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ES51

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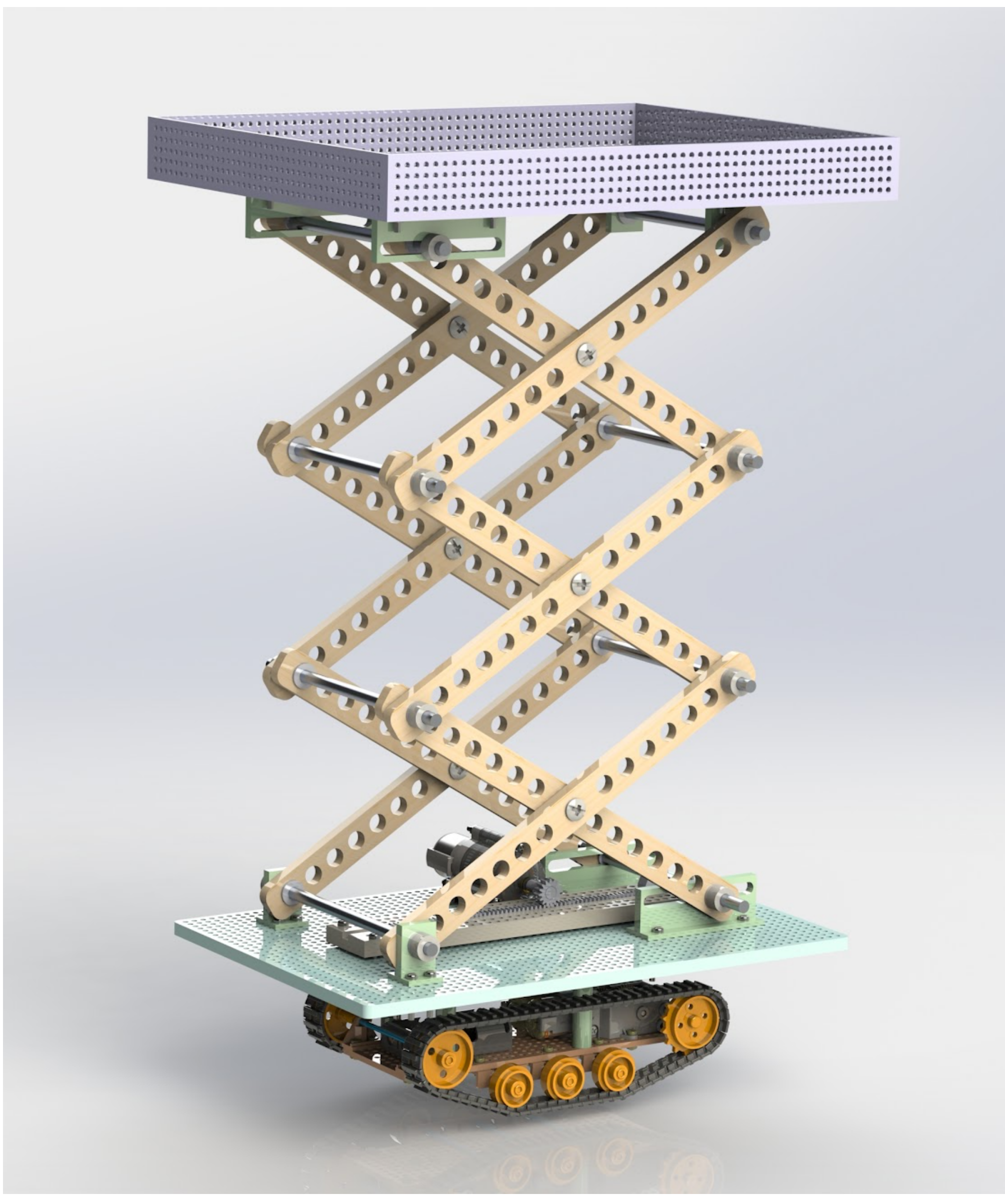


I. ABSTRACT
Healthy eating habits are challenging to develop and maintain, especially amongst university students. In fact, the average rate of weight gain over the course of the first year of college is roughly six times that reported for the general population [1], in part due to limited time, lack of motivation to prepare food, and ubiquity of junk/convenience foods [2]. To address this problem, we designed a snack delivery robot that can be pre-loaded with nutritious foods and summoned on-command via remote control. We conducted research to identify design inputs, calculated critical parameters to ensure safety and functionality, built virtual 3D models using computer-aided design software, and constructed and tested prototypes to isolate the best solution. Our final design is compact and functional in its subsystems, but would benefit from additional design/prototyping iterations before being translated into a product. While our final robot does not perfectly address the aforementioned problem as intended, we hope that the present effort inspires more people to think creatively about how to leverage technology to help college students maintain nutritious diets during their most critical years of learning and development.

II. INTRODUCTION
IIa. Problem, motivation, and stakeholders
As the number of responsibilities assigned to undergraduate university students continues to grow, students struggle more and more to prioritize what actually matters most: their health, and in particular, their nutrition. “Freshman 15” is an expression that has historically been used to jokingly describe the amount of weight gained by students in their first year of college, but sadly research has shown that there may be some truth underlying this expression. Data from several studies have shown that the average rate of weight gain over the first year of college is significantly greater than it is for the general population. [1] An explanation for this phenomenon emerges through other research showing that college students struggle to maintain healthy eating habits due to limited time, lack of motivation to prepare food, and ubiquity of junk/convenience foods. [2] The short- and long-term consequences of poor nutrition are devastating, and affect not only physical but also mental functional capabilities [3]. To this end, the goal of the present work was to build a robot that would address this critical need by providing quick, on-demand delivery to healthy snack food items. This snack delivery robot would be pre-loaded with healthy food items, and could be summoned in real-time via remote control. Our hope was for this robot to both facilitate and inspire healthier eating habits amongst time- and energy-limited college students.

While our primary stakeholder is the busy college student [4], this healthy snack delivery robot could be useful to a diverse range of potential clients, including other time-limited contributors to the academy such as graduate students, postdoctoral fellows, and tenure-track professors, in addition to busy professionals working long hours, and stretched mothers and fathers. In the era of COVID-19, Zoom fatigue may lead someone to reach for the bag of chips on their bookshelf rather than walking to the kitchen for a banana - our robot would thus be useful for individuals facing back-to-back Zoom calls as well. Workers whose jobs require them to not leave their desks, such as, for example, CCTV operators, may also benefit from a robot that brings them nutritious snacks. Finally, individuals with limited mobility may find some added freedom with a robot that minimizes their reliance on a person when they just want a quick snack.

