Final Report

Belt-Up!

ME 345: Automation and Manufacturing Methods, Lab Section C6

Prepared for:

Will Boley

Prepared by:

Charlotte Derose

Anna Tretiakova

Julie Bui

Alexander Yao

Zakir Kadwa

Joaquin Ko

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Introduction

Figure 1. Amazon Belt Storage Figure 2. Etsy Belt Storage

The current market for belt holders offers several large and luxury solutions targeted towards homeowners and individuals with large collections of belts as seen in Figures 1 and 2. These products are often mounted through screws, take up a lot of space, and have a price range of around $8.99 (Amazon) to $31.50 (Belt Rack…) for an artisanal version. Our product is aimed towards people who own up to 5 belts, have limited access to space, are working within a smaller budget, or simply looking for a product that can be mounted in a renter-friendly manner. BeltUp! provides these solutions. The BeltUp! design allows for belts up to 1.44” in width to be stored on the main body. The front lid also offers a hook feature that can accommodate other accessories or necessities such as waist chains, jewelry, or even keychains. The design is light enough to be secured to a flat surface using a standard command strip placed on the back of the main body. It is important that our design is created in an automated assembly line like the ADML to ensure cheaper production through the use of the available machines and stock material. This allows for relatively fast and low cost production. The BeltUp! provides a positive contribution to society by presenting a low profile, low cost, accessible, and removable organizational solution for belt owners. In particular, the mounting, compact size and low weight of the product allows for easy storage and transportation. Reducing luggage while keeping functionality is critical for this product.

Project Plan

1. Introduction:

The purpose of this project plan is to give a rundown on the major product and manufacturing changes since the project progress report. The majority of parts of the project have stayed consistent with our previous proposal. This report will detail our final project features and improvements. More specifically, with BUMES, the CIM table, and reflections on future improvements if given the time.

2. Product design:

a. CAD models

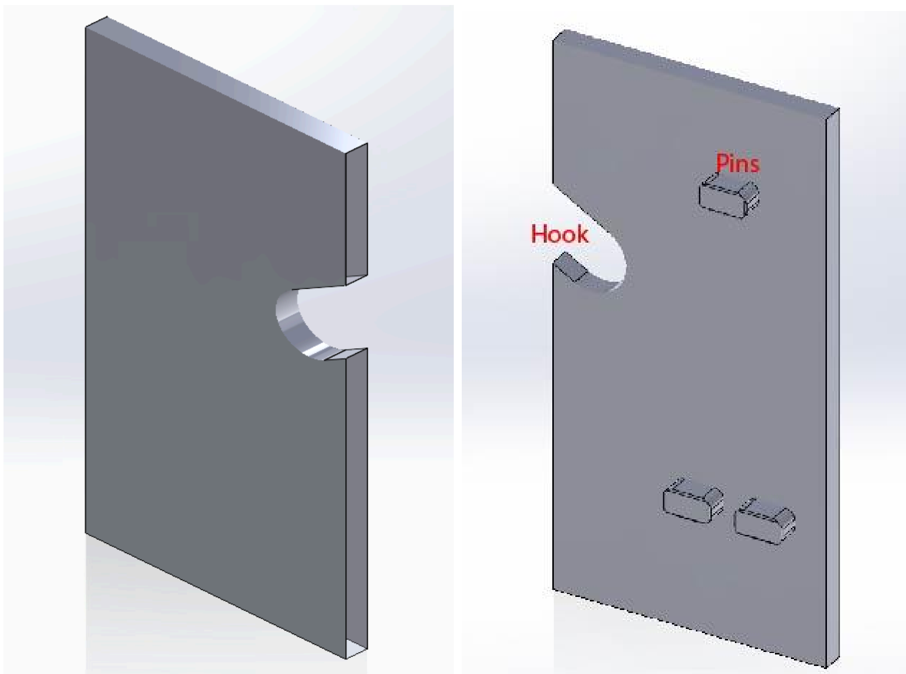

Figure 3. Lid Design, This is the current/final design for the lid of our Belt Up product. It is to be machined out of the Polycarbonate Stock W provided by the ADML. There are three pins to connect with the main body, as well as a hook to hold things such as necklaces and belt loops.

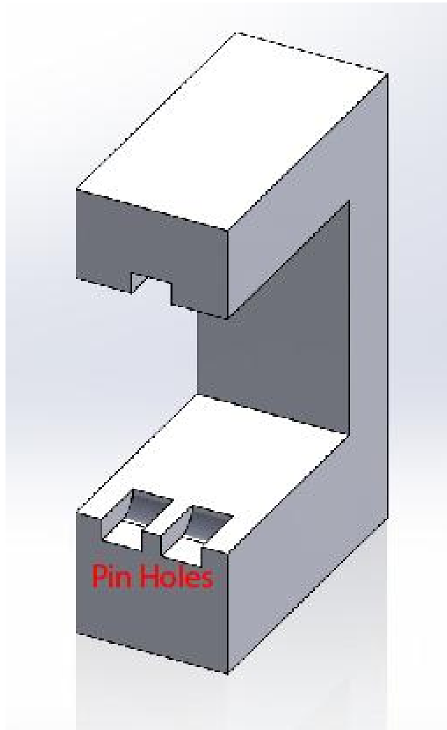

Figure 4. Body Design, This is the current/final design for the main body of our product. It is to be milled out of the HDPE stock V provided to us by the ADML. There are three pin holes to connect with the lid. The cavity is 1.5 inches deep to be able to hold most standard belts. The back is flat to enable the attachment of things such as command strips and hooks.

