

# 12 - Design Justification Day 3

March 21, 2021 12:22 PM

**START<sub>1</sub>: 12:15 PM**

**START<sub>2</sub>: 3:00 PM**

**END<sub>1</sub>: 1:00 PM**

**END<sub>2</sub>: 3:45 PM**

## Summary of all relevant mech constraint/objective mapping:

Item #	Part #	Source	Description	Unit Price (CAD)*	Quantity	Total Price	Unit Weight (g)	Total Weight (g)
<b>Intermediate Stage</b>								
1	Filament spool		3D Printed Components	\$20.00	1.28308	\$25.66		1283.08
2	1528-1062-ND	DigiKey	Stepper Motor	\$19.02	1	\$19.02	200.03	200.03
3	TRM4000_0	Phidgets	8mm Rotary Shaft***	\$6.50	0.95	\$6.18	363.575	345.39625
4	1611-0514-0008	gobilda	8mm ID Ball Bearing, 2 pack	\$4.36	4	\$17.45	6	24
5	217-5888	VEX Robotics	GT3 Timing Belt, 100T	\$8.49	1	\$8.49		Negligible
6	2130	openbuilds	GT3 Timing Pulley, 20T, 9mm bel	\$12.49	2	\$24.98		Negligible
7	90592A095	McMaster-Carr	M5x0.8mm Hex Nut	\$0.02	16	\$0.35	1.21	19.36
8	91290A231	McMaster-Carr	M5x0.8mm, 15mm long socket h	\$0.26	16	\$4.14	3.68	58.88
9	91290A572	McMaster-Carr	M3x0.5mm, 15mm long socket h	\$0.25	12	\$3.00	1.12	13.44
10	95947A502	McMaster-Carr	M3x0.5mm standoff, 50mm long	\$2.23	4	\$8.90	2.17	8.68
11	95947A018	McMaster-Carr	M3x0.5mm standoff, 25mm long	\$1.35	2	\$2.70	0.8	1.6
12	92605A652	McMaster-Carr	M3x0.5mm set screw	\$0.33	5	\$1.66	0.244	1.22
13	92095A177	McMaster-Carr	M3x0.5mm, 5mm long button hc	\$0.08	4	\$0.31		Negligible
<b>Output Stage</b>								
1	Filament spool		3D Printed Components	\$20.00	1.1711	\$23.42		1171.1
2	1528-1062-ND	DigiKey	Stepper Motor	\$19.02	1	\$19.02	200.03	200.03
3	91290A231	McMaster-Carr	M5x0.8mm, 15mm long socket h	\$0.26	10	\$2.59	3.68	36.8
4	90592A095	McMaster-Carr	M5x0.8mm Hex Nut	\$0.02	10	\$0.22	1.21	12.1
5	92095A177	McMaster-Carr	M3x0.5mm, 5mm long button hc	\$0.08	4	\$0.31		Negligible
						<b>Total</b>	\$168.38	3376
Mass in kg:								
3.376								

## 3D printing estimates (data courtesy of Colin):

Part (File Name)	Print Time (hour)	Print Time (minute)	Filament length (mm)	Plastic Weight (g)	# Units Needed	Filament length (mm)	Plastic Weight (g)	See Note
1_Gear_Mod_1_25_Teeth_5mm_D_bore	0	30	2203	6.62	1	2203	6.62	
2_Gear_Mod_1_50_Teeth_5mm_D_bore	0	51	4132.6	14.43	2	8265.2	28.86	
3_Gear_Mod_1_100_Teeth_8mm_D_bore	2	11	13087.9	39.35	2	26175.8	78.7	
4_Intermediate_4mmSpacer	0	2	162.9	0.49	2	325.8	0.98	
5_Intermediate_5mmSpacer	0	2	152.7	0.46	4	610.8	1.84	
6_Intermediate_BackWall	3	35	20376.4	61.26	1	20376.4	61.26	*
7_Intermediate_FrontWall	3	38	20338.5	61.15	1	20338.5	61.15	*
8_Intermediate_LeftGearShield	12	12	67454	202.81	1	67454	202.81	*
9_Intermediate_MidPlate	2	12	11677.8	35.11	1	11677.8	35.11	*
10_Intermediate_MidWall	3	20	17966.4	54.02	1	17966.4	54.02	*
11_Intermediate_MotorMount	0	37	3051.4	9.17	1	3051.4	9.17	*
12_Intermediate_RightGearShield	4	45	25218	75.82	1	25218	75.82	*
13_Intermediate_SideCover	5	34	28627.6	86.07	2	57255.2	172.14	*
14_Intermediate_TrapDoor	14	49	82252.8	247.3	2	164505.6	494.6	*
15_Output_BackPlate	21	9	110936.7	333.54	1	110936.7	333.54	*
16_Output_Lip	11	13	56820.7	170.84	1	56820.7	170.84	*
17_Output_Shell1	14	46	84574	254.28	2	169148	508.56	*
18_Output_Shell2	9	17	52603.3	158.16	1	52603.3	158.16	*
						<b>Total (Intermediate)</b>	425423.9	1283.08
						<b>Total (Output)</b>	389508.7	1171.1
						<b>Grand Total</b>	814932.6	2454.18