IIb. Problem statement
Healthy eating habits are challenging to develop and maintain, especially amongst university students. In fact, the average rate of weight gain over the course of the first year of college is roughly six times that reported for the general population [1]. Studies have shown that limited time, lack of motivation to prepare food, and ubiquity of junk/convenience foods serve as critical barriers to healthy eating amongst college students [2]; thus, an innovation that facilitates fast, easy access to healthy food options for students would dramatically improve their abilities to stay healthy during their most critical years of learning and development.

IIc. Key achievements

Although the final design was unable to be considered fully complete, given our unfunctional motor, it still accomplished several of its initial goals and mechanical properties. For instance, a proof of concept was established through our rack and pinion; even though the operation had to proceed manually, the prototype indeed demonstrated engagement between the pinion gear sliding the rack and propelling the "lift" of the scissor arms. Additionally, the design actually exceeded our target height of 40 centimeters, with a final value of 55.3 centimeters. Despite this gain, stability was not compromised. In testing phases, the scissor lift did not topple, even when fully unfolded. The addition of carrying weight added some degree of wobble, but overall: the system never collapsed.

III. CONCEPT DEVELOPMENT

IIIa. Technical Specifications

With a justified goal in mind, we proceeded with setting down criteria which would then direct the remainder of our design and development process. The following specifications were established:

- *Carrying Capacity:* considering the primary purpose of any design should be to serve as a snack transportation vessel, food weight is a considerable concern. Thus, all proposed concepts must be able to withstand and lift the addition of a minimum standard load. To quantify this value, we approximated the weight of three pears and determined them to be 650 grams. This value, used within torque calculations, then guided our motor and pinion gear size selections.
- *Tray Dimensions:* Just as the design must be able to withstand food weight, it must also consider food volume, allotting enough tray space to ensure the inclusion of multiple snacks and reducing reload frequency. An area of at least 400 cm^2 is comparable to that of small TV trays; this measurement can be computed with a simple length x width calculation.
- *Travel Speed:* In order to emphasize the convenience of this snackbot, it was established that the pursued design should travel at a speed either equitable or even faster than human walking speeds (approximately three miles per hour), making its operation the preferred choice over manually getting up and walking to a pantry to grab food. Through test trials involving a predetermined distance (ex. one feet) and a stopwatch, the experimental speed of any prototype can be converted from, say, feet per second to miles per hour.
- *Height*: When taking into consideration sitting height, the robot itself or one of its subcomponents should be able to exist at or extend to a tall enough level from which it is second-nature to grab items off of. Not only would this alleviate uncomfortable straining (especially given our target demographic and their association with back issues) but this component would also benefit those who are wheelchair bound or have similar medical hardships. This minimum height was established as 40 centimeters, using a desk chair for reference, and can be measured with a ruler or meter stick.
- *Raising Speed:* If a lifting subcomponent was required in order to achieve the "height" technical specification, this addition should not operate slowly to the point where it inconveniences the functionality of the overall system. Instead, the actions of traveling and lifting should move as a unit, flowing in one smooth motion. Thus, the minimum raising speed was set to be equal to the minimum traveling speed, whose reasoning was provided above. This technical specification would be measured by timing how long it takes for the robot to extend to Y height. Then, divide Y by that experimental time and convert to miles per hour for ease of comparison.
- Overall Dimensions: The resulting design should still be portable enough to easily integrate into a common household, dormitory, or workplace environment, meaning it cannot take up a considerable amount of floor space. Thus, we capped the length x width plane at an area of 2000 cm^2, deduced from a proportionality of a standard cubicle size.

TABLE I
SUMMARY OF TECHNICAL SPECIFICATIONS

Specifications	***Justification***	***Measurement***
Carrying Capacity Minimum: 650 grams	withstand food weight	torque calculations (from motor/gearbox system)
Tray Dimensions Minimum: 400 cm^2	withstand food volume	ruler
Travel Speed Minimum: 3 mph	match human walking speed	ruler + stopwatch (gauge rate)
Raising Speed Minimum: 3 mph	match human operation	ruler + stopwatch (gauge rate)
Extended Height Minimum: 40 cm	obtain sitting desk height	ruler
Overall Dimensions Maximum: 2000 cm^2	preserve floor space	ruler

IIIb. Prior Art
IIIb.1. Carnegie Mellon University (CMU) "SnackBot"
CMU's SnackBot (**Fig. 1**) is an autonomous robot that delivers snacks to "CMU students who are left gasping for breath when forced to drag themselves away from their studies to get a snack [5]." SnackBot's purpose is to serve as an ongoing platform for studying human-computer interaction (HCI), so it is specifically programmed to engage and converse with people.

Fig.1. Image of CMU SnackBot, a snack delivery platform for studying HCI [5].

- *Relevance*: SnackBot relieves students' stress levels by delivering snacks to them, minimizing the effort required for them to stay nourished. This purpose and the corresponding stakeholders overlap with ours.

- *Strengths*: SnackBot is automated, highly intelligent, and interactive, engaging stakeholders with its positive demeanor. We intend for our robot to engage positively with its users.
- *Weaknesses*: SnackBot does not encourage its users to choose healthy over unhealthy options. Thus, while it saves users time and energy, it does not encourage healthy eating habits.
- *Improvements:* Our robot will engage positively with its users and will facilitate healthy eating by discouraging unhealthy eating choices. Our present ideas include: incorporating an obstacle (e.g. a puzzle, extended reaching distance) for access to unhealthy snacks; integrating an LED display in the robot's mouth region that lights up as a smiley face when the user chooses healthily, and a sad face when the user chooses unhealthily.

IIIb.2. PepsiCo "Snackbot"

PepsiCo's Snackbot (**Fig. 2**) is an outdoor, self-driving robot that carries Hello Goodness (PepsiCo's health brand) snacks and beverages. The robot's purpose is to make healthy snacking ultra-convenient for college students who seek on-the-go nourishment amidst packed schedules [6].

Fig. 2. Image of student retrieving healthy snacks from PepsiCo's Snackbot [6].

- *Relevance*: Similar to CMU's SnackBot, PepsiCo's Snackbot reduces the level of effort required for students to stay nourished over the course of a busy day. PepsiCo's bot additionally includes only healthy snack options. Snackbot's stakeholders and overarching purpose overlap with ours.
- *Strengths*: Snackbot refrigerates cold beverages while keeping dry snacks crisp. We explored the possibility of incorporating a cooling mechanism in our robot, and ultimately decided against it due to limited time and resources
- *Weaknesses*: Not all of PepsiCo's "healthy" options are actually healthy; for example, a single serving of SunChips contains 240 calories, 11 grams of fat, and 370mg of sodium [7].
- *Improvements:* The healthy snacks we include in our robot will be undeniably healthy. Our present ideas include lightweight fruit, baked crackers, trail mix, granola bars, and cereal packets.

