University of Toronto

Faculty of Applied Science and Engineering

APS111 & APS113

Conceptual Design Specifications (CDS)

Team #	121	Date	November 29th, 2021

Tutorial Section	0121
Teaching Assistant	Najah Hassan
Prepared By (Names and Student #s of Team Members)	• Matthew Grech (1007997544) • Cameron Whitefield (1008026280) • Erie Wu (1007997571) • Tanya Rustogi (1007828665) • Joyce Chen (1007954590) • Safiyyah Atcha (1007954242)

Please check off which components you are submitting for your assignment.

_x_ CDS submitted as a PDF to Quercus with the following components:

_x_ Cover Page
_x_ Executive Summary
_x_ Introduction
_x_ Problem Statement
_x_ Service Environment
_x_ Stakeholders
_x_ Detailed Requirements (FOCs)
_x_ Alternative Designs
_x_ Proposed Conceptual Design
_x_ Measures of Success
_x_ Conclusion
_x_ Reference list
_x_ Appendices

__ Attribution table with ALL team members' signatures submitted as a PDF to Quercus. An incomplete or missing attribution table will result in zero on the assignment for the team.

Executive Summary

The client of this project is a Toronto-based startup named “Tiny Mile”, which provides an affordable food delivery service for local restaurants using a remotely operated robot named “Geoffrey”. The company is looking for an improved design of Geoffrey that enhances the delivery experience for the restaurant staff and customers.

Based on the company’s client statement, it is clear that a major gap in their current design is that the customer needs to bend down to Geoffrey's height to get the food, which can be uncomfortable and challenging. As such, there is a need for a design that will facilitate the handoff in a way that demands minimal physical effort from the customer. The scope of this project will encompass a mechanism that brings the food to within arm’s reach of the customer.

Geoffrey will mainly function near the entrance of residential buildings, as this will be the site where the unloading of the food takes place. Hence, the design will need to consider the physical, technological, and human elements of this environment. This includes the need for the design to be effective in a variety of weather conditions. Geoffrey must withstand temperatures -7ºC and 28ºC, rainfall of 55mm accumulating on the ground and 90mm of snow accumulating on the ground, and wind speeds up to 23km/h.

The stakeholders which Geoffrey’s design may affect include City of Toronto’s Pedestrian Safety Committee, Health Canada, and the Accessibility for Ontarians with Disabilities Act. The potential effects of the design on these stakeholders have been identified and taken into account.

The team has developed a list of functions, objectives and constraints for the design. The functions are what the design will do to address the problem identified. The primary function of the design is to present the food to the customer without requiring them to bend down. The objectives are goals that the design aims to achieve, which will be used to measure the success of the design. These include reaching a height of 115cm, costing less than $3750, and being able to lift at least 7kg of cargo. The project constraints are the absolute requirements and limits for the design. These include keeping Geoffrey's current durability statistics (withstand 55mm of rain, 90mm of snow, etc.), keeping the cost below $5000 (twice that of the original design), and reaching a height of at least 75cm.

A variety of strategies such as free brainstorming, SCAMPER, analogy, and the morphological chart were used to come up with a list of 65 unique ideas. The three most suitable designs were then chosen through the alternative design selection process, which includes feasibility checks, multivoting, and the graphical decision chart.

The team prepared 3 alternative designs to consider: an inflatable mattress, a pneumatic lifting cylinder and a scissor lift. Using the Pugh Matrix, the scissor lift was chosen as the proposed conceptual design. The design addresses the problem while satisfying all constraints and meeting the objectives of cost, stability, lightweight, height reachable and durability. The scissor lift utilizes a pneumatically powered mechanism to raise the food from the base of Geoffrey’s cargo bay to a height of 124cm above the ground.

In addition to the proposed design, the team has developed testing methods that can be used as measures of success to ensure the design is capable of meeting its objectives. This report will be submitted for review on November 29th, 2021.

1.0 Introduction
Tiny Mile is a startup that offers affordable food delivery for restaurants in downtown Toronto through the use of remotely-controlled delivery robots [1]. These robots can deliver within 2 km of the client restaurant [1]. Upon the robot's arrival at the client restaurant, the staff loads the food into the cargo bay of the robot, which then travels to the customer's location [1]. Once the robot arrives, the customer shows their order number to the cameras before the remote operator unlocks the cargo bay, allowing the customer to retrieve the food [2].

