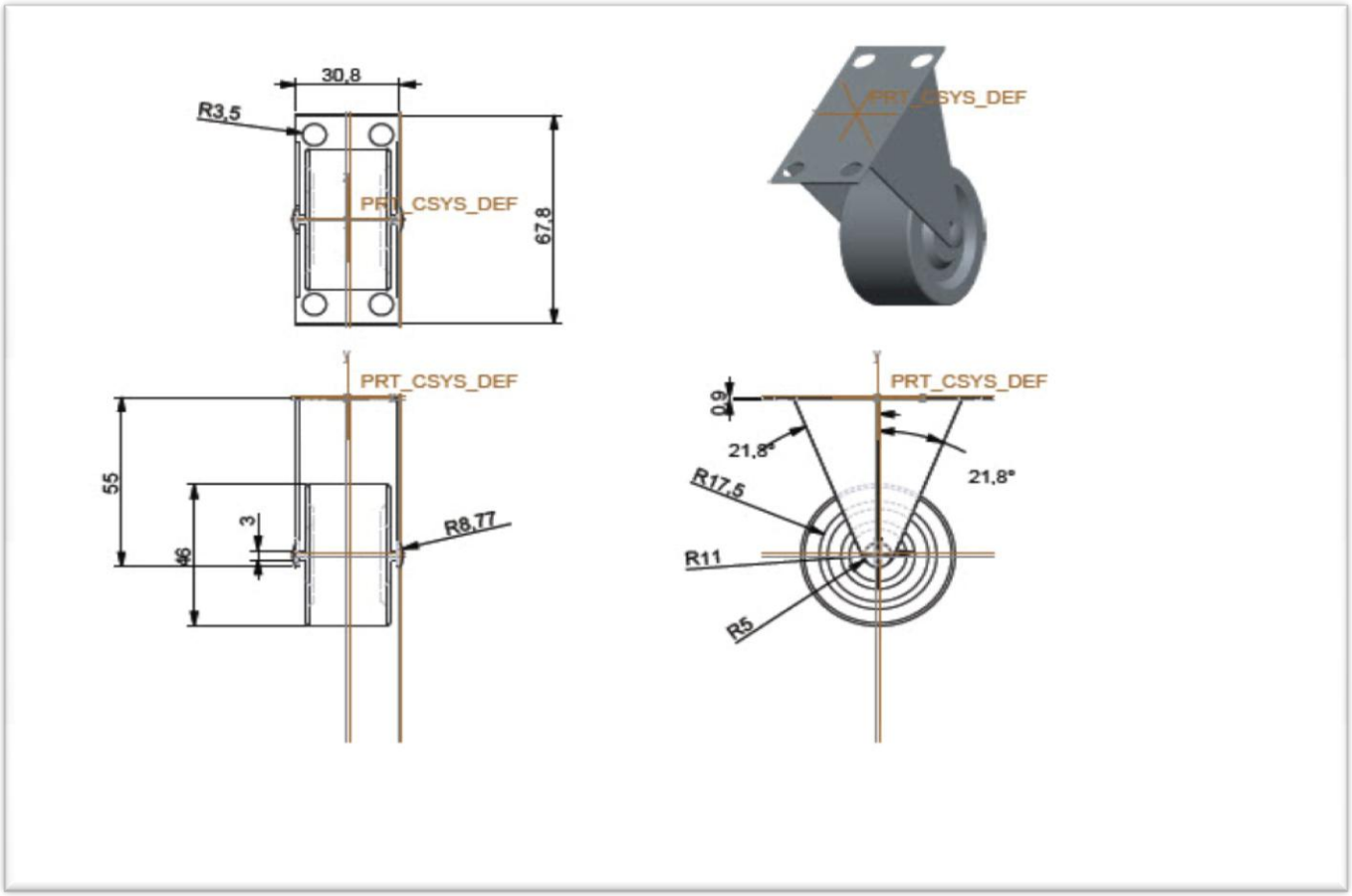
7.1.2. Drawing - Bolt



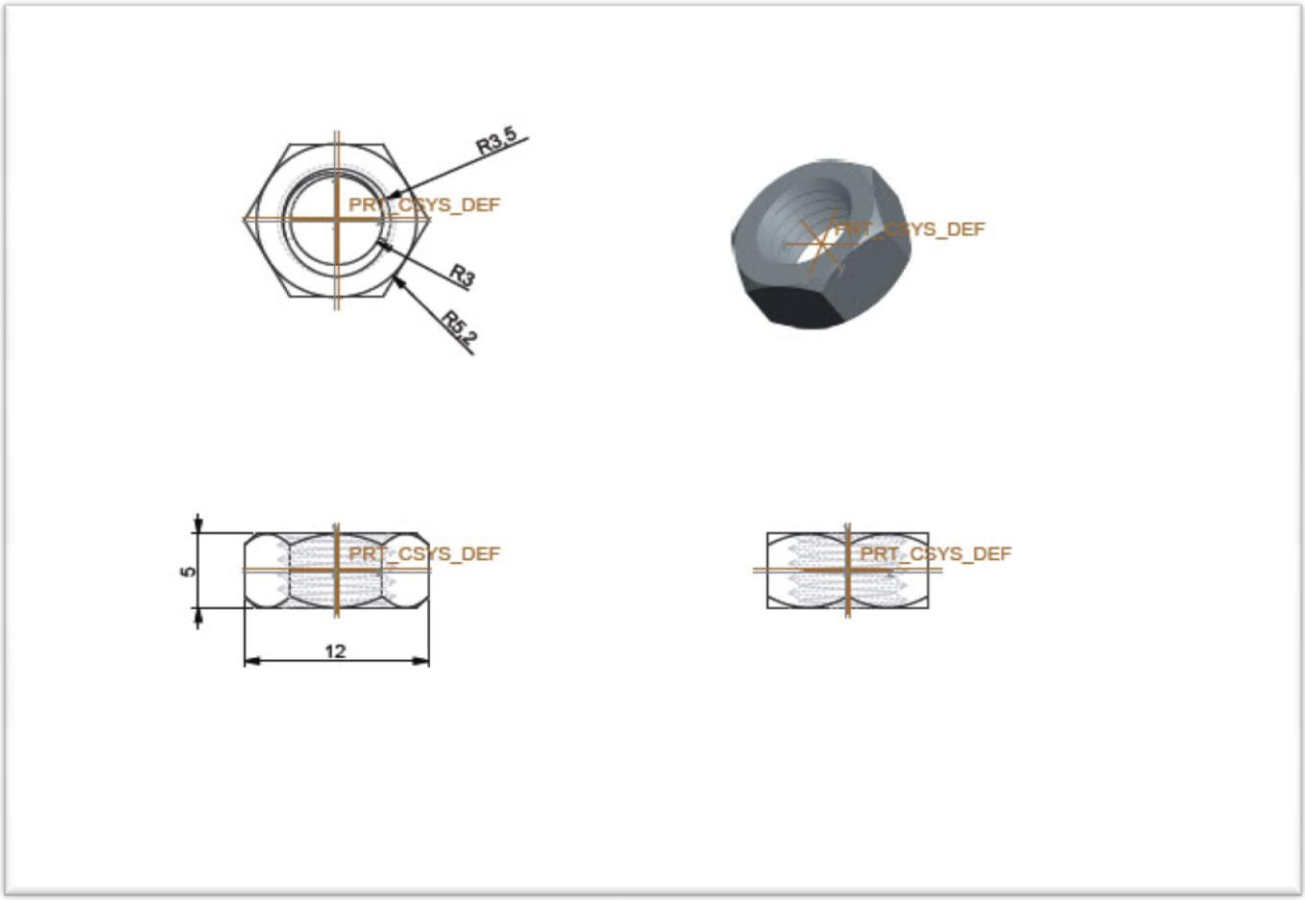
7.1.3. Drawing - Washer



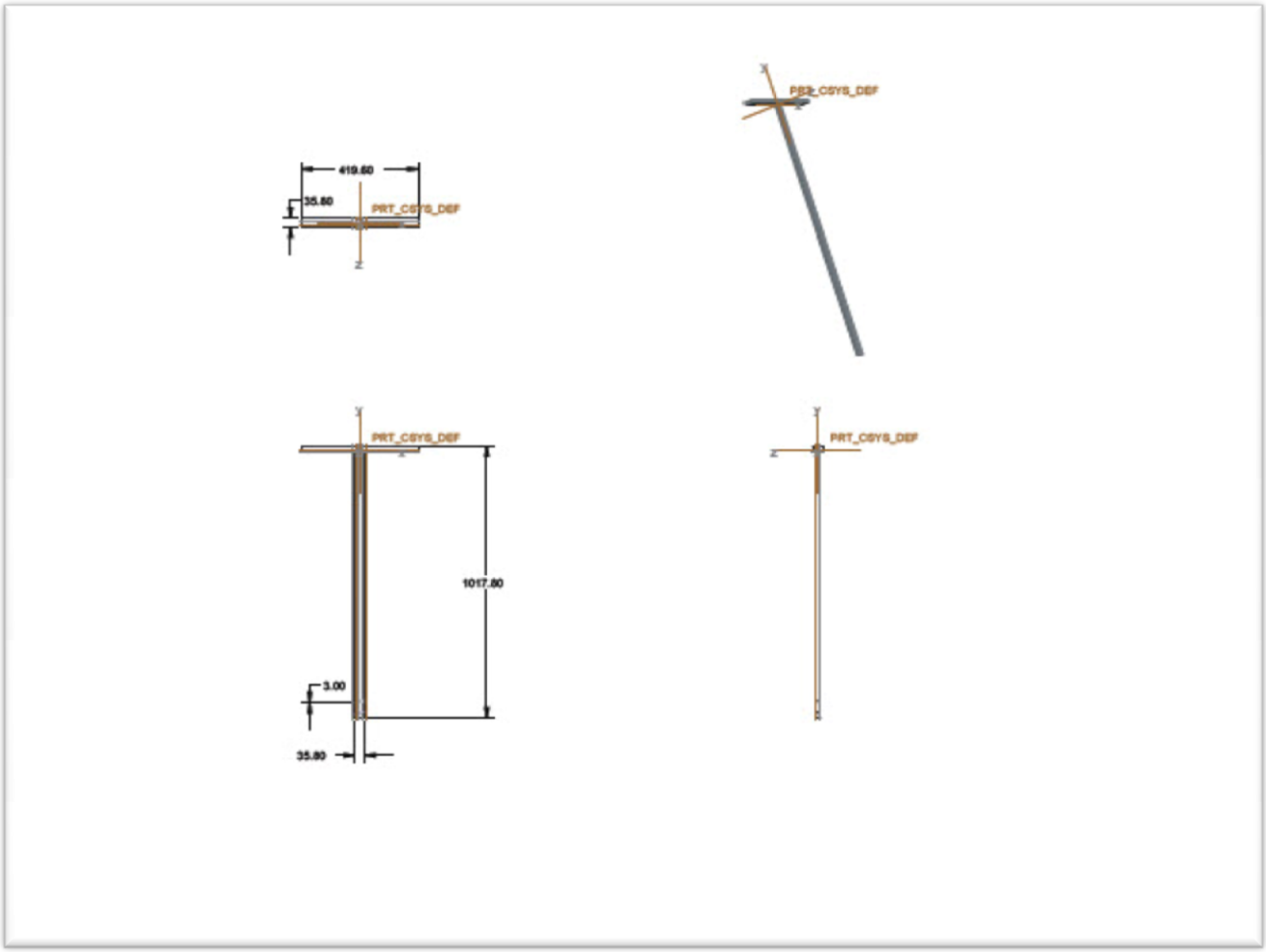
7.1.4. Drawing - Wheel



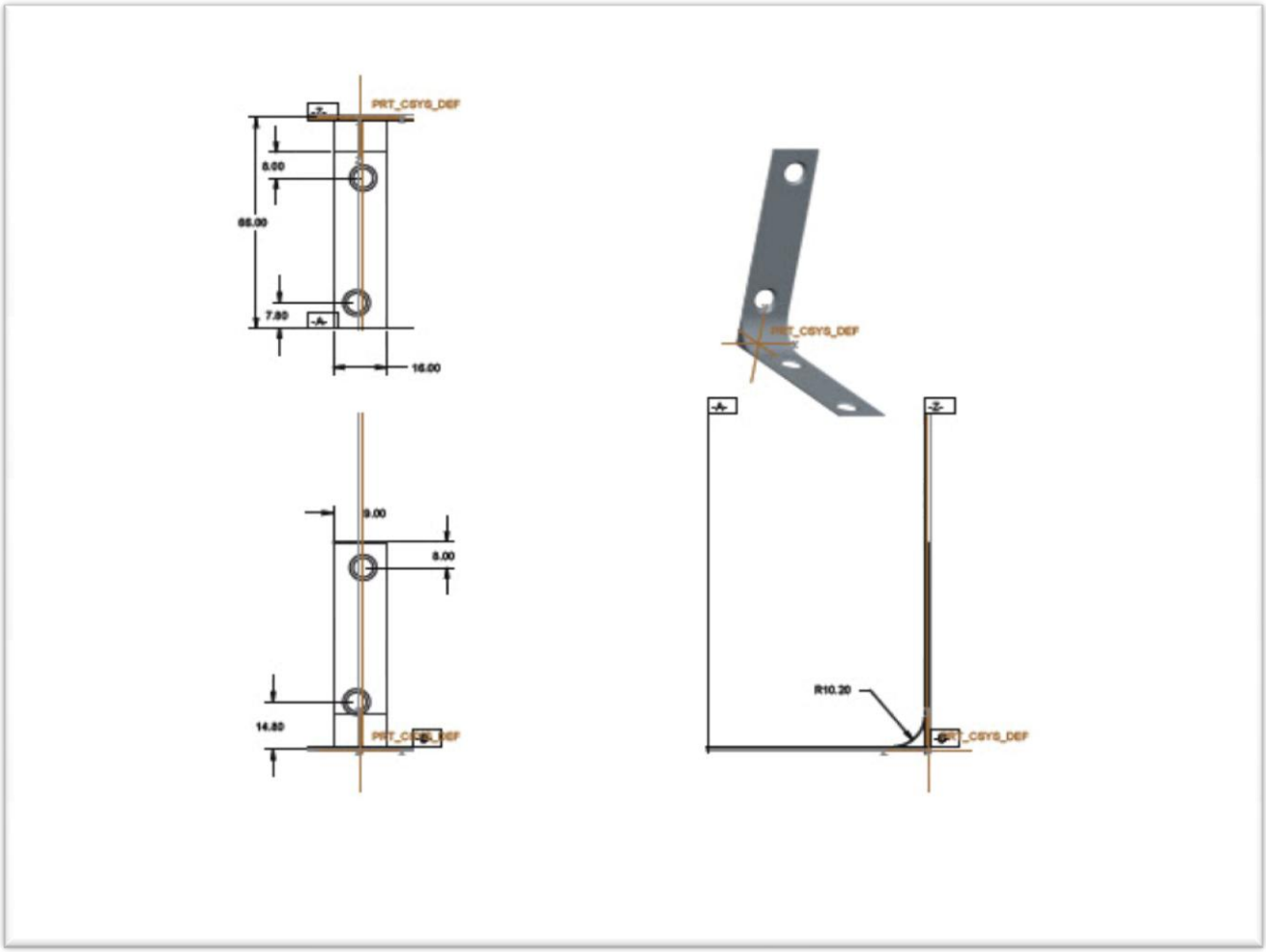
7.1.5. Drawing - Nut



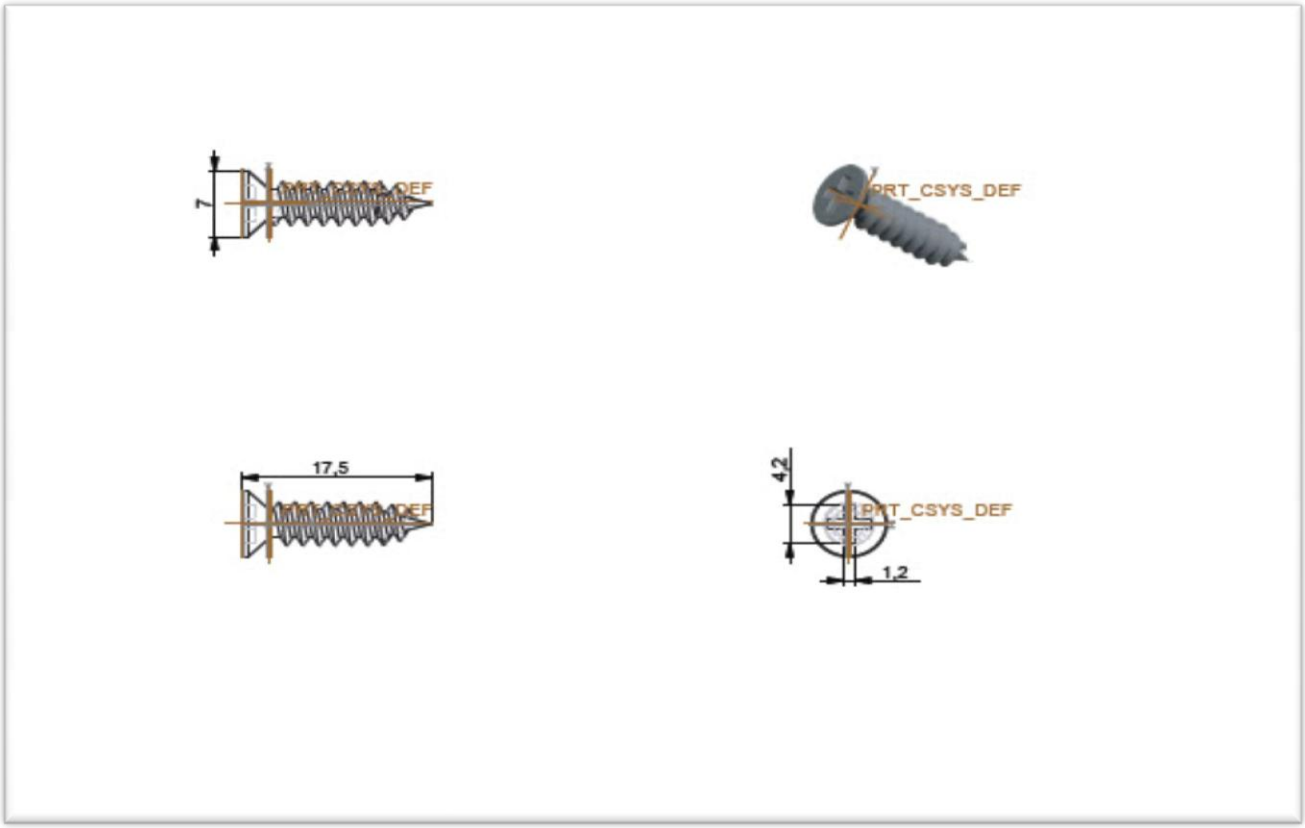
7.1.6. Drawing - T bar



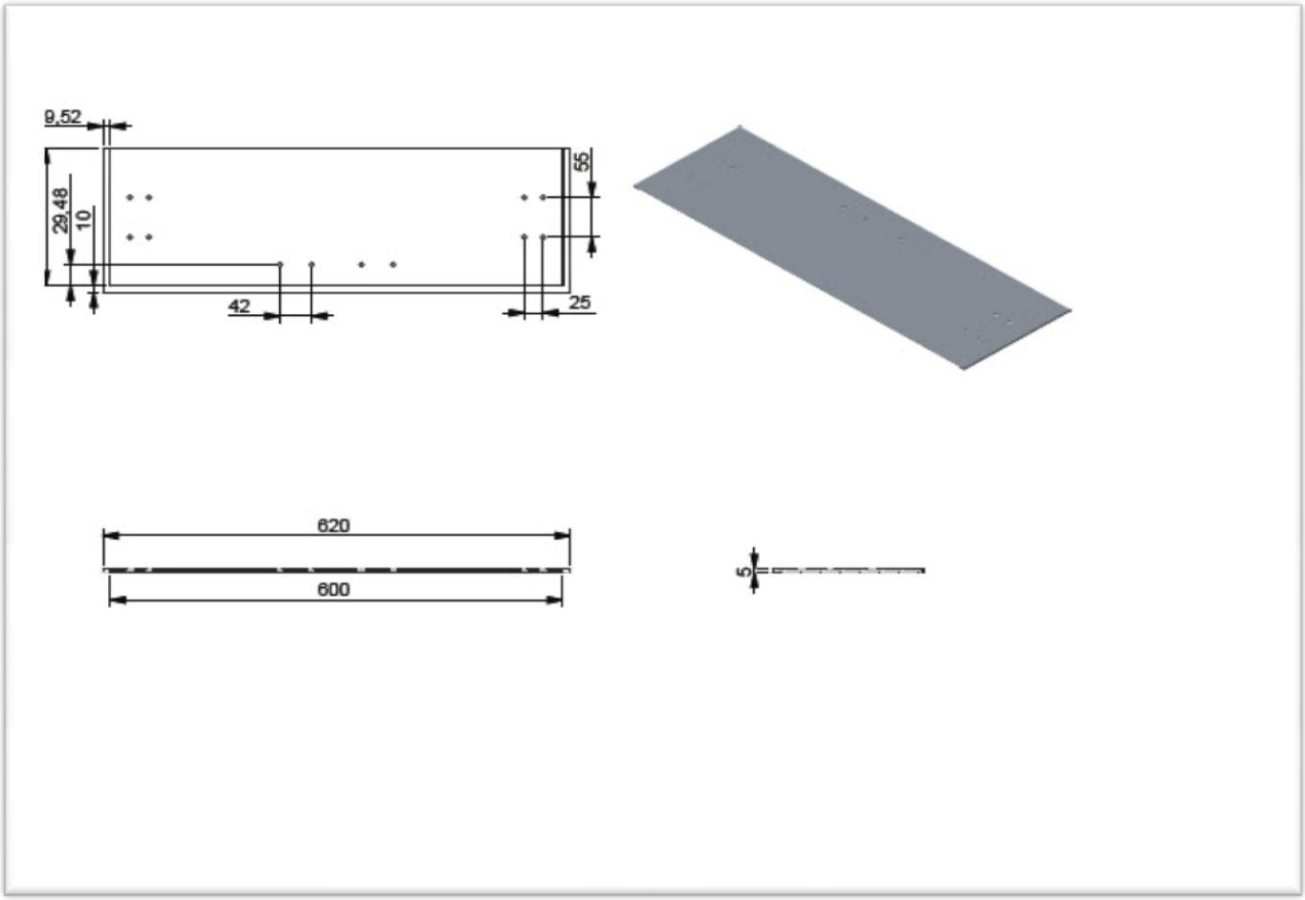
7.1.7. Drawing - Bracket



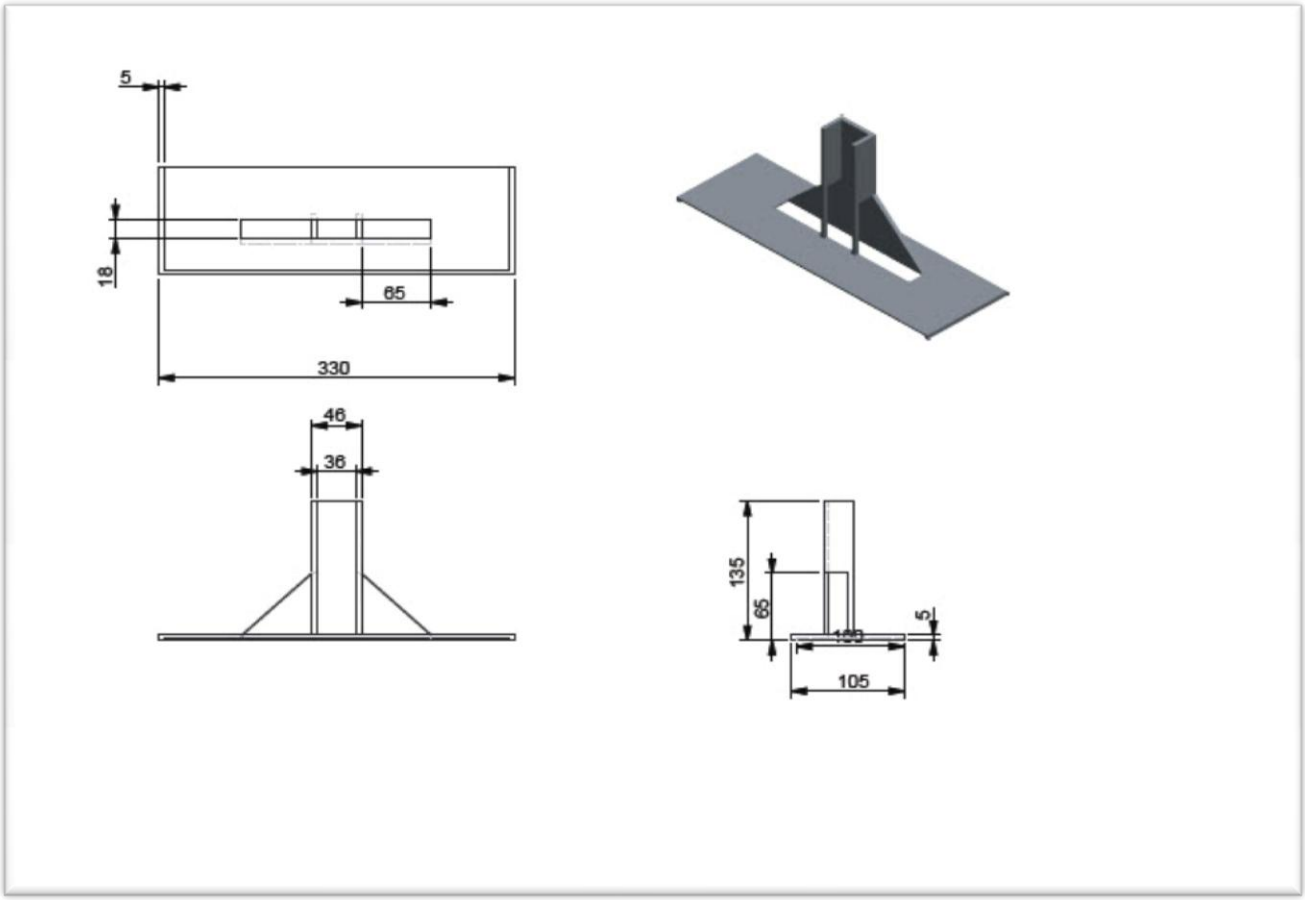
7.1.8. Drawing - Screw



7.1.9. Drawing - Fixture template



7.1.10. Drawing - Fixture T bar support