IIIb.3. Kiwi Campus "KiwiBot"

Kiwibot (**Fig. 3**) is a delivery service that delivers food in addition to other products. This robot's purpose is to provide quick, affordable (as low as $3.99/delivery today, target is $1.00) [8] delivery service to city dwellers and college students. KiwiBots are semiautonomous - they are supported remotely by teleoperators who assist in challenging situations such as traffic crossings.

Fig. 3. Image of Kiwi Campus KiwiBot, an affordable food and product delivery service [8].

- *Relevance*: Similar to the aforementioned delivery robots, KiwiBot reduces the amount of time and energy required for students to quickly receive basic necessities. Our stakeholders and general mission are similar.
- *Strengths*: Kiwibot insulates cold and hot foods, and has a backlit face that communicates warm and inviting emotions, making it personable. We explored the possibility of incorporating heating/cooling mechanisms in our robot and giving it a personality that encourages healthy choices, but ultimately decided against including these features due to resource and time limitations.
- *Weaknesses*: Kiwibot unfortunately does not always arrive at its intended destination, forcing users to, for example, walk across the street to receive their delivery [9].
- *Improvements:* Our robot's movement will be directly guided via remote control, so it will always arrive at its intended destination.

IIIc. Alternative solutions

We considered several possible solutions to address the aforementioned challenge, as outlined below. Ultimately, our design was hugely influenced by two factors: **1)** limited time, and **2)** limited resources. Due to these two constraints, we ended up paring our design down to a basic form of a motor-enabled scissor lift mechanism to raise and lower a tray of healthy snacks. Although we were unable to implement many of the design ideas we generated, we learned a tremendous amount from the simple exercise of stripping our robot design down to its essentials, and focusing on ensuring that the essentials functioned as intended.

One functionality that we considered was the ability to heat up or cool down snacks to maintain them at their optimal temperature range (**Fig. 4**). The advantage of this design feature is that it would have enabled serving of hot and cold healthy foods. This would have been executed through shake-activated hot or cold packs. The motor would move the rotational end of the crankshaft, which would transform rotational motion into translational motion at the other end. This end would be connected to the hot/cold pack, and this translational oscillation would activate the pack. Hence, the tray would have been cooled down or heated up. This functionality would have been controlled by two channels of the remote controller. We ultimately decided against pursuing this option due to time and resource constraints.

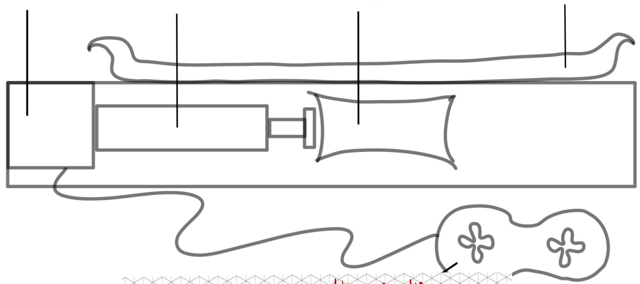


Fig. 4. A potential heating up - cooling down mechanism works to keep snacks at optimal temperatures.

Since our robot was originally intended to interact with its user and encourage healthier decisions, we envisioned a social aspect to our robot (**Fig. 5**). Specifically, we imagined our robot would display an LED-enabled smile when the user chose the healthy option, and a frown, by contrast, when the user selected the unhealthy option. Alternatively, the unhealthy option might have been restricted with a numerical or physical puzzle. The advantage of this design feature is that it would have leveraged what is known about human psychology in encouraging users to choose healthy over unhealthy options. We ultimately decided against pursuing this option due to limited time.

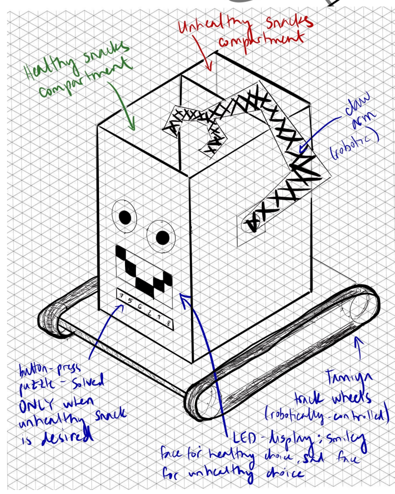


Fig. 5. Use of eyes, and a LED "smile" anthropomorphizes our robot and gives positive feedback to the users when they opt for healthier options.

Another solution we considered entailed a difference in accessibility between healthy and unhealthy snacks (**Fig. 6**). In this design, the user loads the tray and the claw with healthy and unhealthy snacks to be driven around in the Tamiya base. While the accordion fold for the healthy snacks lifts the tray to the desk level, the unhealthy snacks are kept out of direct reach with the arm. The advantage of this design feature is that the slight inconvenience of bending down for a snack has the potential to greatly influence user preference. We ended up maintaining the scissor lift design to enable easy access to the healthy snacks; we decided against pursuing the option of providing an unhealthy snack option at floor level due to time constraints.

Fig. 6. To encourage healthier options over unhealthy ones, the accordion fold carries the tray of healthy snacks, while the clawed arm holds the unhealthy snacks out of easy reach.

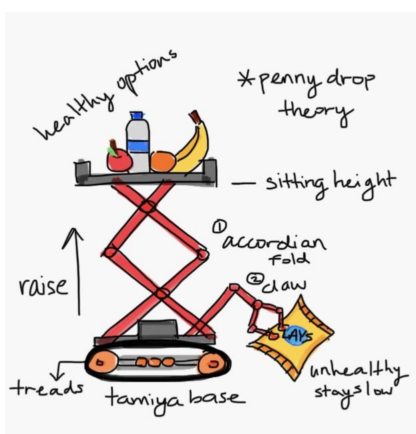
IIId. Design criteria

The design criteria is informed by the technical specifications of the robot. Among the technical specifications that were described earlier, the carrying capacity, tray size and height of the tray were determined to be most important. Speed and overall size of the robot were determined to be of lowest significance, and were given a weight of 1. Beyond the technical specifications, stability of the design was determined to be an important element for the robot's success. This criterion was defined by the tendency of the robot to topple over when lateral forces were applied, and was given an intermediate weight of 2.

Baseline for the pugh matrix was determined as placing snacks on top of the provided Tamiya robot.