## Constraint 2: Must be made from >= 30% recycled material

- Moving components are majorly made of new material
  - o Motors have to be purchased, parts are 3D printed (such as the flap for the trap-door mechanism)
    - BUT 3D printed components were designed with PLA in mind as the material
      - Not necessarily recycled, but is biodegradable: <https://www.creativemechanisms.com/blog/learn-about-polylactic-acid-pla-prototypes>
- Outer housing (not designed due to time constraint) can definitely be made partially of recycled material
  - o Outermost housing is essentially a stationary box
    - Can be made of any flat surface that can be combined together via fasteners/glue/etc.
      - Wood, recycled plastic, metal even, etc.
      - These materials can be sourced from recycled/repurposed materials

### **Constraint 3: Must identify/sort >= 6 items in a minute (1 every 10 seconds)**

- Max speed for stepper motor can be calculated using the following eqs: <https://www.allaboutcircuits.com/tools/stepper-motor-calculator/>

$$\text{Max Speed} = \frac{V}{2LI_{max} \cdot spr}$$

$$\text{Minimum Time per Step} = \frac{2LI_{max}}{V}$$

Using the motor's rated specs (<https://cdn-shop.adafruit.com/product-files/324/C140-A+datasheet.ipG>):

$$V = 12 \text{ V}$$

$$I_{max} = 0.35 \text{ A}$$

$$L = 33 \times 10^{-3} \text{ H}$$

$$\text{Max Speed} = \frac{V}{2LI_{max} \cdot spr} = \frac{12}{2 \times 33 \times 10^{-3} \times 0.35 \times 200} = 2.597 \text{ rev/sec}$$

$$\text{Minimum Time per Step} = \frac{2LI_{max}}{V} = \frac{2 \times 33 \times 10^{-3} \times 0.35}{12} = 1.925 \text{ msec}$$

Intermediate stage:

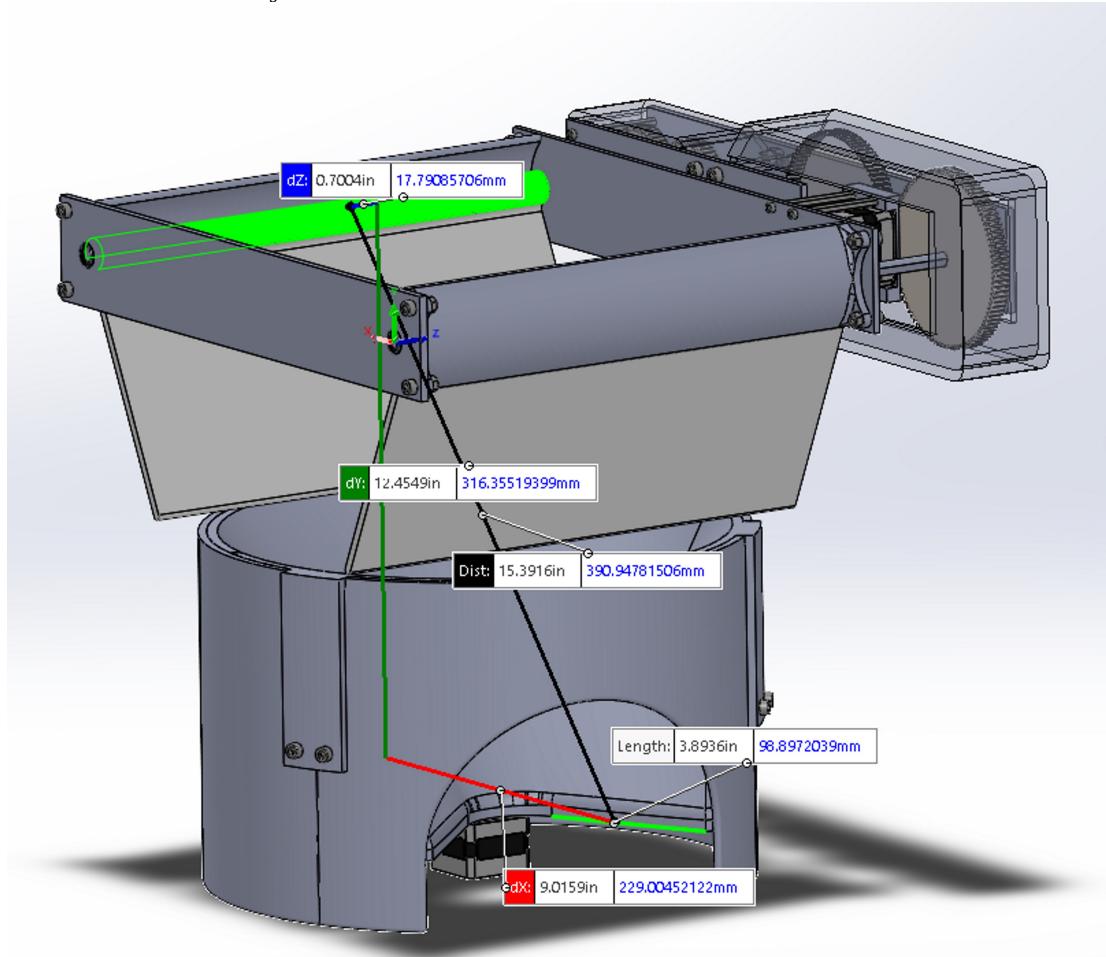
Using the minimum time per step for an approx 65 deg rotation (assuming that is the max opening angle, based off CAD of final design):