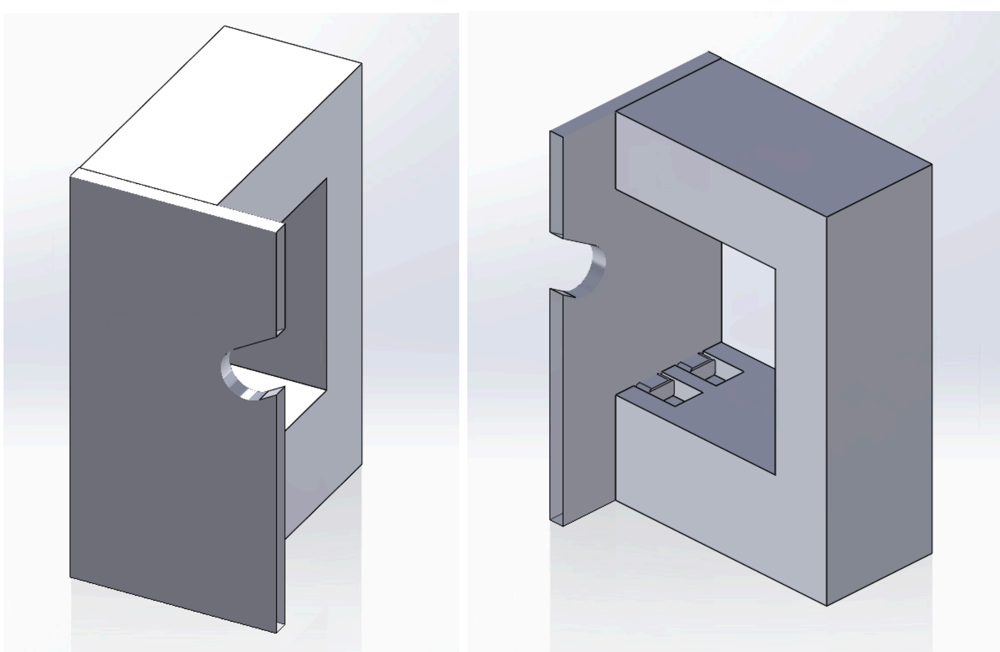

Figure 5. Assembly, This is the CAD model of the assembly. The pins and pin holes have tolerances to ensure the robots can effectively assembly them together.

Figure 6. Physical Prototypes

These are some images of our physical prototypes, both old and most recent. The top one is our old design, where we still had two hooks. The bottom two are our newest designs, where we altered the tolerances, only had one hook, and changed the thicknesses of the body widths. Below that is our 8 designs that we cut during our final lab time in the ADML.

b. The parts are designed in such a way that the ADML CNC machines are able to easily cut them out of the stock provided. The improved design to be manufactured on the wider side has been proven to be a success. The mill is able to easily cut out the stock without coming out of the vice when we do not want it to. The changes to the pins and holes design has also proven to be a nice and tight fit. The main body was designed to hold the lid. Thus, the holes made in the body were design to be manufactured just using tool #7. This kept the body design simple and easy to manufacture.

For the lid, we used boundary boxes to ensure the CNC machines won't cut into the vice when milling. To match the holes on the stock that uses tool #7, we had the pins be elliptical instead of circular for a better fit. We also ensured that the milled out hook section is the exact size as tool #3. All of this ensured that the CNC mill and vice jaws were the perfect fit for our product's machinability.

To ensure our parts work with the robotic arms and the assembly vice, we removed one of the hooks so that the arms are more able to efficiently grab the lid and assemble the two parts together. We also increased the thickness of the back support of the body so that the assembly vice does not accidentally compress the part of the body that has the pin holes, ensuring assembly can run smoothly.

c. These can be made using the ADML as they are milled on their wide side down, so there are no problems with moments of forces that exceed what the vice can handle. The body is made with HDPE stock V, as it was the largest stock available and was long enough to be able to hold belts and still be sturdy. The lid was made with the Polycarbonate stock W, as we felt the clear/semi clear stock was best for this application. It was also one of the thinner stocks, which helps ensure it won't fall out of the pin holes due to its weight. Both of these parts will be milled in the CNC machines, and use tools such as tool #4 and tool #3. They both have features such as adaptive cuts and 2d contours to ensure all design features are adequately milled. After they are machined, they are then placed on the assembly line and later assembled by the robot arms. The body is rotated and placed in the vice, while the lid is flipped and then placed on top of the body. All of these are able to be completed with the machines provided by the ADML.

d. Since the CNC, robots, and stock dimensions can all vary, we had to alter our design to ensure that even in the worst case scenarios our parts can be effectively created and assembled. For the body, we did not have to change much. Since the pin holes are just one cut each with tool #7, the size stayed the same as our original design. We also did not change the location, as all of these would be better added to the lid. We did send the tool for the adaptive cut slightly below the stock model when milling the cavity, to ensure all of it is cut out. For the lid, we did the same for the hook as we did for the body cavity. We decreased the pin sizes by ~0.0025 to ensure that even if the pinholes got -0.0005-0.009 and the pins themselves got +0.0005+0.009 and the stock was slightly different than the nominal dimensions, they should still get milled correctly. We also added chamfers of 0.01 inches to the pins so that they can be assembled even with the robots potentially being slightly off, yet still have enough surface area to combine with the pin holes.

e. The main design iteration to the lid was to take away the bottom hook for additional accessories. Due to how the belts will be resting, the belts would interfere with the accessibility of that bottom hook for accessories. Two options were to remove the hook entirely or move it to be mirrored from the other hook. Ultimately, we chose to remove it entirely. This was because another hook would make the lid thin width wise, which could lead to the robots having trouble grabbing it or assembling the prototypes. Additionally, large enough components would instead be interrupted by the bottom of the body.

One design change we made to the body was making the back and bottom components thicker. This was to ensure greater support, as we noticed with the thinner design the vice jaws could compress it slightly, leading to greater differences between the CAD model and milled product. These changes ensured the part stayed fully in the vice and did not encounter any compromises.