TABLE 2
PUGH MATRIX FOR CONCEPT SELECTION

Criteria		Concepts		
Name	**Weight**	**Baseline**	**Claw**	**Scissor fold**



Carrying capacity	3	0	0	0
Tray size	3	0	-1	1
Height of tray	3	0	1	1
Stability	2	0	-2	-1
Speed	1	0	-1	-1
Overall size	1	0	-2	-1
Weighted Sum		**0**	**-7**	**2**
Rank		**2**	**3**	**1**

Compared to the baseline, claw and scissor-fold designs performed equally well in terms of carrying capacity. As the scissor-fold design had an expanded tray and the claw design limited size to the claw, they performed respectively better and worse than the baseline in terms of the tray size. Both alternative designs increased height of the snacks, hence were awarded 1 for height of tray. Both designs suffered from greater instability compared to the baseline, but claw design was significantly more unstable, hence it was awarded '-2' compared to scissor-fold's '-1'. Both alternative designs require the tamiya base to move slower, hence they were both awarded '-1' for speed. Lastly, compared to the baseline, both alternative designs occupied a larger space, but the foldable/extendable feature of the scissor-fold design led to it receiving a '-1' to the claw design's '-2'.

IV. BUILD AND ANALYSIS

IVa. Physics

Physics and engineering concepts were applied to model and predict our robot's critical functionalities, including its overall dimensions and its rack and pinion parameters. **Figs. 7**, **8**, and **9** below show examples of the kinds of computations that were conducted to make these predictions.

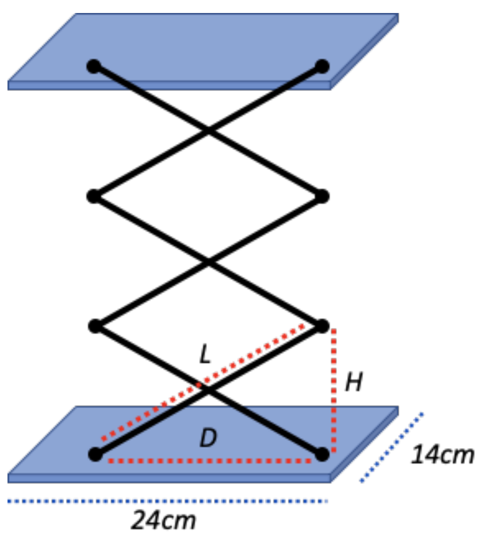


Fig. 7. Diagram of scissor lift mechanism depicting critical dimensions.

L = 24cm
D = 20cm

$H^2 + D^2 = L^2$
$H^2 + (20cm)^2 = (24cm)^2$
H = 13.266cm
3H = 39.798cm ≈ 40cm ✓

This series of computations shows that, using scissor arms of length 24cm, we are able to achieve our target extension height of roughly 40cm, which equates to desk-level.

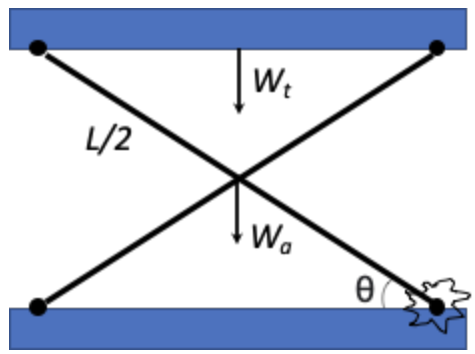


Fig. 8. Diagram of scissor linkage mechanism allowing calculation of force requirements.

L/2 = 12cm = 0.12m
$\mathbf{W_t}$ = 650g -> $\mathbf{F_t}$ = 0.65kg * 9.81m/sec^2 = **6.38N**
(650g was selected for the overall snack weight by scaling 3 pears)
$\mathbf{W_a}$ = 20g -> $\mathbf{F_a}$ = 0.02kg * 9.81m/sec^2 = **0.1962N**
Number of scissor linkages = **N = 3**

The amount of force required to push a rack against the pinion gear depicted in **Fig. 5** above to achieve our desired extension given the weight of the system is defined as:

$$\mathbf{F} = \frac{N\left(\frac{F_t + F_a}{2}\right)}{\tan\theta} = \frac{N(F_t + F_a)}{2\tan\theta}$$

We know that the maximum force will occur when the angle θ in **Fig. 5** is smallest, so we calculated this maximum force in order to translate this requirement such that it could guide our choice of motor.

Maximum Force at θ ≈ 0°:

$$\mathbf{F} = \frac{3(6.38N + 0.1962N)}{2\tan 10°} = \mathbf{55.943N}$$

To account for losses due to friction, we rounded this figure up to **<u>F = 70N</u>**

This series of computations shows that the amount of force required to extend a scissor linkage element carrying our target weight to our target extension distance is roughly **70N**.

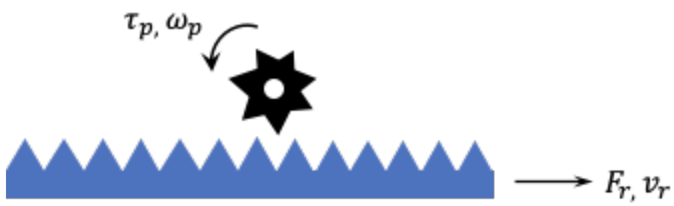


Fig. 9. Diagram showing force and torque relations in rack and pinion translation system.

Old screwdriver motor specifications (provided by Tony):
Operating voltage = 6V
ω_0 at 1.2V = 3560 RPM
τ_{stall} at 1.2V = 4.72mNm

Converting to 6V:
ω_0 = 3560 rev/min * 2π rad/rev x 1min/60sec x 5 = **1864.012 rad/sec**
τ_{stall} = 4.72mNm * 1Nm/1000mNm * 5 = **0.0236Nm**

These computations tell us that the **no-load speed** at 6V is **1864.012 rad/sec**, and the **stall torque** at 6V is **0.0236 Nm**. We can then determine the equation that defines the **motor torque-speed curve**:

τ_{stall} = 0.0236Nm
ω_0 = 1864.012 rad/sec
τ = bω + 0.0236

$$b = \frac{0.0236 - 0}{0 - 1864.012} = -1.266 \times 10^{-5}$$

τ = (-1.266E-5)ω + 0.0236
τ_{max} = $\tau_{stall}/2$ = 0.0236Nm/2 = **0.0118Nm**

Planetary gearbox ratio: **400:1**
τ_{stall} = 400* 0.0236Nm = 9.44Nm
ω_0 = 1864.012 rad/sec /400 = 4.66 rad/sec
τ = bω + 9.44

$$b = \frac{9.44 - 0}{0 - 4.66} = -2.0258$$

τ = -2.0258ω + 9.44
τ_{max} = 9.44Nm/2 = **4.72Nm**

For a 32DP pinion gear with 64 teeth:
D = N/DP = 64/32 = 2in -> **r** = 1in = **0.0254m**
τ_p = Fr = 70N * 0.0254m = **1.778Nm < τ_{max}**