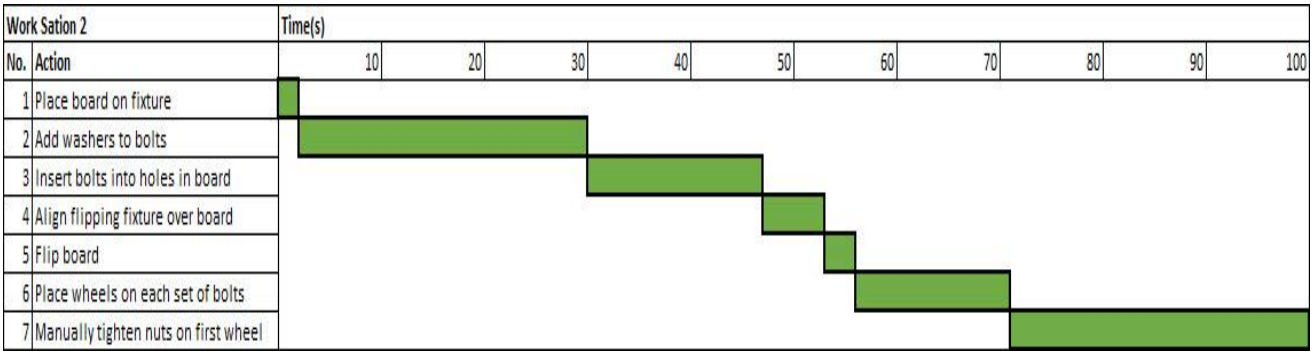


7.2. Gantt chart

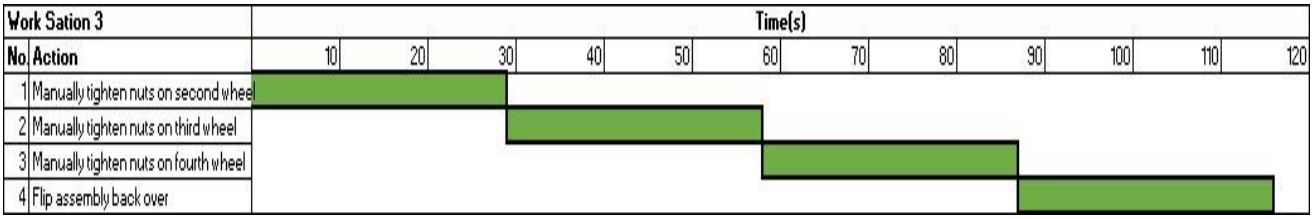
7.2.1. Gantt chart - Work station 1

Work Sation 1		Time(s)										
No.	Action	10	20	30	40	50	60	70	80	90	100	110
1	Move plank from pallet to work station											
2	Clamp right side of plank to table											
3	Clamp left side of plank to table											
4	Line up drill template on 1st corner											
5	Drill 4 holes on 1st corner											
6	Line up drill template on 2nd corner											
7	Drill 4 holes on 2nd corner											