It would take  $1.925 \times 200 \times \frac{65}{360} = 69.51$  msec for the trap doors to make a quarter rotation (their assumed max movement to release an object completely).

Output stage:

Using the minimum time per step for a 3/5 rotation (the farthest the output would have to rotate from any point to get to any other output slot, assuming 5 sorting categories):

It would take  $1.925 \times 200 \times \frac{3}{5} = 231$  msec to get the output rotated into the correct position



After the motors move to position, the system relies on gravity to move the object itself.

- Assuming a drop height of ~0.32m from the trap doors to the bottom of the output
- Assuming friction of output diverter is negligible and that the object follows a fairly smooth path (doesn't get stuck)

Kinematic equation describing free fall motion is:

$$d = v_0 \times t + \frac{1}{2} \times a \times t^2$$

Where:

$v_0$  = initial velocity

t = falling time

a = acceleration

d = fall distance

Taking the initial velocity to be ~0, a to be 9.81 m/s^2 (acceleration due to gravity), and d to be 0.32 m:

$$0.32 = \frac{1}{2} \times (9.81) \times t^2$$

$$t = \sqrt{\frac{0.32 \times 2}{9.81}}$$

$$t = 0.2554 \text{ s}$$

The falling time would be approximately 0.2554 seconds.

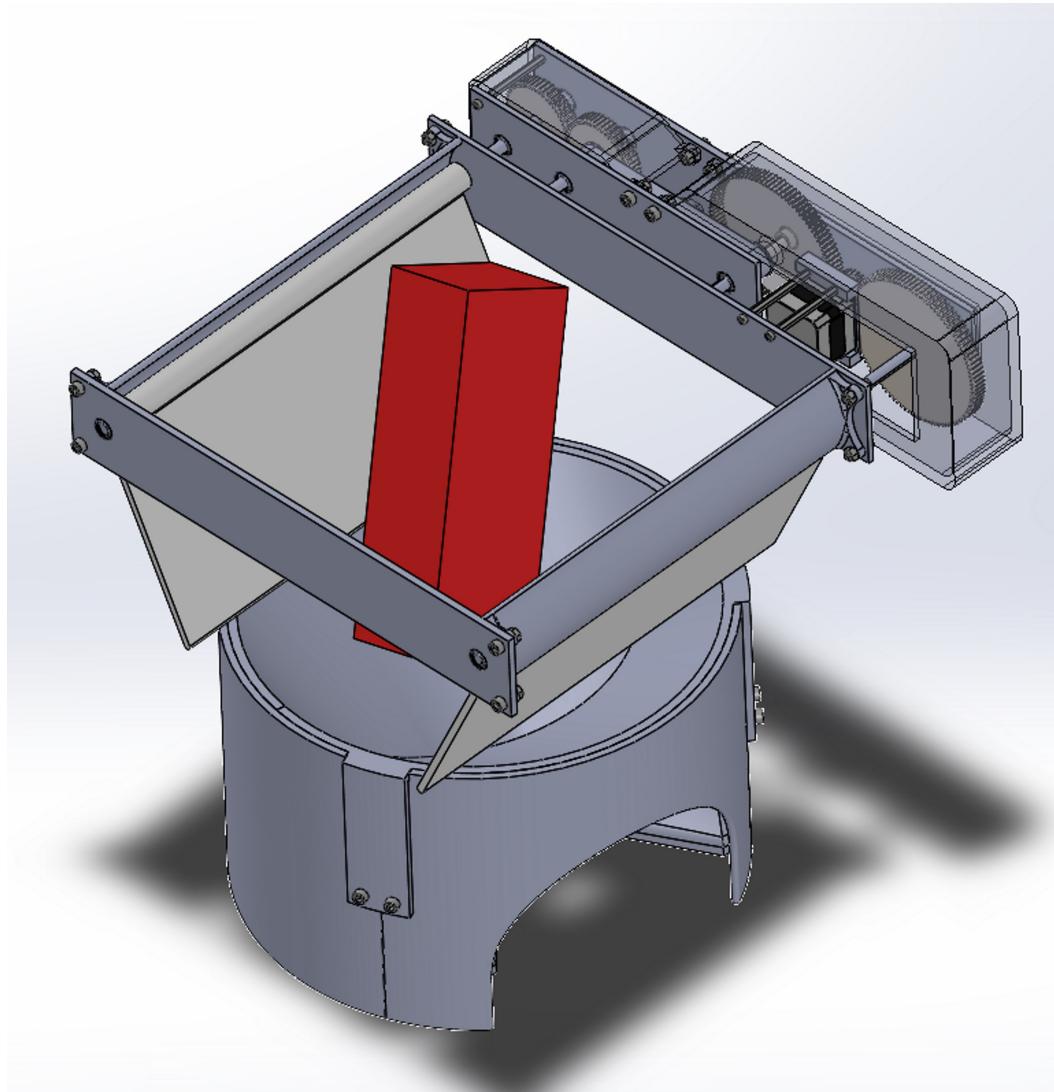
Total time to move an object through the sorting system after releasing it from the trap doors is therefore approximately 0.56 seconds. Even if we double this value to accommodate for any assumptions, it still comes to only ~1 second, which is well within the 10 second/item time constraint. Only other factor to consider is the time it takes to identify the object (from the controls side) and any lag in the electrical components (which will likely be negligible).

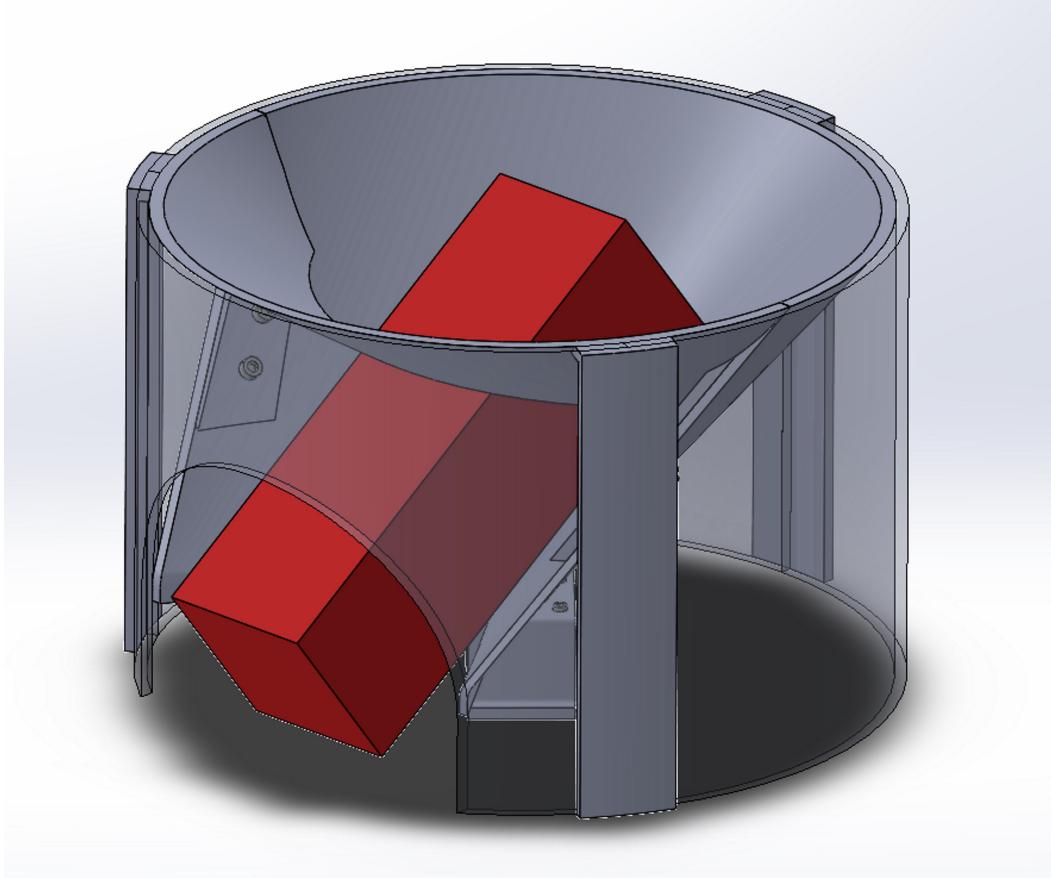
#### **Constraint 4: Must cost <= \$250**