Speed calculation:
τ_p = -2.0258ω + 9.44

$$\omega = \frac{1.778 - 9.44}{-2.0258} = 3.782 \text{ rad/sec}$$

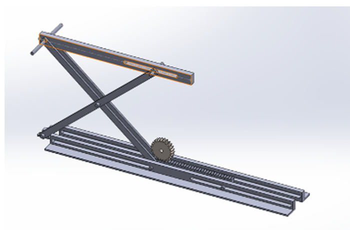
v_{rack} = ωr = 3.782 rad/sec * 0.0254m = 0.09606m/sec

$\mathbf{t_{rack}}$ = 0.04m * 1sec/0.09606m = **0.4 sec**

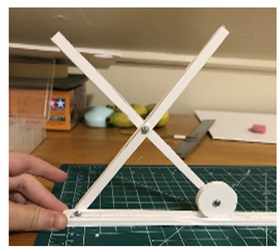
These computations reveal that coupling the screwdriver motor with a 32DP 64-teeth pinion gear allows us to both **a)** achieve our desired torque, and **b)** achieve full extension of the scissor linkage system in significantly less than our target time. In a future iteration, we would consider using a different gearbox and pinion gear combination, as the current combination provides significantly more torque and greater speed than is needed.

IVb. Modeling

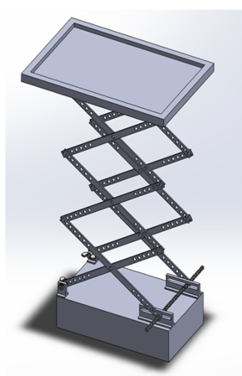
To ensure the range of motion for the scissor-fold mechanism, a preliminary Solidworks assembly was created to determine positioning of rack and pinion mechanism and the slots for the scissor-fold mechanism. Kinematics of the mechanism were also investigated using a foam-core model. Later, this design was revised for a three-layer scissor-fold mechanism. The evolution of the design is presented in **Fig. 10**.



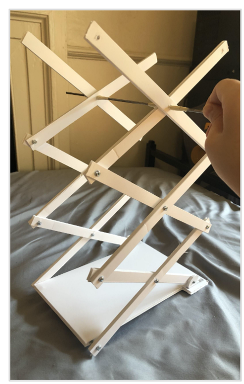
(a) CAD model of the first design iteration



(b) Foamcore model of the first design iteration



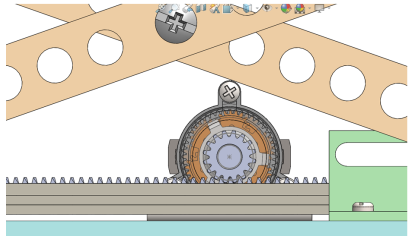
(c) CAD model of the second design iteration



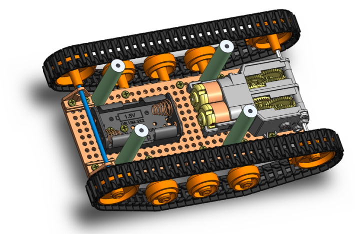
(d) Foamcore model of the second design iteration

Fig. 10. CAD and foam core modeling of different iterations of the robot design. These models were used to determine placement of other parts in the assembly and to check the kinematics of the design.

One source of concern with the final design was the position of the motor and gearbox assembly that power the rack and pinion assembly. The CAD model of the Tamiya kit gearbox was sourced from [10] and mated to the design assembly with different configurations to ensure enough space was available for the gearbox and the motor. A similar design decision was made with the CAD model of the completed Tamiya robot sourced from [11] and the placements of the spacers between the Tamiya base and the extended base plate (**Fig. 11**).



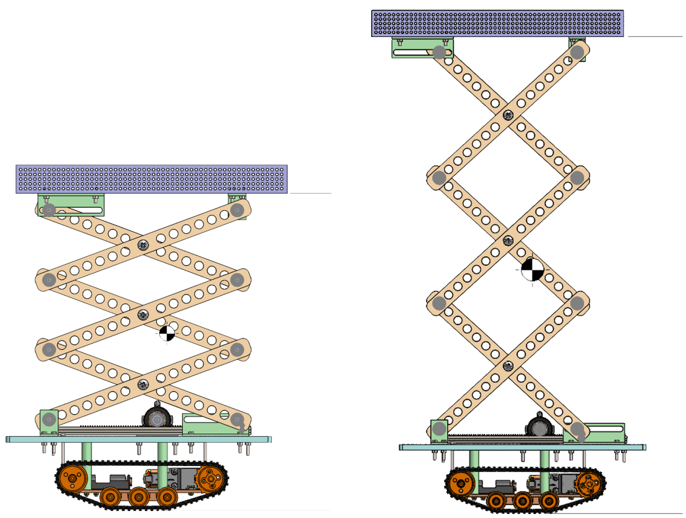
(a) Positioning the gearbox to prevent interference with the scissor-fold mechanism



(b) Positioning the spacers for attaching the Tamiya base to the extended base

Fig. 11. Positioning different parts of the assembly with the help of CAD models.

The center of mass feature of the Solidworks assembly was also employed to determine the positioning of the scissor-fold mechanism to minimize instability as seen in **Fig. 12**.

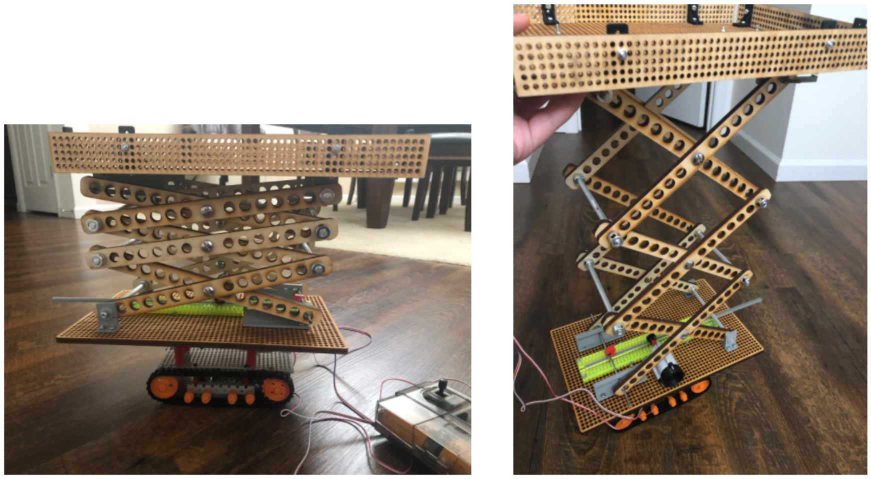


(a) Center of mass at minimum tray height (b) Center of mass at maximum tray height

Fig. 12. The CAD model of the final design was used to determine the position of the scissor-fold assembly relative to the extended base plate to minimize instability. Center of mass is indicated with the black and write filled circle. The design aimed to ensure the center of mass did not move beyond the contact area of the tracks at any configuration.