8	Line up drill template on 3rd corner											
9	Drill 4 holes on 3rd corner											
10	Line up drill template on 4th corner											
11	Drill 4 holes on 4th corner											
12	Remove right clamp											
13	Remove left clamp											

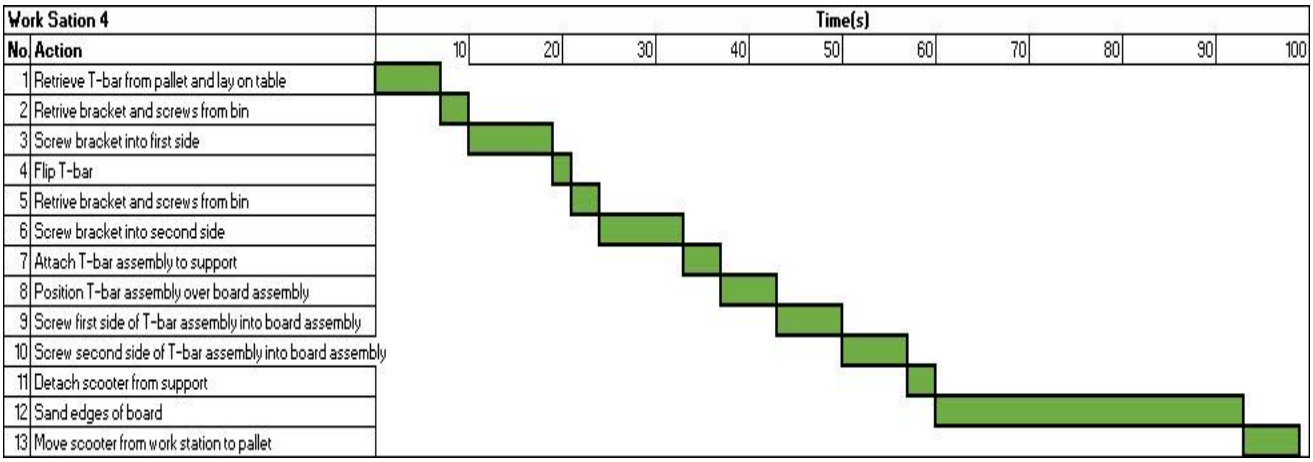
7.2.2. Gantt chart - Work station 2



7.2.3. Gantt chart - Work station 3

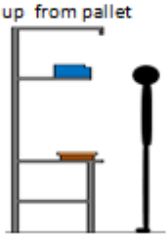


7.2.4. Gantt chart - Work station 4



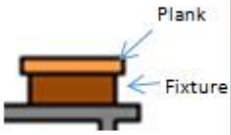
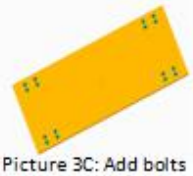
7.3. Standardized Operating procedure (SOP)