- Mechanical costs come to ~\$168.38 (see Excel sheet screenshot above)

#### **Constraint 5: Must accept items of up to size 7.5 x 7.5 x 22.5 cm rectangle**

Red block represents max item size





#### **Constraint 6: Must weigh <= 25 kg**

- Mass of all components, excluding any outer housing, comes to ~3.4 kg (see Excel sheet screenshot above)
  - o Very realistic to assume that with housing and electrical components we'll double the weight at worst
  - o Either way, still have ~20 kg of wiggle room

#### **Constraint 8: Must meet all applicable Canadian Safety Standards**

- Kept safety in mind while designing: limiting pinch points, designing enclosures for moving parts, etc.
- Further safety standards would have to be verified in the prototyping/testing stage, which is out of scope for our project
  - o For example, motor testing: <https://www.machinedesign.com/markets/article/21828181/how-to-meet-canadian-standards>

#### **Constraint 9: Must be compatible with standard recycling/garbage bin sizes**

- Modular design allows for customizability
- Outer casing not designed (out of scope for this project) but it is not vital to the success of the sorting system itself
  - o Can be designed however user sees fit to fit the user's exact needs and output bin sizes/geometry
    - Compatible with all bin sizes by default due to open source/modular nature

#### **Objective 11: Should have a long lifespan >= 15 years**

- Under regular conditions in a room, PLA can survive for up to 15 years: <https://3dprintgeeks.com/pla-3d-printed-object-durability/>
  - o We will likely not reach our 15 year objective without needing some upgrades/replacements, but we could get close
    - This also likely depends on frequency of use
  - o However, luckily, PLA will begin to fail because it will begin to biodegrade
    - Supports our environmental ethos for this project
    - Replacement parts could simply be reprinted and the cycle could continue

#### **Objective 12: Should fit in average Canadian appliance footprint for residential design**

- See constraint 9
  - o Merging constraint 9 with objective 12 (or rather, constraint 9 is absorbing objective 12)
    - Two sides of the same coin - repetitive

#### **Objective 13: Should be open source**

- 3D printed components are modelled in SolidWorks
  - o Can easily upload them to a platform such as GrabCAD or thingiverse for use by others

#### **Objective 14: Should be modular**

- Because many major components are 3D printed, adjusting the design to fit exact user needs is fairly simple

#### **Objective 15: Should be scalable**

- Similar note as with modularity. Only concern would be the strength of the materials - i.e. You would probably have to start looking into stronger materials for 3D printing to handle increasingly large torques
  - o May lose biodegradable perk of using PLA
  - o Could use metal for very large scales though, which would be recyclable

#### **Objective 16: All parts should be available locally/within Canada**

- Much of the mechanical design consisted of 3D printed components
  - o PLA printing filament can be found locally
- Other parts are hobby level (items such as the bearings and timing pulleys)
  - o Could potentially be found at local hobby shops
    - Slightly different sizes are acceptable too (because of the modularity/scalability of the design)
- Items such as rotary shafts can be found at any metal supplier - wouldn't be difficult to find local source
- US sources were just used as a base sometimes for this design because they provided unit prices without having to request quotes
  - o Quick way to estimate the cost