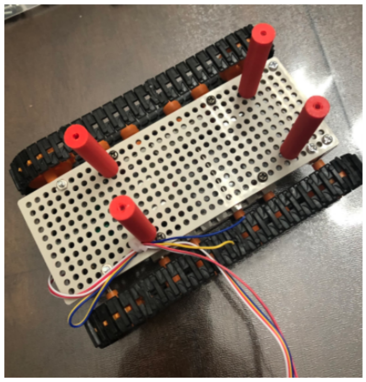
IVc. Robot fabrication and testing

The construction of the robot was a layer-by-layer procedure, stacking up to the final design. The completed prototype is as follows in **Fig. 13**:

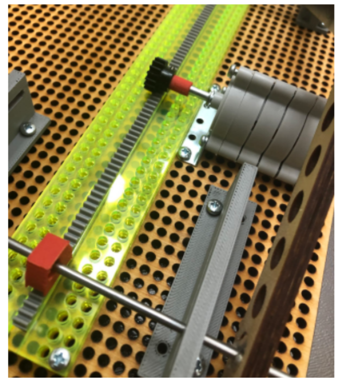


(a) Final prototype in its folded state (b) Final prototype in its unfolded state

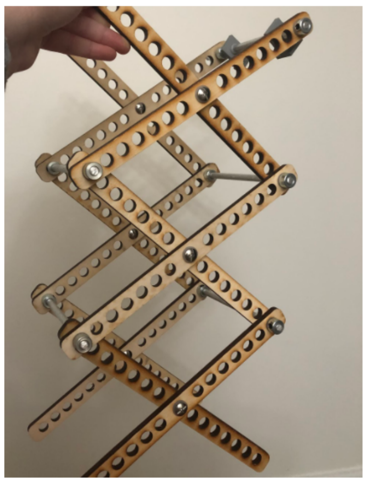
Fig. 13. Demonstration of the final design in its fully compressed and its fully extended forms
The design can be broken down into four main components, as expanded upon in **Fig. 14**.



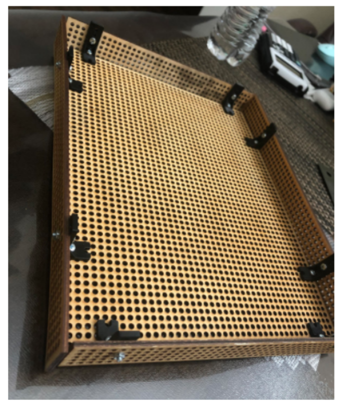
(a) Tamiya robot tread model base with custom spacers



(b) extended base plate containing rack and pinion



(c) scissor lift



(d) storage tray

Fig. 14. The four subcomponents of the final robot design, as deduced from the prototype

Although this method of subdivision enabled us to ensure the functionality of each individual element before contributing it to the end design (allowing for an ease of investigation when issues occured), it did result in frustrations when too much focus and pre-planning was placed on subcomponents rather than the overall system.

For instance, the weight of the scissor lift and its influence upon the direction of forces exerted created issues with slippage of the rack-shaft coupler, as discovered while testing the connection between the rack and pinion and its translation to the scissor arms. When folding up the lift from its expanded state, this small 3D printed piece would sometimes rise off its rails, resulting in disengagement with the rack. This would then require the user to manually snap the piece back into place, taking away from the autonomous nature of the robot. A suggestion for future iterations would be to bind the coupler to the rack or to introduce a parallel rack and pinion, distributing the amount of force pushing on a single region. The structural integrity of the coupler itself should also be reinforced to reduce the risk of stress-induced bending or snapping

Additionally, the majority of our focus was placed upon the operation of the scissor lift. Thus, we failed to fully consider the effect of the design's overall weight upon travel speed, one of the established technical specifications. As a result, it was discovered in the travel test (timing and maneuvering the robot over a set distance in order to calculate its driving speed) that the goal of 3 mph was missed by a large margin. The prototype required an average of 7.44 seconds to travel a distance of one foot, equating to a rate of about 0.092 mph. To improve this value, there should exist less dead weight in the design. Additionally, the motors powering the Tamiya base could be swapped to ones providing more power, or their gear ratios could be increased.

Despite this drawback, the technical specifications of tray size, height, and overall dimensions were all achieved. The final tray was 21.5 cm x 28 cm, resulting in an area of 602 cm^2, falling above the proposed 400 cm^2. The extended height of the scissor lift reached 55.30 cm, significantly above the established minimum of 40 cm. Finally, the overall length x width of the design (31.5 cm x 22 cm) equated to 693 cm^2, settling below the maximum area of 2000 cm^2.

Unfortunately, the specifications of carrying capacity and raising speed were unable to be tested experimentally due to non-functional motors.

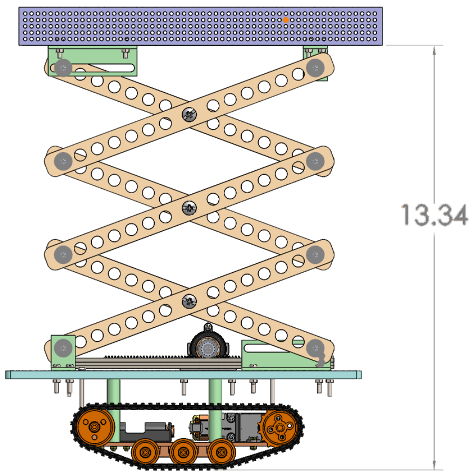
Another major issue encountered was an incorrect slot size of the 3D printed rail posts. The slot size was only ⅛" when it should have been ¼". This discrepancy was too significant to simply file down the difference. Thus, our team had to swap in a ⅛" steel rod (provided in the first supply shipment). However, this created a new issue: all of the holes in the scissor arms were suited for ¼" rods. After consultations, the best solution was determined to be for hot glue to be used to "plug" the necessary holes to their desired diameters. In a lab environment, this predicament could have been easily solved by 3D printing new rail posts with correct slot sizes.

Additional quick fixes for minor complications include substituting shaft collars for snap rings or e-clips to reduce weight and the possibility of loosening, swapping out the binding barrels for another mechanisms (they would often unscrew from the motion of the scissor arms' folding and unfolding), and reinforcing the corners of the trays and/or using T-slots so they properly align.