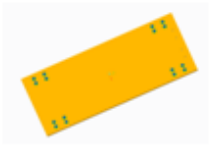
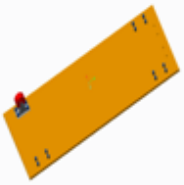
7.3.1. SOP - Work station 1

Standardized Operating Procedure			Page 1 of 2	
Work Station 1			Estimated total time: 107.8 sec	
No.	Action	Description	Pictorial reference(s)	
			Job	Product
1	Move plank from pallet to work station	1.1 Bend over to retrieve plank from pallet. 1.2 Transfer plank from pallet to work station by using both hands. 1.3 Ensure that proper body posture is maintained throughout the transportation of plank. 1.4 Place plank horizontally and parallel to the edge of the table onto plank support.	 Picture 1A: Pick plank up from pallet  Picture 1B: place plank on work station	 Picture 1C: Wooden plank
2	Clamp right side of plank to table	2.1 Pick up clamp from the side. 2.2.Position mouth of clamp at the right corner edge of plank. 2.3 Engage clamp trigger multiple times until plank is securely fasten onto table.	 Picture 2A: Clamping wooden plank(right)	 Picture 2B: Wooden plank
3	Clamp left side of plank to table	3.1 Pick up clamp from the side. 3.2.Position mouth of clamp at the right corner edge of plank. 3.3 Engage clamp trigger multiple times until plank is securely fasten onto table.	 Picture 3A: Clamping wooden plank(left)	 Picture 3B: Wooden plank
4	Line up drill template on corner	4.1 Place drill template on plank. 4.2 Align drill template with the corner edges of the plank.	 Picture 4A: Drill template  Picture 4B: Align drill template	 Picture 4C: Wooden plank

Standardized Operating Procedure			Page 2 of 2	
Work Station 1			Estimated total time: 107.8 sec	
No.	Action	Description	Pictorial reference(s)	
			Job	Product
5	Drill 4 holes on 1st corner	5.1 With one hand firmly securing the drill template, align drill with the first hole. 5.2 Press the drill trigger lightly to initiate drilling process. 5.3 Increase pressure on trigger gradually to increase drill rotational speed. 5.4 Drill a hole through the plank. 5.5 Repeat steps 5.1 to 5.4 four times.	 Picture 5A: Drill hole	 Picture 5B: Wooden plank
6	Drill rest of holes on other corners	Repeat Step 4 and 5 (X3) on each corner	 Picture 6A: Align drill template  Picture 7A: Drill hole	 Picture 6C: Wooden plank
7	Remove right clamp	7.1 With one hand holding onto clamp, grip onto clamp handle. 7.2 Move thumb towards the back of handle, press eject button to release clamp.	 Picture 7A: Release clamping (right)	 Picture 7B: Wooden plank
8	Remove left clamp	8.1 With one hand holding onto clamp, grip onto clamp handle. 8.2 Move thumb towards the back of handle, press eject button to release clamp.	 Picture 8A: Release clamping (right)	 Picture 8B: Wooden plank

7.3.2. SOP - Work station 2

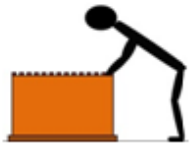
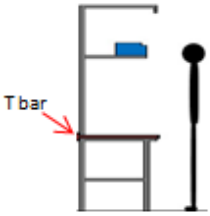
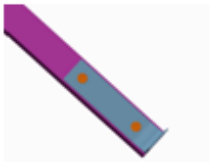
Standardized Operating Procedure			Page 1 of 2	
Work Station 2			Estimated total time: 99.0 sec	
No.	Action	Description	Pictorial reference(s)	
			Job	Product
1	Place board on fixture	1.1 Place drilled plank on fixture	 Picture 1A: Plank on fixture	 Picture 1C: Wooden plank
2	Add washers to bolts	2.1 Pick washer out from parts container 2.2 Add washer to bolt 2.3 Repeat steps 2.1 and 2.2 (X16)	 Picture 2A: Pick up parts from container  Picture 2B: Add washer to bolt	 Picture 2C: Washer and bolt
3	Insert bolts into holes in board	3.1 Insert bolt and washers into each of the 16 drilled holes.	 Picture 3A: Insert washer bolt assembly into board	 Picture 3B: Add bolt and washer  Picture 3C: Add bolts and washers (X16)
4	Align flipping fixture over board	4.1 Place flipping fixture over board. 4.2 Ensure flipping fixture covers all bolts at each corner.	 Picture 4A: Placing flipping fixture	 Picture 4B: Bolts and washer filled

Standardized Operating Procedure			Page 2 of 2	
Work Station 2			**Estimated total time: 99.0 sec**	
No.	**Action**	**Description**	**Pictorial reference(s)**	
			Job	**Product**
5	Flip board	5.1 With each hand on each side of the board, pick the whole assembly up. 5.2 Place flipped side of board face down on work station,	 Picture 5A: Flip flipping fixture and board	 Picture 4B: Bolts and washer filled
6	Place wheels on each set of bolts	6.1 Pick wheels out from parts container 6.2 Align wheel's holes onto first corner with bolts 6.3 Insert wheels into place. 6.4 Repeat steps 6.1 to 6.3 (X3) on other corners.	 Picture 6A: Pick up parts from container  Picture 6A: Placing wheels on bolts	 Picture 6B: First wheel on  Picture 6C: All wheels on
7	Manually tighten nuts on first wheel	7.1 Pick nut out from parts container 7.2 Place washer on bolt. 7.3 Use fingers to screw in washer 7.4 Use wrench to tighten nut	 Picture 6A: Pick up parts from container  Picture 6A: Tighten nut with wrench	 Picture 6B: First nut on bolt

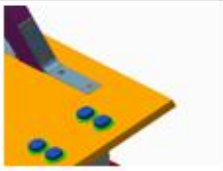
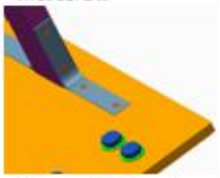
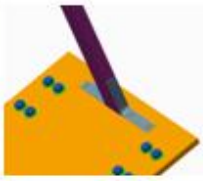
7.3.3. SOP - Work station 3

Standardized Operating Procedure			Page 1 of 1	
Work Station 3			Estimated total time: 115.6 sec	
No.	Action	Description	Pictorial reference(s)	
			Job	Product
1	Manually tighten nuts on second wheel	1.1 Pick nut out from parts container 1.2 Place washer on bolt. 1.3 Use fingers to screw in washer 1.4 Use wrench to tighten nut	 Picture 1A: Pick up parts from container  Picture 1B: Tighten nut with wrench	 Picture 1C: First nut on bolt
2	Manually tighten nuts on rest of wheels	2.1 Repeat step 1 (X3) for the other wheels	 Picture 2A: Pick up parts from container  Picture 2B: Tighten nut with wrench	 Picture 2C: First nut on bolt
3	Flip assembly back over	4.1 With each hand on each side of the board, pick the whole assembly up. 4.2 Place flipped side of board face down on work station,	 Picture 3A: Flip flipping assembly over	 Picture 3B: First nut on bolt

7.3.4. SOP - Work station 4

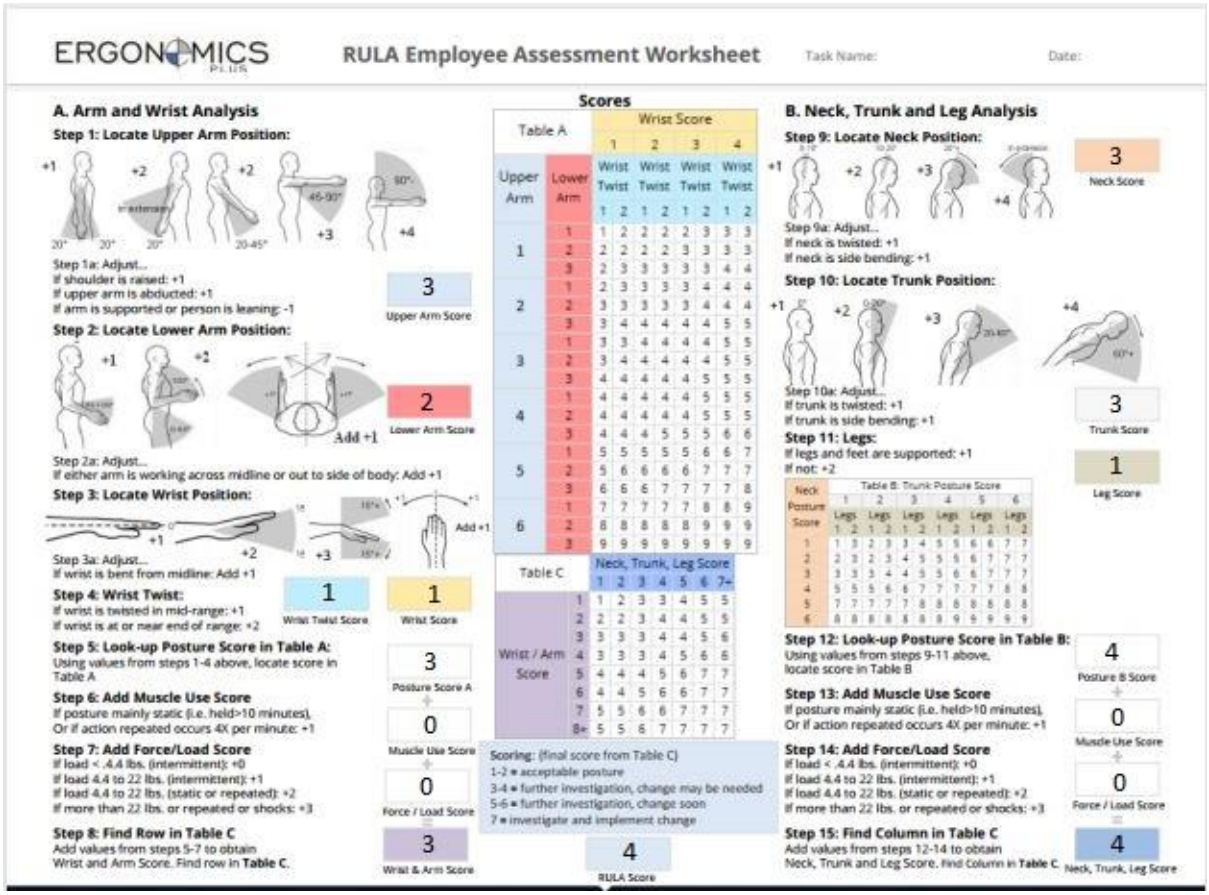
Standardized Operating Procedure			Page 1 of 3	
Work Station 4			**Estimated total time: 97.9 sec**	
No.	**Action**	**Description**	**Pictorial reference(s)**	
			Job	**Product**
1	Retrieve T-bar from pallet and lay on table	1.1 Bend over to retrieve T bar from pallet. 1.2 Transfer plank from pallet to work station by sing both hands. 1.3 Ensure that proper body posture is maintained throughout the transportation of T bar. 1.4 Place T bar vertically, with the positio of handle parallel to the edge of the table flat on work station.	 Picture 1A: Pick up T bar rom container  Picture 1B: Place T bar on work station	 Picture 1C: T bar
2	Retrive bracket and screws from bin	2.1 Pick out brackets and screws from parts container	 Picture 2A: Pick up parts from container	 Picture 2C: T bar
3	Screw bracket into first side	3.1 Align bracket on T bar. 3.2 Place screw on top of bracket. 3.3 Use power screw driver to screw in screw.	 Picture 3A: Screw in screw with bracket	 Picture 3B: Screw first screw  Picture 3C: Screw second screw
4	Flip T-bar	4.1 Flip T bar	 Picture 4A: Flip T bar	 Picture 4B: T bar