3. Manufacturing strategy:

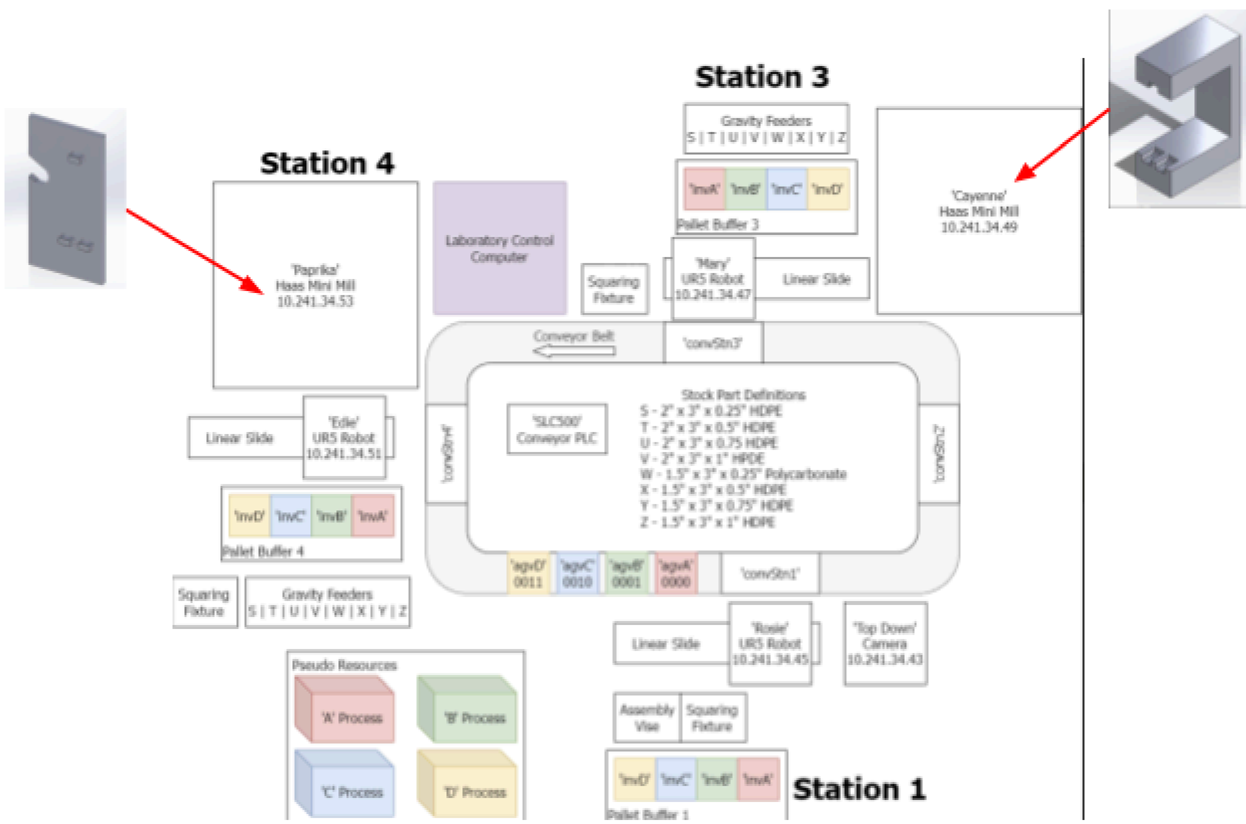

Figure 8. ADML Layout and Assembly line

a. In the ADML we will manufacture the body at station 3 (Cayenne) and the lid at station 4 (Paprika) simultaneously. The body takes a shorter time to manufacture so it will be placed on the conveyor belt and sent to station 1 (Rosie) first as the lid finishes its CNC process. Once the lid is finished, it will execute the same process and send the finished product to station 1 as well for assembly.