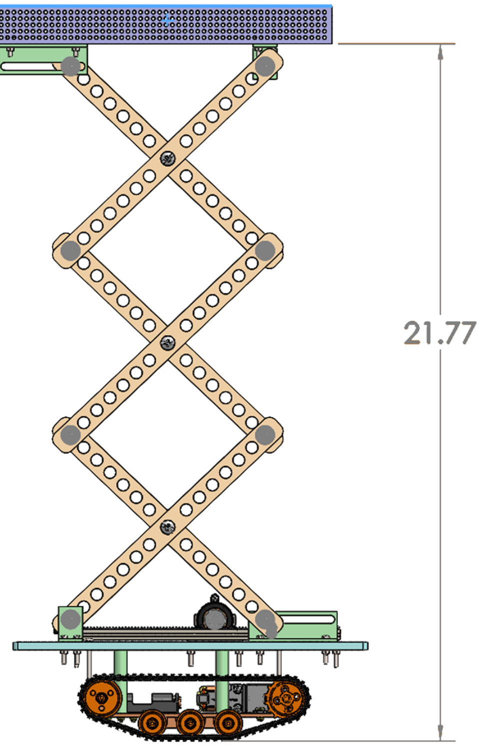
V. FINAL SOLUTION

On December 8, 2020, we pitched our robot prototype to a team of potential investors to explain our vision and outline our progress. We are proud of the work that we presented and we felt that we delivered a crisp and compelling summary of our process and our final result. In the following paragraphs, we provide additional detail on the final outcome of our design challenge.

The finalized design focuses on the primary functionality of the robot - a remote-controlled tray for snacks that can move up and down. When fully lowered, the tray has a height of 13.34 inches, and can rise up to a height of 21.77 inches, as seen in **Fig. 15**.



(a) Minimum tray height



(b) Maximum tray height

Fig. 15. The minimum and maximum height configurations of the robot. Units are in inches.

The motion is controlled by one channel of the Tamiya remote controller. Alongside the tray's motion, the same remote controller enables the robot to move across the floor with the built-in Tamiya robot functionality, as described in **Fig. 16**.

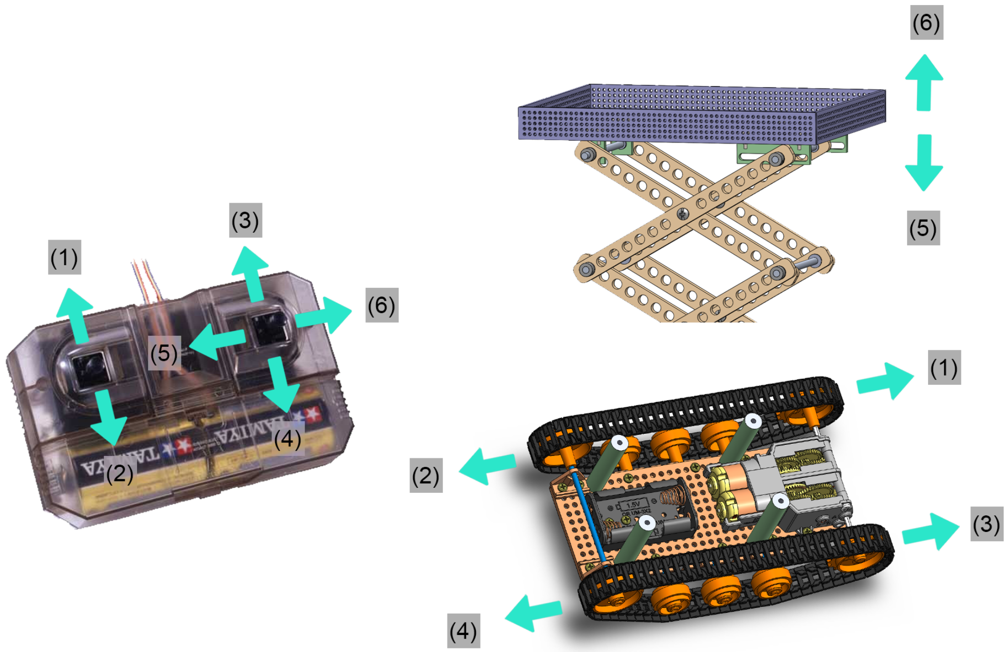
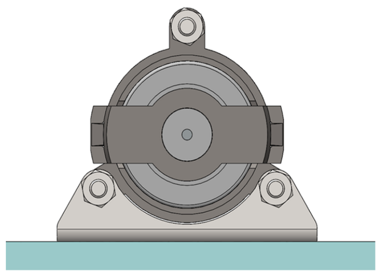


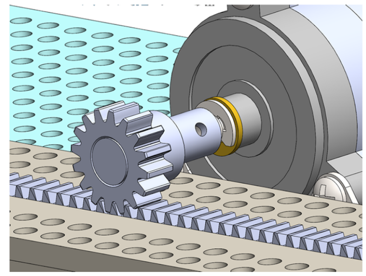
Fig. 16. The controls for the robot using the Tamiya remote controller. Corresponding numbering shows how different channels of the remote controller drive different parts of the robot.

The locomotion of the robot is described in the instructions for the Tamiya kit. Briefly, one channel of the remote sends power to rotate one of the tracks. When both tracks are instructed to rotate in the same direction, the robot moves in one direction. Steering is achieved by sending power to rotate only one track or both tracks in opposite directions.

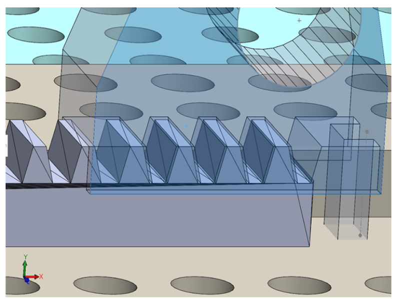
The vertical motion of the tray starts from the power from the third channel of the remote controller. The power is delivered to the motor on top of the extended base, which spins its output shaft. The planetary gearbox gears down the output from the motor and rotates the pinion gear coupled to its output shaft. The pinion gear is meshed with a rack that is positioned on top of greased acrylic laser-cut pieces that act as rails. The pinion gear's rotation is transformed into linear motion of the rack. The rack's motion is coupled with the motion of the bottom shaft of the scissor-fold with the rack-shaft coupler piece. When the rack moves, the shaft moves in its slot, which pushes the arms of the scissor-fold mechanism together. The scissor-fold mechanism gets narrower and taller. As a result, the tray on top of the scissor-fold rises. The same process occurs in the opposite direction (of the motor's rotation) to lower the tray. This process is summarized in **Fig. 17**.



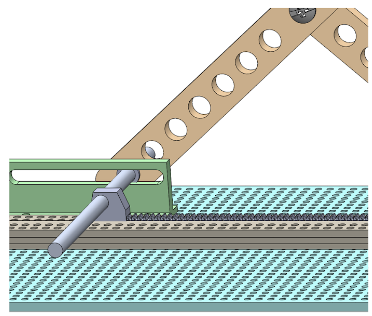
(a) Power is sent to the motor, causing it to spin its output shaft attached to the gearbox.