Standardized Operating Procedure			Page 2 of 3	
Work Station 2			Estimated total time: 97.9 sec	
No.	Action	Description	Pictorial reference(s)	
			Job	Product
5	Retrive bracket and screws from bin	5.1 Pick out brackets and screws from parts container	 Picture 5A: Pick up parts from container	 Picture 5B: T bar
6	Screw bracket into second side	3.1 Align bracket on T bar. 3.2 Place screw on top of bracket. 3.3 Use power screw driver to screw in screw.	 Picture 6A: Screw in screw with bracket	 Picture 6B: Place second bracket  Picture 6C: Screw third screw  Picture 6D: Screw forth screw
7	Attach T-bar assembly to support	7.1 Attach T bar to T bar assembly. 7.2 Enusre T bar assembly with fixture is place on the side with holes for T bar.	 Picture 7A: T bar support fixture	 Picture 7B: T bar on board assembly
8	Position T-bar assembly over board assembly	8.1 Position T bar assembly over board assembly.		 Picture 8B: T bar on board assembly

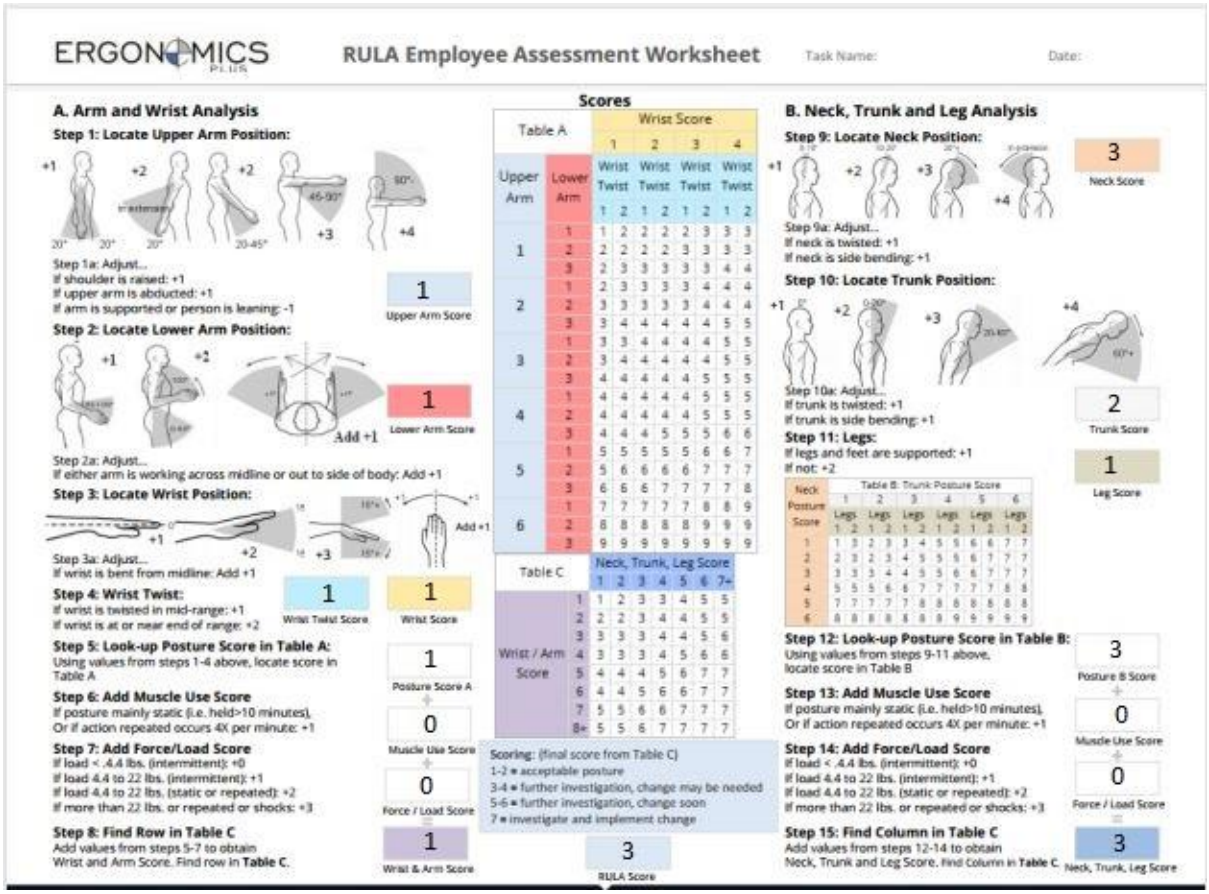
Standardized Operating Procedure			Page 3 of 3	
Work Station 2			Estimated total time: 97.9 sec	
No.	Action	Description	Pictorial reference(s)	
			Job	Product
9	Screw first side of T-bar assembly into board assembly	9.1 Scew in screws using power screw driver on one side	 Picture 9A: Screw in screws into boad	 Picture 9B: Screw in first screw  Picture 9B: Screw in second screw
10	Screw second side of T-bar assembly into board assembly	9.1 Scew in screws using power screw driver on other side	 Picture 9A: Screw in screws into boad	 Picture 9B: Screw in third screw  Picture 9C: Screw in forth screw
11	Sand edges of board	11.1 Using a power sand buffer, sand off the edges to smooth out the edges	 Picture 11A: Sand edges	 Picture 11B: Fully assembled scooter
12	Move scooter from work station to pallet	12.1 Move scooter to packaging area.	 Picture 12A: Move scooter to pallet	 Picture 12B: Fully assembled scooter