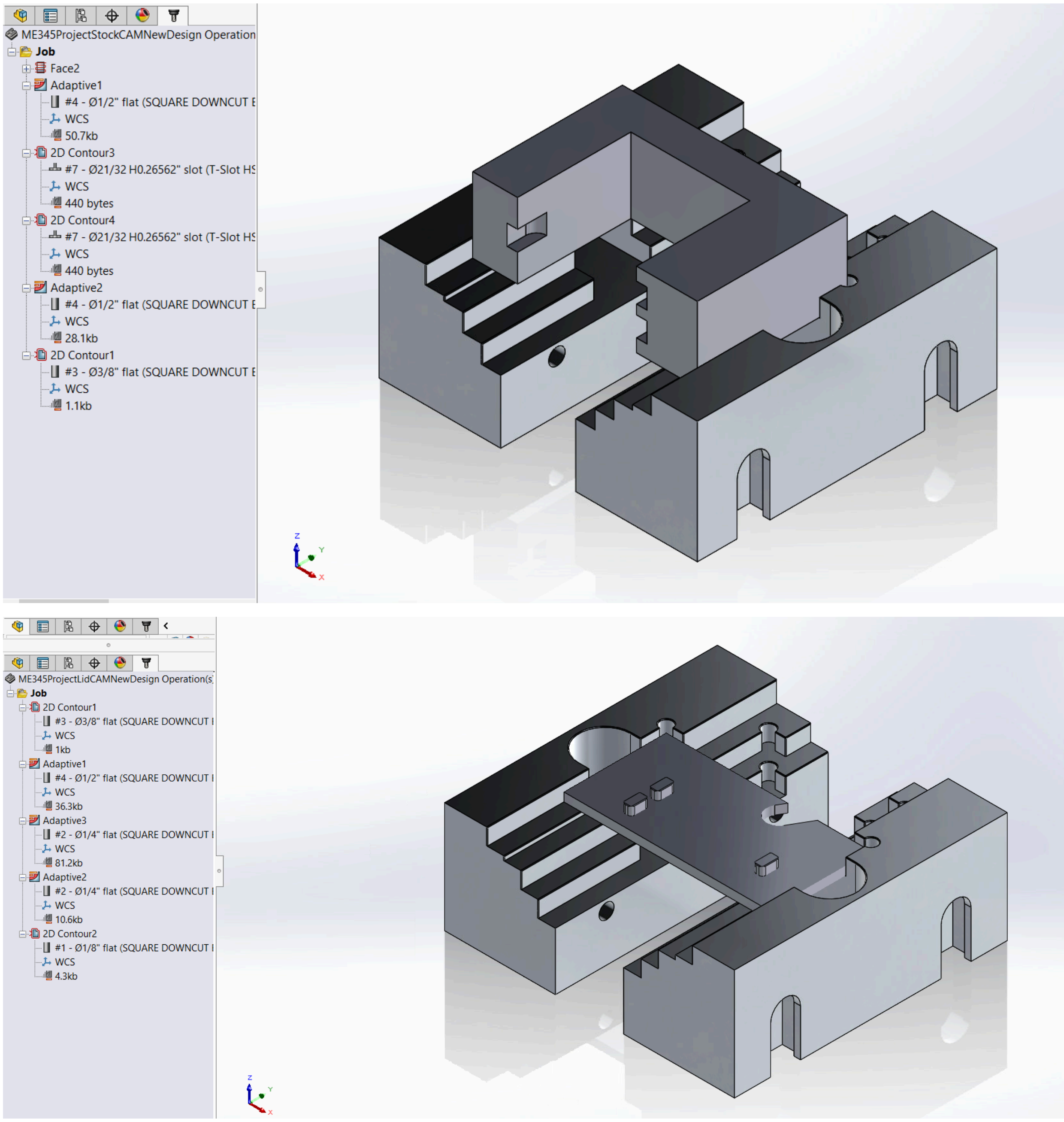

Figure 9. CAM for Body and Lid, Layouts for the milling process of the body (top) and lid (bottom). The specific processes are located to the left of the vice. Annotations were excluded as the image got too crowded.

b. For the body, since we are keeping most of the main shape of the stock, our first operation is a facing procedure to ensure that the width of the stock is uniform across several trials. Afterwards, there is an adaptive cut that mills out most of the body cavity up until it gets past the location of the lowest pin hole. Then, the three holes are cut with tool #7. Since we have had errors with burrs in prior trials, it does this twice to ensure the holes are properly cut. Then an adaptive cut to remove the rest of the cavity occurs. Lastly, a 2D contour cut is run along all the edges to ensure all burrs and shavings are off.

For the lid, there is not much need to ensure the lids are the same width, as it is laying on top of the base anyway. So, our first cut is a 2D contour with tool #3 to perfectly cut the hook. Then there are two adaptive cuts, first with tool #4 and second with tool #2, to mill out half of the lid (making most of the shapes of the pins). Another adaptive is for the finer details and to ensure all parts except the two pins together are cut out. Then a 2D contour finalizes the pins and goes around the edges to ensure everything is cleaned up.

4. Computer integrated manufacturing (CIM) control:

Initially, we created two separate BUMES files, one for the body and one for the lid. Each process involved picking up the pallet at rosie's station, placing the pallet at the respective station (Edie or Mary), collecting the stock from the gravity feeder and manufacturing, placing the finished product onto the pallet, then finally placing the pallet back onto the conveyor belt to send to rosie for assembly. Once both scripts were completed, we combined them into one file in order to reduce waiting time between steps. The script for the combined process can be seen in figure 10 below. It is also important to note that we created our own versions of the admin files on the UR robots as some waypoints needed to be changed either because they were slightly off or needed to be specific to picking up our finished stock.

This entire process was ordered in this way because as it drops off the pallet at Mary's station, it then immediately drops off the next pallet at edie as well and they run their respective programs to mill the pieces. This helps us ensure that the two CNC mills are running in parallel and reduce overall manufacturing time. A similar procedure is repeated for the picking up of the manufactured pieces which are sent to Rosie's station together.

Figure 10: Combined BUMES script for the manufacturing of the body and lid and assembly

```
//BELTUP!

//Move Empty Pallet to Conveyor at Station 1 (LID)
resourceSeize('convStn1','agvA')
urDashboard('Rosie','me345_admin/_adminCG-invAToPHome.urp', 5)
urDashboard('Rosie','me345_admin/_adminCG-PHomeToConveyor.urp', 7)
resourceRelease('convStn1')

//Move Empty Pallet to Conveyor at Station 1 (BODY)
resourceSeize('convStn1','agvB')
```

```
urDashboard('Rosie','me345_admin/_adminCG-invBToPHome.urp', 5)
urDashboard('Rosie','me345_admin/_adminCG-PHomeToConveyor.urp', 7)
resourceSeize('convStn4','agvA')
resourceRelease('convStn1')

//Retrieve Empty Pallet from Conveyor at Station 3 (BODY) CHECKED

resourceSeize('convStn3','agvB')
urDashboard('Mary','C6_WEDS_8:00AM/_adminCG-ConveyorToPHome.urp', 2)
urDashboard('Mary','C6_WEDS_8:00AM/adminCG-PHometoInvB.urp', 4)
resourceRelease('convStn3')

//Retrieve Empty Pallet from Conveyor at Station 4 (LID) CHECKED
urDashboard('Edie','C6_WEDS_8:00AM/_adminCG-ConveyorToPHome.urp', 2)
urDashboard('Edie','C6_WEDS_8:00AM/_adminCG-PHomeToInvA.urp', 4)
resourceRelease('convStn4')

//Collect raw material and manufacture (BODY) CHECKED
urDashboard('Mary','C6_WEDS_8:00AM/gravityFeederV.urp', 3)
urDashboard('Mary','C6_WEDS_8:00AM/_adminCG-WXYZLoadMill.urp', 15)
resourceSeize('convStn3','agvB')

//Collect raw material and manufacture (LID) CHECKED
urDashboard('Edie','C6_WEDS_8:00AM/gravityFeederW.urp', 3)
urDashboard('Edie','C6_WEDS_8:00AM/_adminCG-WXYZLoadMillMakeBody.urp', 15)

//Move the completed body to the inventory, then conveyor (BODY) CHECKED
urDashboard('Mary','C6_WEDS_8:00AM/_adminCG-WXYZUnloadMill.urp', 15)
urDashboard('Mary','C6_WEDS_8:00AM/_adminCG-WXYZToInvB.urp', 2)
urDashboard('Mary','C6_WEDS_8:00AM/adminCG-InvBtoPHome.urp', 6)
urDashboard('Mary','C6_WEDS_8:00AM/_adminCG-PHomeToConveyor.urp', 2)
resourceRelease('convStn3')

//Move the completed body to the inventory, then conveyor (LID) CHECKED
resourceSeize('convStn1','agvB')
urDashboard('Rosie','me345_admin/_adminCG-ConveyorToPHome.urp', 4)
urDashboard('Rosie','me345_admin/_adminCG-PHomeToInvB.urp', 2)
resourceRelease('convStn1')

//Send finished part to station 1 (BODY) CHECKED
resourceSeize('convStn4','agvA')
urDashboard('Edie','C6_WEDS_8:00AM/_adminCG-WXYZUnloadMillBody.urp', 15)
urDashboard('Edie','C6_WEDS_8:00AM/_adminCG-WXYZToInvA.urp', 1)
urDashboard('Edie','C6_WEDS_8:00AM/_adminCG-InvAToPHome.urp', 6)
urDashboard('Edie','C6_WEDS_8:00AM/_adminCG-PHomeToConveyor.urp', 2)
resourceRelease('convStn4')
```

```
//Send finished part to station 1 (LID) CHECKED
resourceSeize('convStn1','agvA')
urDashboard('Rosie','me345_admin/_adminCG-ConveyorToPHome.urp', 4)
urDashboard('Rosie','me345_admin/_adminCG-PHomeToInvA.urp', 2)
resourceRelease('convStn1')

//Get body ready for assembly
//Pick up body from Inv B flip with tall vise the go pHome
//Place body into floor vise grip from pHome
urDashboard('Rosie', 'C6_WEDS_8:00AM/InvB_bodytoVise.urp', 2)

//Assemble lid onto body
//Pick up lid from Inv A
//Put lid into tall vise grip
//Pick up upside down (flip)
urDashboard('Rosie', 'C6_WEDS_8:00AM/InvA_lidtoVise.urp', 2)
```