The robots are still undergoing development, and the company is looking for new designs that will improve the delivery experience for the restaurants and customers, which will be the focus of this design project [1].

This document first outlines the service environment in which the new design will operate, analyses multiple perspectives of the stakeholders, and describes a list of detailed requirements [1]. Next, it presents three proposed alternative designs that were created using a variety of idea generation and selection methods, which are outlined. Finally, the measures of success that will be used to judge the performance of the selected design are described.

2.0 Problem Statement
Geoffrey's current method of unloading food demands physical effort from the customer. As seen in the right side of Figure 1.0, the lid of the cargo bay opens from the top and the customer must bend down to retrieve their food. With the average Canadian adult standing at a height of 66.5 inches [3] and Geoffrey being 21.5 inches tall [4], reaching 45 inches down can be uncomfortable for the customers, especially for those with physical disabilities [5]. As such, Geoffrey needs an unloading mechanism that delivers the food to customers without them physically straining their body. This will ensure an ergonomic handoff for customers with accessibility issues who may have difficulties reaching for the food, like those in wheelchairs and those with back injuries [6][7]. The scope of the project will encompass an unloading mechanism that will deliver food within arm's reach of the customer.

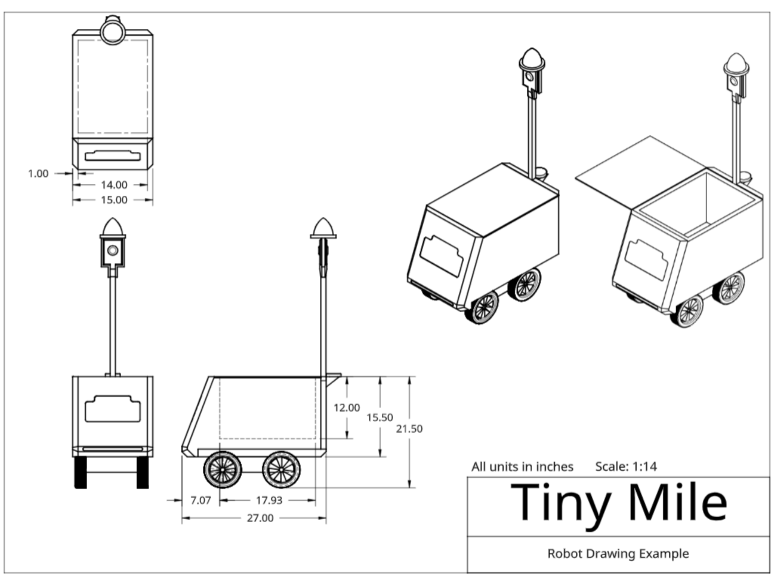


Figure 1. Measurements of Geoffrey's dimensions. [4].

.3.0 Service Environment

This section outlines the physical, technological, and human conditions of the environment in which Geoffrey would navigate. The physical conditions constitute the natural elements of the environment without the influence of human and technological behaviour; the technological conditions are the effect that external technological devices have on the service environment; human conditions are the influence that *people* have on the service environment. Geoffrey's service environment in the scope of unloading will be confined to entrances of buildings in the downtown core of Toronto

Table 1: Aspects of the Service Environment

Physical	The annual temperature reaches a minimal average monthly temperature of -7ºC in January and a maximum of 28ºC in July. [8] The average annual precipitation per month is 69.25mm; the lowest average is 53.0mm in March; the highest is 85.0mm in September. [9] The average annual wind speed ranges from 11.7km/h in July to 19.5km/h in January. [10] Average annual accumulation of snow is roughly 122cm. The highest snowfall month is January which accumulates roughly 37cm. [11][12] Minimum elevation (measured above sea level) of 79m (closest to the shore) and a maximum elevation of 149m (northern boundary of the downtown area). [13]
Technological	There are roughly 1000 cellular towers in Toronto's downtown core, [14] each emitting a range of 700-2600MHz frequencies. [15] WiFi and Bluetooth signals typically carry a frequency range of 2.4-5GHz. [16][17]
Human	Pedestrian traffic at busiest intersections regularly reaches over 80000 people, counted in a 24 hour time frame [18] (see Appendix A). Domestic animals and children may interfere with unloading systems. Operators may pull/pry at the system, damaging brackets, joints, arms, etc. Additional risk of theft.