7.4. Rapid Upper Limb Assessment (RULA)

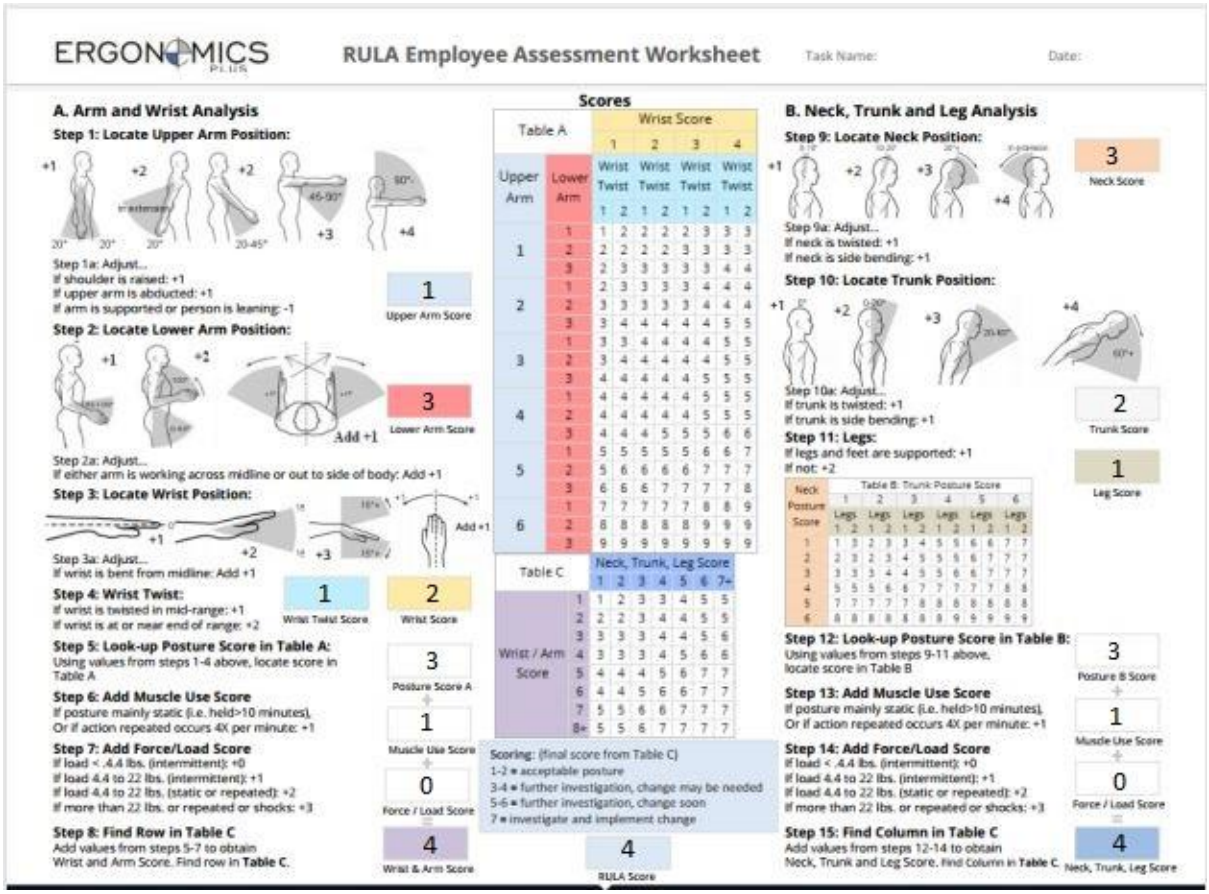
7.4.1. RULA - Move plank



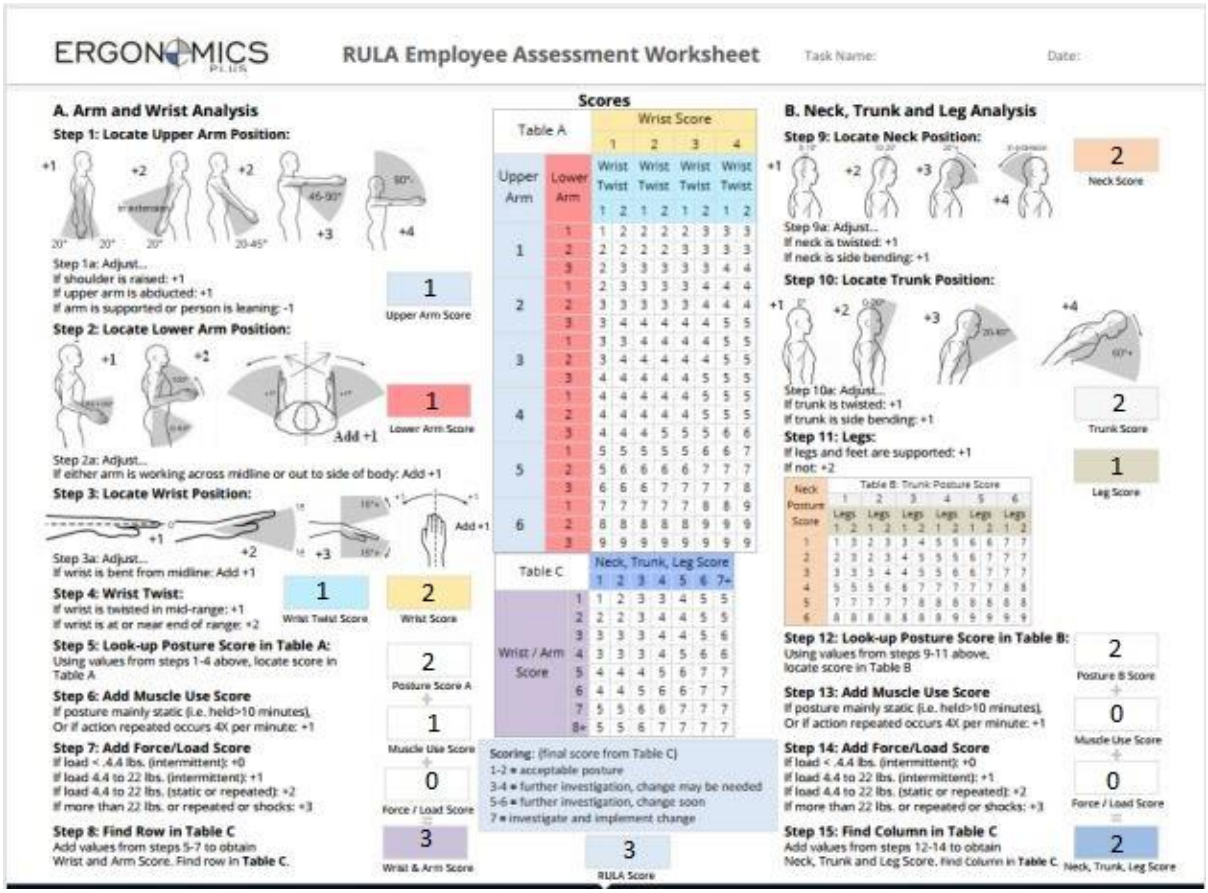
7.4.2. RULA - Clamp plank



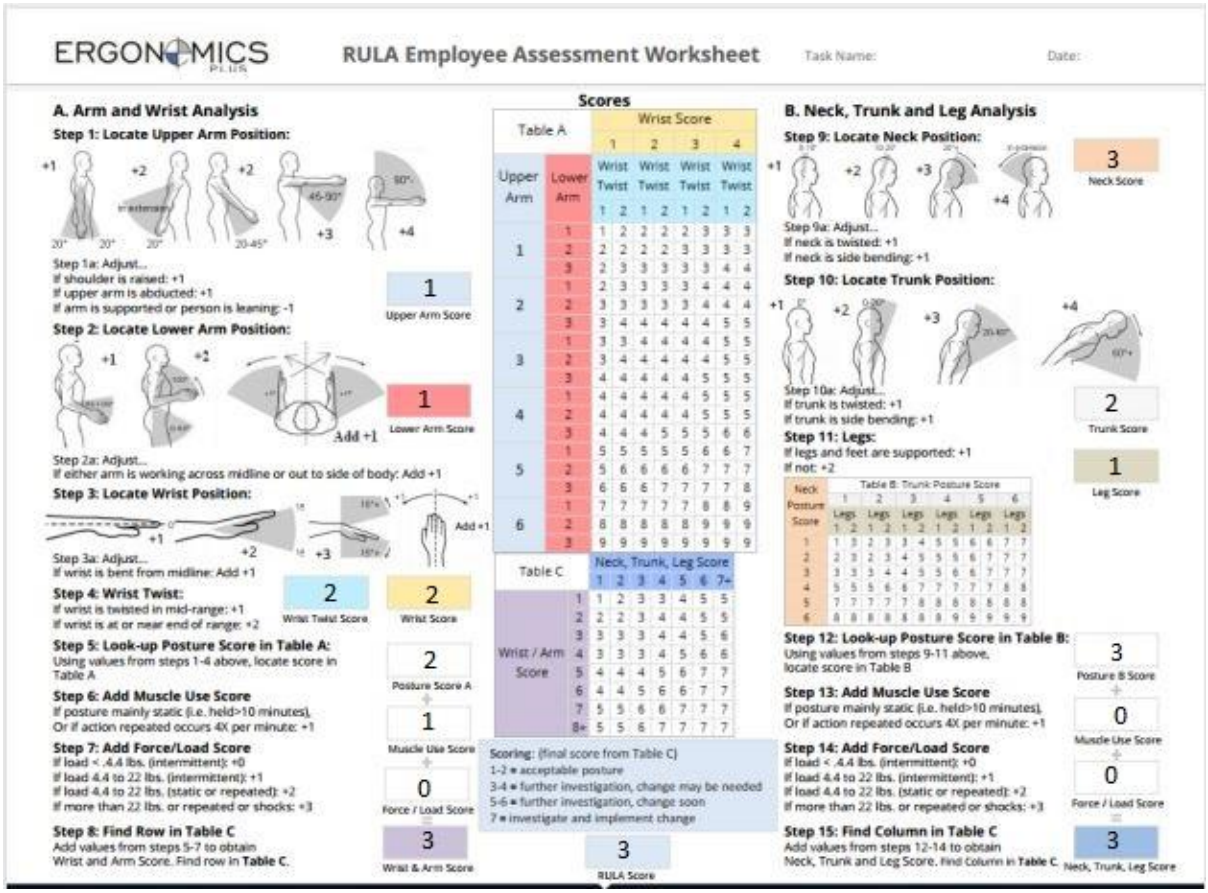
7.4.3. RULA - Drilling



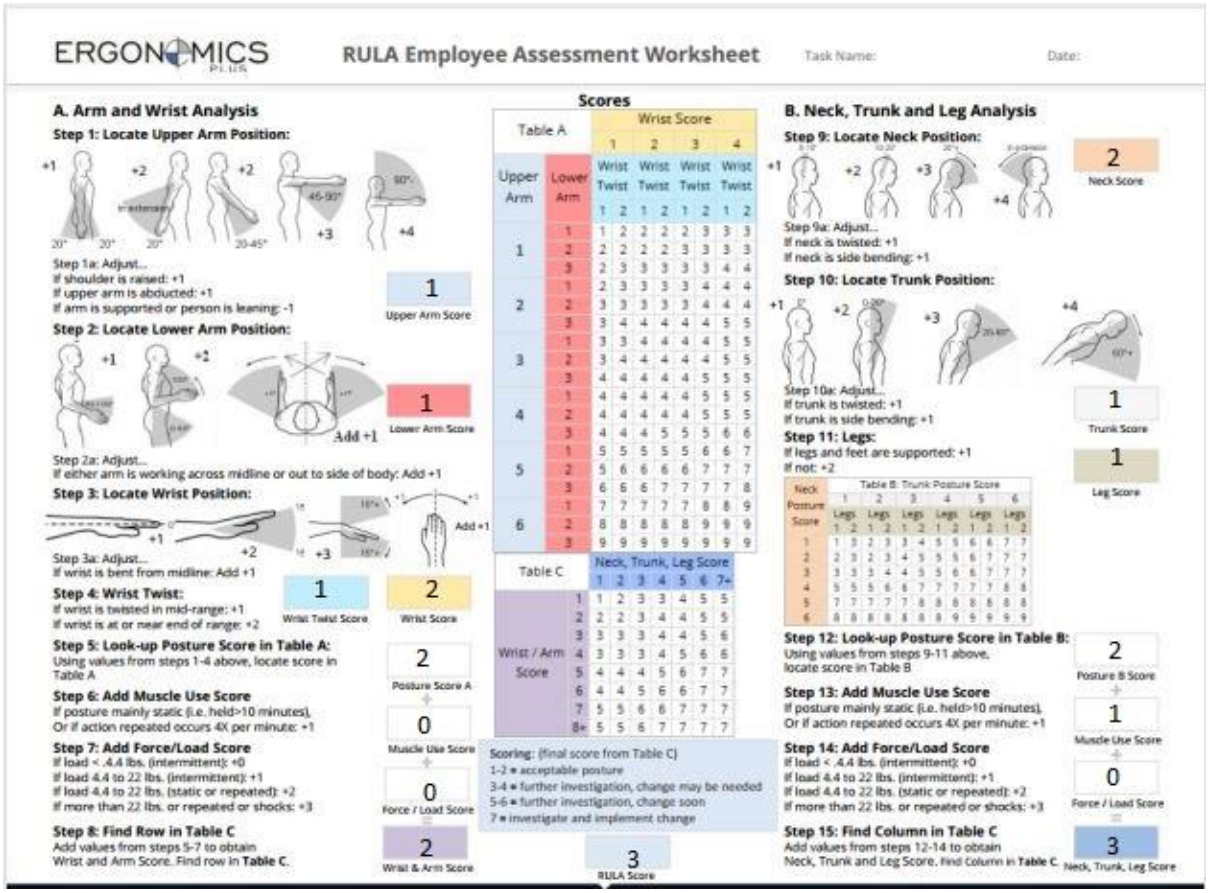
7.4.4. RULA - Add washers to bolts



7.4.5. RULA - Attach wheels



7.4.6. RULA - Attach T bar



7.5. Hand Activity Level Threshold Limit Value (HAL TLV)

7.5.1. Task summary (before)

Task summary (Before)					Page 1 of 2
No	Task (before)	Left hand		Right hand	
		Start	End	Start	End
1	Move plank from pallet to work station	Grab plank from pallet	Place plank on work station	Grab plank from pallet	Place plank on work station
2	Clamp right side of plank to table	Provide support on plank	Plank is clamped down	Place clamps on plank	Plank is firmly secured
3	Clamp left side of plank to table	Provide support on plank	Plank is clamped down	Place clamps on plank	Plank is firmly secured
4	Line up drill template on 1st corner	Pick up template	Template is lined up	Pick up template	Template is lined up
5	Drill 4 holes on 1st corner	Support lined up template	All for holes are drilled	Grab drill handle	All holes are drilled
6	Line up drill template on 2nd corner	Pick up template	Template is lined up	Pick up template	Template is lined up
7	Drill 4 holes on 2nd corner	Support lined up template	All for holes are drilled	Grab drill handle	All holes are drilled
8	Line up drill template on 3rd corner	Pick up template	Template is lined up	Pick up template	Template is lined up
9	Drill 4 holes on 3rd corner	Support lined up template	All for holes are drilled	Grab drill handle	All holes are drilled
10	Line up drill template on 4th corner	Pick up template	Template is lined up	Pick up template	Template is lined up
11	Drill 4 holes on 4th corner	Support lined up template	All for holes are drilled	Grab drill handle	All holes are drilled
12	Remove right clamp	grab head of clamp	Remove clamp	Grab handle while pressing eject button	Clamp is released
13	Remove left clamp	Grab head of clamp	Remove clamp	Grab handle while pressing eject button	Clamp is released
14	Place board on fixture	Grab left end of board	Board is placed on fixture	grab left end of board	Board is placed on fixture
15	Add washers to bolts	Pick up washer	Bolt is inserted into washer	Pick up bolt	Bolt is inserted into washer
16	Insert bolts into holes in board	Bolt and washer assembly is on hand	Bolt and washer assembly is inserted into hold	Bolt and washer assembly is on hand	Bolt and washer assembly is inserted into hold
17	Align flipping fixture over board	Pick up flipping fixture	Fixture aligned	Pick up flipping fixture	Fixture aligned
18	Flip board	Grab side of board	Board is flipped	Grab side of board	Board is flipped
19	Place wheels on each set of bolts	Pick up wheel	Bolts are inserted into wheel	Align wheel	Bolts are inserted into wheel
20	Manually tighten nuts on first wheel	Support wheel support	Nut tighten	Pick up wrench	Nut tighten
21	Manually tighten nuts on second wheel	Support wheel support	Nut tighten	Pick up wrench	Nut tighten
22	Manually tighten nuts on third wheel	Support wheel support	Nut tighten	Pick up wrench	Nut tighten
23	Manually tighten nuts on fourth wheel	Support wheel support	Nut tighten	Pick up wrench	Nut tighten
24	Flip assembly back over	Grab side of board	Board is flipped	Grab side of board	Board is flipped

Task summary (Before)					Page 2 of 2
No	Task (before)	Left hand		Right hand	
		Start	End	Start	End
24	Flip assembly back over	Grab side of board	Board is flipped	Grab side of board	Board is flipped
25	Retrieve T-bar from pallet and lay on table	Grab T bar stem	T bar placed on table	Grab T bar handle	T bar placed on table
26	Retrieve bracket and screws from bin	Pick up bracket and screw	Required number of parts retrieved	Idle	Idle
27	Screw bracket into first side	Support bracket	Screw is screwed in	Pick up power tool	Screw is screwed in
28	Flip T-bar	Grab T bar stem	T bar placed on table	Grab T bar handle	T bar placed on table
29	Retrieve bracket and screws from bin	Pick up bracket and screw	Required number of parts retrieved	Idle	Idle
30	Screw bracket into second side	Support bracket	Screw is screwed in	Pick up power tool	Screw is screwed in
31	Attach T-bar assembly to support	Grab T bar stem	T bar is placed on support	Grab T bar handle	T bar is placed on support
32	Position T-bar assembly over board assembly	Grab T bar stem	T bar is placed on support	Grab T bar handle	T bar is placed on support
33	Screw first side of T-bar assembly into board assembly	Support bracket	Screw is screwed in	Pick up power tool	Screw is screwed in
34	Screw second side of T-bar assembly into board assembly	Support bracket	Screw is screwed in	Pick up power tool	Screw is screwed in
35	Sand edges of board	Guide sanding machine	Edges are sanded	Grab on sanding machine handle & guide movement of sanding machine	Edges are sanded
36	Move scooter from work station to pallet	Grab one side of board	Scooter is placed on pallet	Grab one side of board	Scooter is placed on pallet

7.5.2. TLV assessment (before)

HAL TLV analysis (Before)									Page 1 of 2
No	Task (before)	Left				Right			