Furthermore, we also needed to create a BUMES file for the assembly of the lid and body together at Rosie's station. We broke down the assembly into 3 steps, flipping the finished body, placing it into the assembly vise, repeating the same flipping process for the lid and finally placing the lid onto the finished body. This assembly process was added onto the main BUMES code so that only 1 code file needed to be added 8 times. For our final BUMES run through, we produced 8 finished products and generated a CIM table for our process as seen below.

Table 1: CIM table for first run through of BUMES program with longest task highlighted

process_name	task_name	start_time	end_time	Time taken (s)	command
BeltUpboth	task_0	1733152224	1733152224	0.0	startupTasksComplete()
BeltUpboth	task_1	1733152225	1733152263	38.1	resourceSeize('convStn1','agvA')
BeltUpboth	task_2	1733152263	1733152275	12.8	urDashboard('Rosie','me345_admin/_adminCG-invAToPHome.urp', 5)
BeltUpboth	task_3	1733152276	1733152288	11.8	urDashboard('Rosie','me345_admin/_adminCG-PHomeToConveyor.urp', 7)
BeltUpboth	task_4	1733152288	1733152288	0.0	resourceRelease('convStn1')
BeltUpboth	task_5	1733152289	1733152292	2.4	resourceSeize('convStn1','agvB')
BeltUpboth	task_6	1733152292	1733152302	10.8	urDashboard('Rosie','me345_admin/_adminCG-invBToPHome.urp', 5)
BeltUpboth	task_7	1733152303	1733152315	11.3	urDashboard('Rosie','me345_admin/_adminCG-PHomeToConveyor.urp', 7)
BeltUpboth	task_8	1733152315	1733152317	1.8	resourceSeize('convStn4','agvA')

BeltUpboth	task_9	1733152317	1733152317	0.0	resourceRelease('convStn1')
BeltUpboth	task_10	1733152318	1733152334	15.9	resourceSeize('convStn3','agvB')
BeltUpboth	task_11	1733152334	1733152348	14.2	urDashboard('Mary','C6_WEDS_8:00AM/_adminCG-ConveyorToPHome.urp', 2)
BeltUpboth	task_12	1733152348	1733152359	10.8	urDashboard('Mary','C6_WEDS_8:00AM/adminCG-PHometoInvB.urp', 4)
BeltUpboth	task_13	1733152359	1733152359	0.0	resourceRelease('convStn3')
BeltUpboth	task_14	1733152360	1733152366	7.3	urDashboard('Edie','C6_WEDS_8:00AM/_adminCG-ConveyorToPHome.urp', 2)
BeltUpboth	task_15	1733152366	1733152372	6.2	urDashboard('Edie','C6_WEDS_8:00AM/_adminCG-PHomeToInvA.urp', 4)
BeltUpboth	task_16	1733152372	1733152372	0.0	resourceRelease('convStn4')
BeltUpboth	task_17	1733152373	1733152402	28.9	urDashboard('Mary','C6_WEDS_8:00AM/gravityFeederV.urp', 3)
BeltUpboth	task_18	1733152402	1733152439	38.5	urDashboard('Mary','C6_WEDS_8:00AM/_adminCG-WXYZLoadMill.urp', 15)
BeltUpboth	task_19	1733152440	1733152444	3.7	resourceSeize('convStn3','agvB')
BeltUpboth	task_20	1733152444	1733152454	32.7	urDashboard('Edie','C6_WEDS_8:00AM/gravityFeederW.urp', 3)
BeltUpboth	task_21	1733152454	1733152487	34.9	urDashboard('Edie','C6_WEDS_8:00AM/_adminCG-WXYZLoadMillMakeBody.urp', 15)
BeltUpboth	task_22	1733152487	1733152521	204.8	urDashboard('Mary','C6_WEDS_8:00AM/_adminCG-WXYZUnloadMill.urp', 15)
BeltUpboth	task_23	1733152522	1733152715	19.3	urDashboard('Mary','C6_WEDS_8:00AM/_adminCG-WXYZToInvB.urp', 2)
BeltUpboth	task_24	1733152715	1733152729	6.9	urDashboard('Mary','C6_WEDS_8:00AM/adminCG-InvBtoPHome.urp', 6)
BeltUpboth	task_25	1733152730	1733152737	15.0	urDashboard('Mary','C6_WEDS_8:00AM/_adminCG-PHomeToConveyor.urp', 2)
BeltUpboth	task_26	1733152737	1733152753	0.0	resourceRelease('convStn3')
BeltUpboth	task_27	1733152753	1733152753	26.8	resourceSeize('convStn1','agvB')
BeltUpboth	task_28	1733152754	1733152858	8.6	urDashboard('Rosie','me345_admin/_adminCG-ConveyorToPHome.urp', 4)
BeltUpboth	task_29	1733152859	1733152875	10.0	urDashboard('Rosie','me345_admin/_adminCG-PHomeToInvB.urp', 2)
BeltUpboth	task_30	1733152875	1733152882	0.0	resourceRelease('convStn1')
BeltUpboth	task_31	1733152882	1733152889	32.4	resourceSeize('convStn4','agvA')
BeltUpboth	task_32	1733152889	1733152889	65.1	urDashboard('Edie','C6_WEDS_8:00AM/_adminCG-WXYZUnloadMillBody.urp', 15)