4.0 Stakeholders

The stakeholders of the project outline all parties interested in the design who may be positively or negatively impacted by its implementation [19]. The stakeholders have been ranked by priority in accordance with the pairwise comparison method (Appendix B).

Table 2: Impact of Design on Stakeholders

Stakeholder	Impact of Design
City of Toronto's Pedestrian Safety Committee	● Design might obstruct pedestrian pathways due to 15 inch width [4]; pedestrians can be injured due to the lack of a direct and continuous clearways, as the width of the average pathway in Toronto is approximately 71 inches [20].
Health Canada	● Design might negatively impact the food handling process; if not in accordance with COVID-19 Safety Guidelines as per Health Canada, the container can be a vector of transmission [21]. ● Design might be a hazardous form of food delivery if the manufacturing of the container does not comply with the Canada Consumer Product Safety Act as per Health Canada [22].
Accessibility for Ontarians with Disabilities Act (AODA)	● Design might positively impact different accessibility groups by broadening accessibilities standards; customers will not have to reach down to grab their food [23]

5.0 Detailed Requirements

The following section details the requirements the design must fulfill, and the criteria for evaluating the success of the design.

5.1 Functions

The functions are the actions the design must be able to perform. They were determined using the functional basis method (Appendix D).

Table 3: Primary and secondary functions

Primary functions	Secondary functions
Present food to customer without needing them to bend down.	Raise food to the height of the customer's arms.
	Return to initial state, allowing cargo bay to close.

5.2 Objectives

The objectives determine how well the design meets the client's requirements and are used to compare potential designs. They are listed in order of decreasing importance using pairwise comparison (Appendix C).

Table 4: Objectives

Objective	Goal	Metric
Stability During Unloading	Unload the cargo without dropping food or drinks.	Maximum angle off horizontal reached during unloading

Height Reachable	Reach a height of 115 cm. The tallest person in Toronto is ~190cm [3], the design should reach roughly ⅔ of that height.	Maximum height reachable with unloading mechanism (cm)
Durability	Lift up to 7 kg. Geoffrey's current cargo limit is 5kg [2].	Maximum weight (kg) of cargo supportable.
Light-weight	Mass of the design itself should be less than 15kg [45]	Mass (kg) of design.
Inexpensive	Maximum cost < $3750	Cost to build design($)

5.3 Constraints

Constraints are the standards which the design must meet in order to be implemented. The constraints for this design are listed below in Table 5 and are based on concerns expressed by the client regarding limitations and safety [1]. The design must also follow government regulations and Health Canada COVID-19 safety protocol [20].

Table 5: Constraints

Constraint	**Limit**	**Metric**
The design must be inexpensive	• The new design must not be double the cost of the original design(<5000$) [1]	CAD ($)
The design must be safe	• Must not present any risk of a COVID-19 infection (contactless handoff of food) [1] [20] • Must not cause bodily harm to customers [1]	Incident reports, public health [24],
The design must be realistic	• Must only use existing technology and materials [1]	Materials required are real and attainable
The design must be able to reach a reasonable height	• The design must be able to get the food to a height of at least 75cm above-ground	Maximum height reached(cm)
The design must be durable	• Must operate in the following weather conditions [2] ○ 55mm rainfall ○ 90mm of snow ○ Withstand wind speed of 23km/h • Must support 5kg of cargo [2]	Testing design in heavy rain and quantitative wind speeds. Weight of food (kg).

6.0 Alternative Design Generation, Selection and Description

This section encapsulates the methods used for idea generation, how the three alternative designs were chosen, and breakdowns of the alternative designs.

6.1 Idea Generation Process

The idea generation process began with structured independent brainstorming, where each team member came up with a list of at least ten ideas each. The ideas were compiled onto a document, and from there the team continued to brainstorm ideas with no limit on their feasibility. During this idea generation session, methods such as analogy, SCAMPER and a morphological chart (Appendices E, F, G, H) were used to find analogous designs from other technology and to combine existing ideas.

6.2 Alternative Design Selection Process

There were four stages to the alternative design selection process. First, the idea list was consolidated by removing duplicates. Next, feasibility checks were performed to eliminate ideas that were unrealistic or incapable of satisfying the constraints. The list of feasible ideas were cut down through multivoting, where each team member voted for their top ten ideas. All ideas with three or more votes were kept, the ones with two votes were chosen through discussion and those with one or less votes were removed. Finally, the remaining list of ten ideas were narrowed down to three with a graphical decision chart. The entire process is documented in Appendices G-M.