		HAL	NPF	Ratio	Results	HAL	NPF	Ratio	Results
1	Move plank from pallet to work station	6	5	1.20	>TLV	6	5	1.20	>TLV
2	Clamp right side of plank to table	2	4	0.50	<AL	3	4	0.75	AL to TLV
3	Clamp left side of plank to table	2	4	0.50	<AL	3	4	0.75	AL to TLV
4	Line up drill template on 1st corner	2	0.5	4.00	>TLV	2	0.5	4.00	>TLV
5	Drill 4 holes on 1st corner	3	4	0.75	AL to TLV	4	5	0.80	>TLV
6	Line up drill template on 2nd corner	2	0.5	4.00	>TLV	2	0.5	4.00	>TLV
7	Drill 4 holes on 2nd corner	3	4	0.75	AL to TLV	4	5	0.80	>TLV
8	Line up drill template on 3rd corner	2	0.5	4.00	>TLV	2	0.5	4.00	>TLV
9	Drill 4 holes on 3rd corner	3	4	0.75	AL to TLV	4	5	0.80	>TLV
10	Line up drill template on 4th corner	2	0.5	4.00	>TLV	2	0.5	4.00	>TLV
11	Drill 4 holes on 4th corner	3	4	0.75	AL to TLV	4	5	0.80	>TLV
12	Remove right clamp	2	4	0.50	<AL	3	5	0.60	AL to TLV
13	Remove left clamp	2	4	0.50	<AL	3	5	0.60	AL to TLV
14	Place board on fixture	8	5	1.60	>TLV	8	5	1.60	>TLV
15	Add washers to bolts	2	0.5	4.00	>TLV	2	0.5	4.00	>TLV
16	Insert bolts into holes in board	2	0.5	4.00	>TLV	2	0.5	4.00	>TLV
17	Align flipping fixture over board	8	5	1.60	>TLV	8	5	1.60	>TLV
18	Flip board	6	5	1.20	>TLV	6	5	1.20	>TLV
19	Place wheels on each set of bolts	4	3	1.33	>TLV	5	4	1.25	>TLV
20	Manually tighten nuts on first wheel	4	4	1.00	>TLV	5	5	1.00	>TLV
21	Manually tighten nuts on second wheel	4	4	1.00	>TLV	5	5	1.00	>TLV

HAL TLV analysis (Before)									Page 2 of 2
No	Task (before)	Left				Right			
		HAL	NPF	Ratio	Results	HAL	NPF	Ratio	Results
22	Manually tighten nuts on third wheel	4	4	1.00	>TLV	5	5	1.00	>TLV
23	Manually tighten nuts on fourth wheel	4	4	1.00	>TLV	5	5	1.00	>TLV
24	Flip assembly back over	6	5	1.20	>TLV	6	5	1.20	>TLV
25	Retrieve T-bar from pallet and lay on table	3	4	0.75	AL to TLV	3	4	0.75	AL to TLV
26	Retrieve bracket and screws from bin	3	0.5	6.00	>TLV	3	0.5	6.00	>TLV
27	Screw bracket into first side	5	6	0.83	>TLV	5	6	0.83	>TLV
28	Flip T-bar	4	3	1.33	>TLV	4	3	1.33	>TLV
29	Retrieve bracket and screws from bin	3	0.5	6.00	>TLV	3	0.5	6.00	>TLV
30	Screw bracket into second side	5	6	0.83	>TLV	5	6	0.83	>TLV
31	Attach T-bar assembly to support	5	4	1.25	>TLV	5	4	1.25	>TLV
32	Position T-bar assembly over board assembly	6	4	1.50	>TLV	6	4	1.50	>TLV
33	Screw first side of T-bar assembly into board assembly	5	4	1.25	>TLV	5	4	1.25	>TLV
34	Screw second side of T-bar assembly into board assembly	6	4	1.50	>TLV	6	4	1.50	>TLV
35	Sand edges of board	7	6	1.17	>TLV	8	7	1.14	>TLV
36	Move scooter from work station to pallet	5	5	1.00	>TLV	5	5	1.00	>TLV
		Average		1.74	>TLV	Average		1.76	>TLV

7.5.3. Task summary (after)

Task summary (After)					Page 1 of 2
No	Task (after)	Left hand		Right hand	
		Start	End	Start	End
1	Move plank from pallet to work station	Grab plank from pallet	Place plank on work station	Grab plank from pallet	Place plank on work station
2	Clamp right side of plank to table	Provide support on plank	Plank is clamped down	Place clamps on plank	Plank is firmly secured
3	Clamp left side of plank to table	Provide support on plank	Plank is clamped down	Place clamps on plank	Plank is firmly secured
4	Line up drill template on 1st corner	Pick up template	Template is lined up	Pick up template	Template is lined up
5	Drill 4 holes on 1st corner	Support lined up template	All for holes are drilled	Grab drill handle	All holes are drilled
6	Line up drill template on 2nd corner	Pick up template	Template is lined up	Pick up template	Template is lined up
7	Drill 4 holes on 2nd corner	Support lined up template	All for holes are drilled	Grab drill handle	All holes are drilled
8	Line up drill template on 3rd corner	Pick up template	Template is lined up	Pick up template	Template is lined up
9	Drill 4 holes on 3rd corner	Support lined up template	All for holes are drilled	Grab drill handle	All holes are drilled
10	Line up drill template on 4th corner	Pick up template	Template is lined up	Pick up template	Template is lined up
11	Drill 4 holes on 4th corner	Support lined up template	All for holes are drilled	Grab drill handle	All holes are drilled
12	Remove right clamp	grab head of clamp	Remove clamp	Grab handle while pressing eject button	Clamp is released
13	Remove left clamp	grab head of clamp	Remove clamp	Grab handle while pressing eject button	Clamp is released
14	Place board on fixture	grab left end of board	board is placed on fixture	grab left end of board	board is placed on fixture
15	Place washers on bolts for first wheel	Pick up bolt	Bolt is inserted into washer	Pick up bolt	Bolt is inserted into washer
16	Line up first wheel, insert bolts through holes	Hold wheel support	Position holes with bolts	Hold wheel	Position holes with bolts
17	Add nuts to each bolt, tightening by hand	Hold on bolt	Nut continuously rotate through thread	Place nut on bolt thread	Tighten nut
18	Place washers on bolts for second wheel	Pick up bolt	Bolt is inserted into washer	Pick up bolt	Bolt is inserted into washer
19	Line up second wheel, insert bolts through holes	Hold wheel support	Position holes with bolts	Hold wheel	Position holes with bolts
20	Add nuts to each bolt, tightening by hand	Hold on bolt	Nut continuously rotate through thread	Place nut on bolt thread	Tighten nut