BeltUpboth	task_33	1733152890	1733152905	16.4	urDashboard('Edie','C6_WEDS_8:00AM/_adminCG-WXYZToInvA.urp', 1)
BeltUpboth	task_34	1733152905	1733152914	6.9	urDashboard('Edie','C6_WEDS_8:00AM/_adminCG-InvAToPHome.urp', 6)
BeltUpboth	task_35	1733152914	1733152925	6.8	urDashboard('Edie','C6_WEDS_8:00AM/_adminCG-PHomeToConveyor.urp', 2)
BeltUpboth	task_36	1733152925	1733152925	0.0	resourceRelease('convStn4')
BeltUpboth	task_37	1733152925	1733152943	13.7	resourceSeize('convStn1','agvA')
BeltUpboth	task_38	1733152943	1733152955	11.7	urDashboard('Rosie','me345_admin/_adminCG-ConveyorToPHome.urp', 4)
BeltUpboth	task_39	1733152956	1733152967	10.4	urDashboard('Rosie','me345_admin/_adminCG-PHomeToInvA.urp', 2)
BeltUpboth	task_40	1733152967	1733152967	0.0	resourceRelease('convStn1')
BeltUpboth	task_41	1733152967	1733153022	54.4	urDashboard('Rosie','C6_WEDS_8:00AM/InvB_bodytoVise.urp', 2)
BeltUpboth	task_42	1733153022	1733153029	7	urDashboard('Rosie','C6_WEDS_8:00AM/InvA_lidtoVise.urp', 2)
BeltUpboth	task_43	1733153029	1733153029	0.0	endProcess()
			Total time:	798.2	

The CIM table above shows the individual task times as well as which tasks are running and their particular order. Some adjustments were made to the conveyance of the pallets in order to reduce the waiting time as much as possible as seen where most resourceSieze commands take a negligible amount of time. As expected, the longest task, which is highlighted in yellow, was a milling task as this accounts for both loading the mill with stock and machining it.

5. Scheduling:

a.

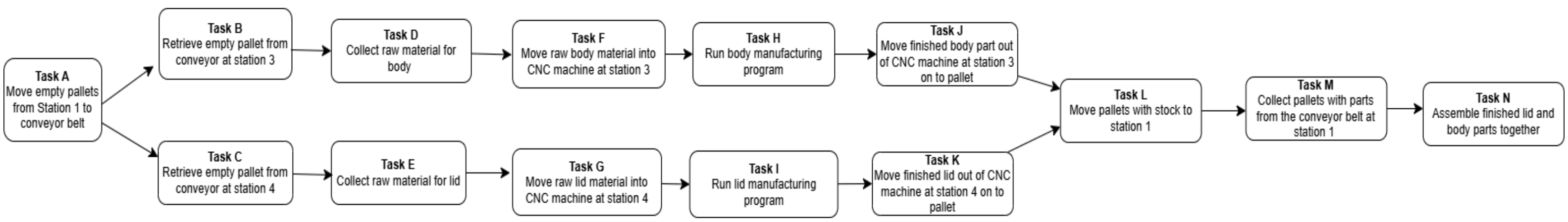

Figure 12. Routing Diagram

Task	Task Description	Times for each process (min:sec)	Utilization (%)
Task A	Move empty pallets	0:10	3.34
Task B	Retrieve pallet at station 3	0:05	1.67
Task C	Retrieve pallet at station 4	0:10	3.34
Task D	Collect raw material for body	0:20	6.69
Task E	Collect raw material for lid	0:20	6.69
Task F	Move body stock to Cayenne	0:15	5.02
Task G	Move lid stock to Paprika	0:15	5.02
Task H	Run Body	4:14	84.94
Task I	Run lid (Start next operation occurs here, when there is ~55 seconds left in the procedure)	4:59	100

Task J	Move body to station 3 pallet	0:15	5.02
Task K	Move lid to station 4 pallet	0:15	5.02
Task L	Move parts to station 1	0:20	6.69
Task M	Collect parts and stock at station 1	0:20	6.69
Task N	Assemble product	3:30	70.23

Table 1. Task List. *Bottleneck is highlighted. Work is shown at the end

b. The maximum possible throughput, assuming best case scenario, is simply the rate of the bottleneck. This would be 1 part every 4.983 minutes (or 1 part every 299 seconds). Practically, the maximum throughput would be lower, as little inefficiencies across the system could occur, leading to slightly longer times. With this throughput and the utilization rates we calculated, we found that the theoretical minimum WIP in steady state was 3.104 parts and the corresponding cycle time was 15.467 minutes/part (928 seconds/part). However, we cannot have a fraction of a part working, so the effective max WIP would be 3, and the corresponding cycle time 14.95 minutes per part (897 seconds per part). As such, there would be three instances for each part (Lid A1 Lid A2 Lid A3, and Body B1 Body B2 Body B3).