6.3.0 Alternative Designs

This section outlines the final three ideas that were chosen via the alternative design selection process. All fulfill the primary function of presenting food to the customer without needing them to bend down, but vary in the extent to which they meet the objectives.

6.3.1 Scissor Lift

The first design, the scissor lift, is a mechanism that can effectively lift heavy objects to a desired height. The dimensions of the design are specified in Figure 2. The loading deck at the top of the lift is where the food will be placed, and is designed to fit within the cargo bay along with the rest of the scissor lift. The scissor lift fulfills the primary function by retracting the two pneumatic cylinders at its base, raising the loading deck to a maximum height of 127cm off the ground*, where the customer can comfortably retrieve their food. The cylinders are then extended to lower the loading deck and return the lift to its retracted state, fulfilling the secondary functions. The design satisfies all constraints and attempts to meet all objectives. Table 6 outlines the ways in which these constraints are satisfied along with the extent to which objectives are met.

*24cm ground to base of cargo bay[4] + 103cm base of cargo bay to top of loading deck(figure 2)

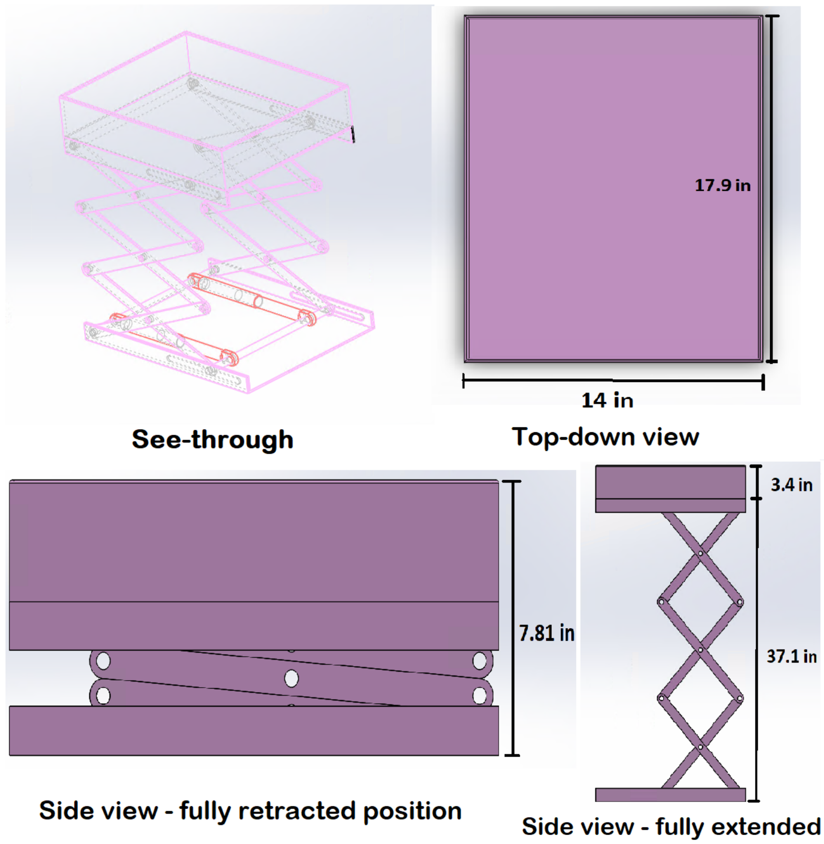


Figure 2: Dimensions and visuals of scissor lift design. Link to CAD file: https://grabcad.com/library/cad-for-scissor-lift-1

Table 6: How the Design meets Objectives/Constraints

Objective	**How Design Attempts to Meet Objective**	**Constraint**	**How Design Satisfies Constraint**
Cost	• Implementation of design increases total cost by $800 ~ $1200, making the total cost <3750) [25]	Cost	• Total cost < $5000
Stability During Unloading	• The loading deck is flat and even throughout the unloading process, preventing spillage of food. (Maximum angle of 0 degrees off horizontal)	Customer Safety	• Customers retrieve their food without touching the lift itself
Lightweight	• The mass of the lift is estimated by Solidworks to be 8.66kg. A safe overestimate(~13kg) would still meet the goal(<15kg)	Materials	• Design uses existing and easily attainable materials (Al3003 for frame and base components, pneumatic parts can vary with manufacturers)