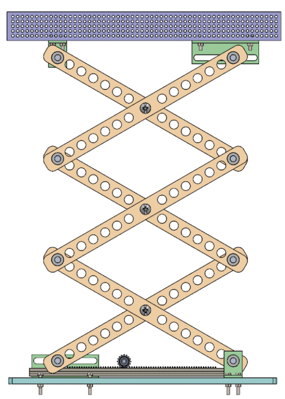
(b) The gearbox gears down the rotation and turns the pinion gear, which moves the rack.



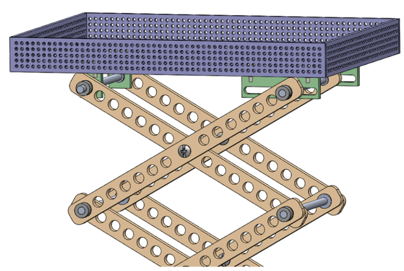
(c) Rack motion is coupled to scissor arm shaft with the rack-shaft coupler, seen here.



(d) Due to the rack, the shaft slides in its slot, moving the scissor-fold arms together.



(e) The scissor-fold mechanism narrows and gets taller as a result.



(f) The tray, attached to the top of the scissor-fold, rises.

Fig. 17. The mechanism powering the vertical motion of the tray.

This final solution meets the criteria outlined in **Table 3**, with an emphasis placed upon the extended height of the robot: 21.77 inches, one of our main goals in order to ensure the utmostly convenient usage of the product. Another change which enhances this aspect is the conjoinment of the two previously separated remote controls: one for driving the robot and another for raising and lowering the scissor lift. Rather than requiring to switch between RCs to perform two separate actions, only one remote would be necessary to fully operate the robot.

As a whole, the advantages of our robot design include its compact nature, food storage space, and ease of operation. Some rooms for improvement are the scissor lift mechanism (perfecting it and reducing instability), the design for the rack-shaft coupler, and ensuring the top-heavy build does not topple, especially with an increased carrying load.

The next manufacturing iteration of this design would recreate the rack-shaft coupler and spacers in Al through milling to increase durability and control over tolerances. It would use smaller rods in the scissor-fold mechanism to reduce weight and lower the center of mass. Additionally, these rods would be machined with grooves to use snap rings instead of shaft collars for axial alignment.

Furthermore, in the time period after ordering the parts and after assembling the robot and testing in real life, we have arrived at many other ideas for improving our robot design.

First, instead of using an off-the-shelf rack and coupling its motion with the scissor-fold shaft's motion with another piece, we can machine a rack out of Al and design it to directly attach to the scissor-fold shaft. We can also manufacture a housing over this custom rack to prevent it from moving up. This design reduces the number of manufactured and moving parts and solves the problem of rack-shaft coupler rotating and losing contact with the rack.

Second, we can make the scissor-fold mechanism to move at both hands. While this design slightly increases complexity and the number of moving parts, the symmetry it provides improves balance. It also has the potential to double the tray raising speed.

Third, we can add caster wheels to the corners of the extended base to increase the area of support, hence make the robot significantly less likely to topple over if the tray is loaded unevenly.

Fourth, we can combine the stagnant and the rail posts of the scissor-fold mechanism to decrease the number of manufactured parts and increase their rigidity, as we observed them to crack under high loads. However, we note that this change would also add to the load carried by the scissor-fold mechanism.

Additionally, we hope to reintroduce the secondary functionalities of our robot in a next iteration. We hope to provide methods for the robot to socially interact with its user(s) and provide incentives for healthy snacking. We also aim to reintroduce the heating-cooling functionality of the tray by making use of the more powerful motor that we have been allocated.

VI. FINAL DESIGN SPECIFICATIONS

TABLE 3
TECHNICAL SPECIFICATIONS REVISITED

Specifications	***Experimental Values***	***Achieved?***
Carrying Capacity Minimum: 650 grams	---	N/A
Tray Dimensions Minimum: 400 cm^2	21.5 cm x 28 cm = <u>602 cm^2</u>	Yes
Travel Speed Minimum: 3 mph	1 ft / 7.44 sec = <u>0.092 mph</u>	No
Raising Speed Minimum: 3 mph	---	N/A

Extended Height Minimum: 40 cm	55.30 cm	Yes
Overall Dimensions Maximum: 2000 cm^2	31.5 cm x 22 cm = 693 cm^2	Yes

It is important to note that, due to issues with motor functionality in the prototype, the final design was unable to be tested in its entirety. However, the technical specification for carrying capacity, 650 grams, was the value used within torque calculations to select a viable motor option and pinion gear size. Therefore, carrying capacity's theoretical value achieves the established specifications, despite its experimental value being unable to be determined. Additionally, our proposal to introduce a parallel rack and pinion so that the scissor-fold mechanism raises from both ends of the X would further guarantee the achievement of our designated minimum carrying capacity and raising speed.

VII CONCLUSION

The foundation of our design process began by focusing upon the unique perspective that us three as college students hold: personal and relevant experience with the issue at hand. Thus, we were well equipped to compile hindrances to healthy eating and develop a list of technical specifications which would address such roadblocks. With these quantitative goals and constraints in mind, the process proceeded into its brainstorm phase. Each member was encouraged to develop three unique ideas without worrying too much about feasibility. Out of these nine options, three were chosen to be evaluated within a pugh matrix. The scissor lift design won and moved on into further research and development, a process which involved 3D and foam core modeling, physics calculations, and several consultations. Finally, a prototype was constructed (both physically and via computer-aided design) and tested, noting rooms for improvement, before being presented in front of a panel. If we were to continue onward with the design process, further iterations of the robot would be produced, and the prototype-evaluate-revise cycle would repeat.

From this process, our team took away several lessons. For hard skills, we gained extensive knowledge and experience through working with SolidWorks and calculating for torque and motor specs. We grew familiar with the design process and learned how to effectively present ideas and improve from criticism. Additionally, we refined our soft skills by facing and overcoming the challenges associated with a semester of online coursework and collaboration: spotty internet connections, major time zone differences, and, of course, the joys of BootCamp. In fact, the need for effective communication became that much more significant because of the online environment. In this aspect, we learned of the power of pictures and videos and live demos.
Next time, given looser time constraints, it would be beneficial for us to spend more time in the design development phase, as well as conduct a greater number of prototype iterations and testing. In addition, the selection of customary versus metric units should be established from the start to prevent any future opportunities for confusion.

Above all, by cultivating an environment where people feel comfortable with speaking up, the design process directly benefits from the wealth of diverse experiences and specialities offered.

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