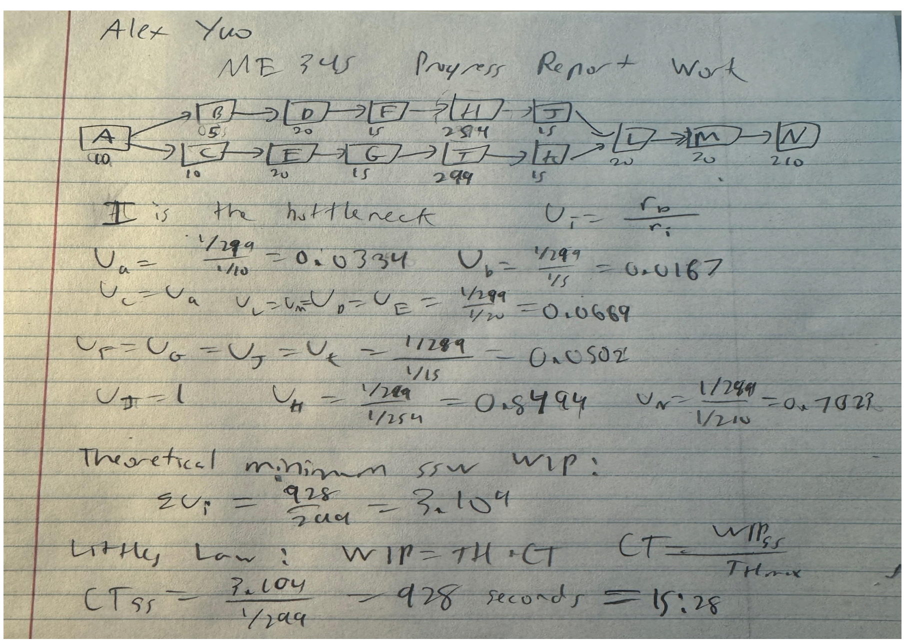

Figure 12. Work for Scheduling

c. Most of the labeled tasks (besides task H, I, and N for manufacturing processes and assembly) are non-value added time through moving the materials and parts around on the conveyor belt or robots. This results in a % non-value added time of 17.78% (165/928). This is not ideal or close to industry goals. Ideally, we could fix it by having a stream line assembly process and make the conveyor belt shorter, however that is not really possible. Realistically, what we can improve is to minimize wait times or unnecessary robot movements as well as resetting home positions to be the start of a process when trying to move or readjust raw materials.

d. For idle time, we have the longest process, process I with its time of 4:59, to be the bottleneck and 4:59 is the workstation cycle time. Combining ABCDEFG into one workstation (workstation 1), H into another (2) I into its own (3), and JKLMN into the fourth and final workstation, we get Workstation 1 has a runtime of 95 seconds, Workstation 2 has 254 seconds, Workstation 3 has 299 seconds, and Workstation 4 has 280 seconds. This means workstation 1 has an idle rate of 68.2%, Workstation 2 has an idle rate of 15.1%, Workstation 3 is perfectly efficient, and Workstation 4 has an idle rate of 6.35%. This results in a total idle time of 22.41%. This, while not being terrible, is too high for industry standards. Adjustments can be made to do things such as alternating which CNC runs the bottleneck process, which would decrease the time of the bottleneck and thus decrease idle time. Alternate processes outside of the limitations of the ADML can be considered, such as having two assembly lines so that the process can run quicker instead of the cycle having to wait for each machine to take their respective pallet and part.

Task	A	B	C	D	E	F	G	H	I	J	K	L	M	N	WIP
Duration min:s	0:10	0:05	0:10	0:20	0:20	0:15	0:15	4:14	4:59 (BN)	0:15	0:15	0:20	0:20	3:30	
0	AB1														1
0:05	AB1														1
0:10	AB1														1
0:15		B1	A1												2
0:20			A1	B1											2
0:25				B1	A1										2
0:30				B1	A1										2
0:35				B1	A1										2
0:40					A1	B1									2

0:45						B1	A1								2
0:50						B1	A1								2
0:55							A1	B1							2
4:59	AB2							B1	A1						3
5:05	AB2							B1	A1						3
5:10	AB2								A1	B1					3
5:15		B2	A2						A1	B1					4
5:20			A2	B2					A1	B1					4
5:25				B2	A2				A1						3
5:30				B2	A2				A1						3
5:35				B2	A2				A1						3
5:40					A2	B2			A1						3
5:45						B2	A2		A1						3
5:50						B2	A2		A1						3
5:55							A2	B2	A1						3
6:00								B2	A2		A1				3
6:05								B2	A2		A1				3
6:10								B2	A2		A1				3
6:15								B2	A2			AB1			3
6:20								B2	A2			AB1			3
6:25								B2	A2			AB1			3
6:30								B2	A2			AB1			3
6:35								B2	A2				AB1		3
6:40								B2	A2				AB1		3

6:45								B2	A2				AB1		3
6:50								B2	A2				AB1		3
6:55								B2	A2					AB1	3
7:00								B2	A2					AB1	3
10:04	AB3							B2	A2					AB1	4
10:10	AB3							B2	A2					AB1	4
10:15	AB3								A2	B2				AB1	4
10:20		B3	A3						A2	B2				AB1	5
10:25			A3	B3					A2	B2				AB1	5
10:30				B3	A3				A2						3

Table 2. Task Times and WIP

e. As can be seen, the steady state WIP alternates between 3, 4, and 5 with 3 being more prevalent compared to 4 and 5 rarely appearing. This aligns with our calculated steady state WIP, should everything run as they theoretically should. Staggering is not as complicated as it may seem, as the next AB pair has to be released when task I, the bottleneck, has 55 seconds left in its process (or when 4 minutes and 59 seconds have passed since the last pair release). There are only ever 3 to 4 parallel operations occurring at a time.

f. When we worked on our project, BUMES was broken and unable to be used. Caroline was not able to reset it until her office hours, which was after our lab section. We plan on going back to the ADML on the 25th of November, at which point we will be able to use BUMES. For now, we do not have actual throughput of the entire cycle from BUMES.