Task summary (After)					Page 2 of 2
No	Task (after)	Left hand		Right hand	
		Start	End	Start	End
22	Line up third wheel, insert bolts through holes	Hold wheel support	Position holes with bolts	Hold wheel	Position holes with bolts
23	Add nuts to each bolt, tightening by hand	Hold on bolt	Nut continuously rotate through thread	Place nut on bolt thread	Tighten nut
24	Place washers on bolts for fourth wheel	Pick up bolt	Bolt is inserted into washer	Pick up bolt	Bolt is inserted into washer
25	Line up first fourth, insert bolts through holes	Hold wheel support	Position holes with bolts	Hold wheel	Position holes with bolts
26	Add nuts to each bolt, tightening by hand	Hold on bolt	Nut continuously rotate through thread	Place nut on bolt thread	Tighten nut
27	Retrieve T-bar from pallet and lay on table	Grab lower portion of T-bar	Lay on table	Grab upper portion of T-bar	Lay on table
28	Retrieve bracket and screws from bin	Pick up screws	Required number of screws are retrieved	Pick up bracket	Required number of screws are retrieved
29	Screw bracket into first side	Firmly secure bracket's position on T-bar	Screw is tightened	Use screw driver to screw in screw	Tighten screw
30	Flip T-bar	Grab lower portion of T-bar	Lay on table	Grab upper portion of T-bar	Lay on table
31	Retrieve bracket and screws from bin	Pick up screws	Required number of screws are retrieved	Pick up bracket	Required number of screws are retrieved
32	Screw bracket into second side	Firmly secure bracket's position on T-bar	Screw is tightened	Use screw driver to screw in screw	Tighten screw
33	Attach T-bar assembly to slide support	Support slide support	T-bar assembly is attached	Position T-bar assembly to slide support	T-bar assembly attached
34	Position T-bar assembly over board assembly	Support board	T-bar assembly is positioned	Hold on T-bar assembly	T-bar assembly is positioned
35	Screw first side of T-bar assembly into board assembly	Support T-bar assembly	Screw is tightened	Use screw driver to screw in screw	Screw is tightened
36	Screw second side of T-bar assembly into board assembly	Support T-bar assembly	Screw is tightened	Use screw driver to screw in screw	Screw is tightened
37	Detach scooter from slide support	Pick up scooter	Detach scooter	Support slide support	Detach scooter
38	Sand edges of board	Guide sanding machine	Edges are sanded	Grab on sanding machine handle & guide movement of sanding machine	Edges are sanded
39	Move scooter from work station to pallet	Grab one side of board	Scooter is placed on pallet	Grab one side of board	Scooter is placed on pallet

7.5.4. TLV assessment (after)

HAL TLV analysis (After)									Page 1 of 2
No	Task (after)	Left				Right			
		HAL	NPF	Ratio	Results	HAL	NPF	Ratio	Results
1	Move plank from pallet to work station	6	5	1.20	>TLV	6	5	1.20	>TLV
2	Clamp right side of plank to table	2	4	0.50	<AL	3	4	0.75	AL to TLV
3	Clamp left side of plank to table	2	4	0.50	<AL	3	4	0.75	AL to TLV
4	Line up drill template on 1st corner	1	0.5	2.00	>TLV	1	0.5	2.00	>TLV
5	Drill 4 holes on 1st corner	3	4	0.75	AL to TLV	4	5	0.80	>TLV
6	Line up drill template on 2nd corner	1	0.5	2.00	>TLV	1	0.5	2.00	>TLV
7	Drill 4 holes on 2nd corner	3	5	0.60	AL to TLV	4	5	0.80	>TLV
8	Line up drill template on 3rd corner	1	0.5	2.00	>TLV	1	0.5	2.00	>TLV
9	Drill 4 holes on 3rd corner	3	5	0.60	AL to TLV	4	5	0.80	>TLV
10	Line up drill template on 4th corner	1	0.5	2.00	>TLV	1	0.5	2.00	>TLV
11	Drill 4 holes on 4th corner	3	5	0.60	AL to TLV	4	5	0.80	>TLV
12	Remove right clamp	2	4	0.50	<AL	3	5	0.60	AL to TLV
13	Remove left clamp	2	4	0.50	<AL	3	5	0.60	AL to TLV
14	Place board on fixture	8	5	1.60	>TLV	8	5	1.60	>TLV
15	Place washers on bolts for first wheel	0	0.5	0.00	<AL	0	0.5	0.00	<AL
16	Line up first wheel, insert bolts through holes	2	3	0.67	AL to TLV	2	3	0.67	AL to TLV
17	Add nuts to each bolt, tightening by hand	4	4	1.00	>TLV	6	6	1.00	>TLV
18	Place washers on bolts for second wheel	0	0.5	0.00	<AL	0	0.5	0.00	<AL
19	Line up second wheel, insert bolts through holes	2	3	0.67	AL to TLV	2	3	0.67	AL to TLV
20	Add nuts to each bolt, tightening by hand	4	4	1.00	>TLV	6	6	1.00	>TLV
21	Place washers on bolts for third wheel	0	0.5	0.00	<AL	0	0.5	0.00	<AL
22	Line up third wheel, insert bolts through holes	2	3	0.67	AL to TLV	2	3	0.67	AL to TLV
23	Add nuts to each bolt, tightening by hand	4	4	1.00	>TLV	6	6	1.00	>TLV
24	Place washers on bolts for fourth wheel	1	0.5	2.00	>TLV	1	0.5	2.00	>TLV
25	Line up first fourth, insert bolts through holes	2	3	0.67	AL to TLV	2	3	0.67	AL to TLV
26	Add nuts to each bolt, tightening by hand	4	4	1.00	>TLV	6	6	1.00	>TLV
27	Retrieve T-bar from pallet and lay on table	3	4	0.75	AL to TLV	3	4	0.75	AL to TLV

HAL TLV analysis (After)									Page 2 of 2
No	Task (after)	Left				Right			
		HAL	NPF	Ratio	Results	HAL	NPF	Ratio	Results
28	Retrieve bracket and screws from bin	3	0.5	6.00	>TLV	0	0	0.00	<AL
29	Screw bracket into first side	5	6	0.83	>TLV	9	6	1.50	>TLV
30	Flip T-bar	4	3	1.33	>TLV	4	3	1.33	>TLV
31	Retrieve bracket and screws from bin	3	2	1.50	>TLV	0	0	0.00	<AL
32	Screw bracket into second side	5	6	0.83	>TLV	9	6	1.50	>TLV
33	Attach T-bar assembly to slide support	4	3	1.33	>TLV	4	3	1.33	>TLV
34	Position T-bar assembly over board assembly	4	3	1.33	>TLV	4	3	1.33	>TLV
35	Screw first side of T-bar assembly into board assembly	5	6	0.83	>TLV	7	6	1.17	>TLV
36	Screw second side of T-bar assembly into board assembly	5	6	0.83	>TLV	7	6	1.17	>TLV
37	Detach scooter from slide support	4	5	0.80	>TLV	4	5	0.80	>TLV
38	Sand edges of board	7	6	1.17	>TLV	8	7	1.14	>TLV
39	Move scooter from work station to pallet	5	5	1.00	>TLV	5	5	1.00	>TLV
		Average		1.09	>TLV	**Average**		0.98	>TLV

7.6. Outline of operations

Outline of operations corresponding to the precedence diagram, and used in line balancing. Task T denotes standard time for each task. Cum. T denotes the cumulative standard time of the operations thus far.

Index	Operation	Task T (s)	Cum. T (s)	Preceded By
1	Move plank from pallet to work station	4.4	4.4	-
2	Clamp right side of plank to table	5.5	9.9	1
3	Clamp left side of plank to table	5.5	15.4	1
4	Line up drill template on 1st corner	3.3	18.7	2
5	Drill 4 holes on 1st corner	20.9	39.6	4
6	Line up drill template on 2nd corner	3.3	42.9	2
7	Drill 4 holes on 2nd corner	16.5	59.4	6
8	Line up drill template on 3rd corner	3.3	62.7	3
9	Drill 4 holes on 3rd corner	17.6	80.3	8
10	Line up drill template on 4th corner	3.3	83.6	3
11	Drill 4 holes on 4th corner	17.6	101.2	10
12	Remove right clamp	3.3	104.5	5,7
13	Remove left clamp	3.3	107.8	9,11
14	Place board on fixture	2.2	110	12,13
15	Add washers to bolts	27.5	137.5	-
16	Insert bolts into holes in board	16.5	154	14,15
17	Align flipping fixture over board	5.5	159.5	16
18	Flip board	3.3	162.8	17
19	Place wheels on each set of bolts	15.4	178.2	18
20	Manually tighten nuts on first wheel	28.6	206.8	19
21	Manually tighten nuts on second wheel	28.6	235.4	19
22	Manually tighten nuts on third wheel	28.6	264	19
23	Manually tighten nuts on fourth wheel	28.6	292.6	19
24	Flip assembly back over	28.6	321.2	20,21,22,23
25	Retrieve T-bar from pallet and lay on table	6.6	327.8	-
26	Retrive bracket and screws from bin	3.3	331.1	-
27	Screw bracket into first side	8.8	339.9	25,26
28	Flip T-bar	2.2	342.1	27
29	Retrive bracket and screws from bin	3.3	345.4	28
30	Screw bracket into second side	8.8	354.2	29
31	Attach T-bar assembly to support	4.4	358.6	30
32	Position T-bar assembly over board assembly	5.5	364.1	31,24
33	Screw first side of T-bar assembly into board assembly	6.6	370.7	32
34	Screw second side of T-bar assembly into board assembly	6.6	377.3	32
35	Detach scooter from support	3.3	380.6	33,34
36	Sand edges of board	33	413.6	35
37	Move scooter from work station to pallet	5.5	419.1	36