We would assess both types of yield by analyzing how many parts did not cause errors/halt the process. Then, for assembly yield, we would analyze how many products are assembled adequately, and for functional yield, we would see how many products are able to hold belts sufficiently and not have the lid fall out easily. We would compare both of these numbers to the number of products produced or attempted. Like part e, as BUMES was down during our scheduled lab time, we were unable to procure actual data for this part.

6. Implementing lean principles:

Our project aims to apply various lean principles to our manufacturing strategy and fulfill elements of the Toyota Production System (TPS) house to produce BeltUp! units on a small automated production line. A key lean principle that was implemented in the design phase was identifying the value of our product by modeling a design that is compact and inexpensive for the customer. We went through multiple CAD design iterations to achieve a product that minimizes waste from the stock material, the machining time in the CNC mill, as well as minimizing time spent in assembly by programming efficient waypoints. Our manufacturing system also allows for products to be manufactured and assembled on demand, which implements key components of the TPS such as Just-In-Time and Kanban which aim to reduce overproduction and inventory. The system we designed creates a workflow between each station, using the robots and conveyor belt to work together in time with each other to move parts from one station to the next. Beyond the manufacturing itself, within our group we implemented the base of the TPS by aiming for process stability, respect and communication between team members, and a standardization of work and understanding of concepts from lecture and lab to develop this project together.

When deciding on the flow of our manufacturing system, we considered what would be more efficient for time and movement of parts. With this in mind, the lid was decided to be manufactured on Cayenne, and the body on Paprika such that the lid can be placed on the conveyor and positioned for assembly while the body is being milled as it takes more time than the lid. This saves time and ultimately cost as the parts speed less time waiting to be assembled.

7. Cost estimation:

The following calculations are used to determine the materials and operating cost of our product using the values given in the project description for the stock material and machining time, as well as the method for calculating the throughput.

a. Materials: High density polyethylene (HDPE) \$0.42/in^3. Polycarbonate \$0.53/in^3.
→Stock V: 2” x 3” x 1” HDPE
2*3*1 = 6in^3
6in^3 * \$0.42in^3
= \$2.52

→Stock W: 1.5” x 3” x 0.25” Polycarbonate
1.5*3*0.25= 1.125in^3
1.125in^3 * \$0.53in^3
= 0.59625
= \$0.60

Cost per part based on stock:
= \$2.52 + \$0.60
= \$3.12

b. From the operating and materials cost given in the project description:
Operating: Robot \$1.00/hr, CNC Mill \$20.00/hr, Conveyor \$1.00/hr
→ 553 seconds CNC

CNC Time (hours) = 553/3600 = 0.1536 hours
CNC Cost= 0.1536 * 20.00
= $3.07
→345 seconds robots
Robot Time (hours) = 345/3600 = 0.0958 hours
Robot Cost = 0.0958 * 1.00
= $0.10
→ 928 seconds of runtime for conveyor
Conveyor Time (hours) = 928/3600 = 0.2578 hours
Conveyor Cost = 0.2578*1.00
= $0.26

Cost per hour based on operating time:
→ Throughput = 928/ 3600
= 3.88 parts/hour
→ $3.07 + $0.10 +$0.26
= $3.43
→ 3.88 parts/ hour * $3.43
= $13.32 / hour

From these calculations we are able to determine that our manufacturing line would cost $13.32 / hour to operate, and each part would cost $3.12 worth of stock material. These values are important to identify as they will help us look for areas of improvement for both our material and operating costs. We can look to identify areas of waste that could be reduced, such as downtime, material use, excess machining time, or base cost of stock material. Identifying these areas are key to apply lean manufacturing principles and increase our profits and output.

Limitations and Future Work

Looking towards the future, if we were given the time to improve this project, there are some optimization changes that could be made to our manufacturing and assembly process. In terms of the CAM, the distance between the tool and the body could be made shorter during the tasks meant to help "debur" the body for a cleaner finish. From the completed lid, there were some issues with the excess on the edges of the stock post CNC process that prevented a smooth assembly. Design wise, as mentioned in the past report, the pins and pin holes are made to be assembled in a fairly specific way, making the assembly more complicated than other products such as the Cordganizer. Finally, Robot movements could be optimized especially during the "flipping" tasks for both the body and the lid. These changes have the strong potential of reducing cost, time, and improving the overall quality of the product.

References

- ADML FMC Layout. Boston University College of Engineering Engineering Product Innovation Center, Boston University. Accessed 2024.
- “Amazon.Com: Percao Belt Organizer, 7 Compartment Belt Holder Belt Hanger Closet and Belt Organizer for Drawer, Belt Rack, Belt Storage Organizer, Belt Hangers for Men and Women (Acacia Wood) : Home & Kitchen.” Amazon, www.amazon.com/PERCAO-organizer-compartment-storage-hangers/dp/B0C7GJ5CT4. Accessed 16 Oct. 2024.
- “Amazon.Com: Tenby Living Belt Rack, Organizer, Hanger, Holder - Stylish Belt Rack, Sturdy. : Home & Kitchen.” Amazon, www.amazon.com/Tenby-Living-Organizer-Hanger-Holder/dp/B00ZNJD1KY. Accessed 16 Oct. 2024.
- “Belt Rack Belt Organizer, Belt Hanger, Fathers Day Gift, Belt Storage, Gifts for Men, Mens Belt Holder, Mens Belt Organizer, Unique Gifts.” Etsy, www.etsy.com/listing/256180382/belt-rack-belt-organizer-belt-hanger. Accessed 16 Oct. 2024.
- CIM table spreadsheet - https://docs.google.com/spreadsheets/d/1mkQiyqC2cvX2KtYgvrelimJSksYkZbs5pDhpGG_KxFA/edit?gid=1513049577#gid=1513049577