Height Reachable	● Capable of reaching 127cm off the ground	Height reachable	● Capable of reaching 127cm off the ground
Durability	● Design can easily lift more than 7kg	Durability	● Design can easily lift more than 5 kg ● Rigid structure resistant to harsh weather conditions

6.3.2 Inflatable Mattress

The design consists of an air-sealed, PVC (polyvinyl-chloride), inflatable ‘mattress’ which, uninflated, exists as a compact structure located at the base of Geoffrey’s cargo bay. The ‘mattress’ after being inflated to capacity has dimensions of about 40cm by 30cm at the base (shown in Figure 3) and would reach a height of 90cm(this is enough to reach a height of 115cm from the ground). The mattress rapidly inflates using a compact air pump located underneath the ‘mattress’ and is also surrounded by an ‘accordion bellow’ shape made of a hard, lightweight polymer(polyethylene, PE preferably) to prevent damage to the PVC. On the top of the mattress is a one inch-thick, light-weight wooden platform on which the food is placed. Table 7 outlines the ways in which these constraints are satisfied and the extent to which objectives are met.

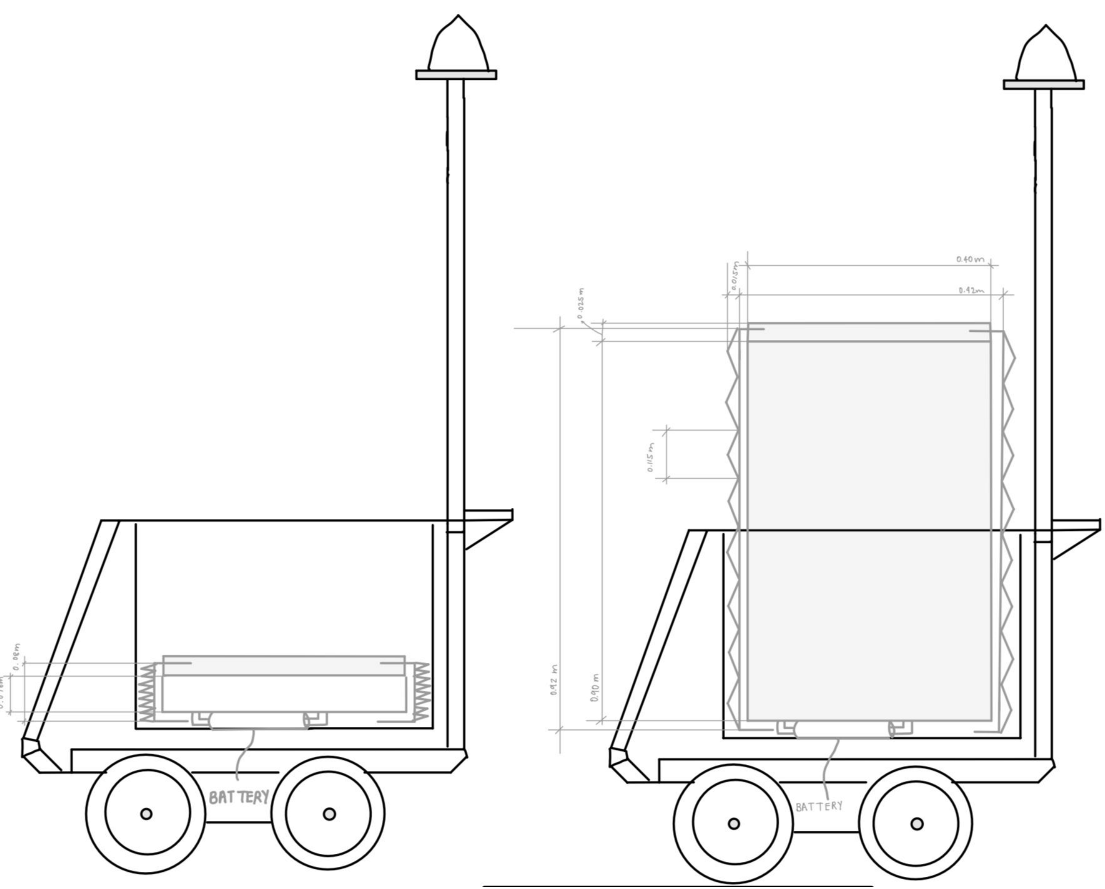


Figure 3: Conceptual sketch of the inflatable mattress

Table 7: How Design meets Objectives/Constraints

Objective	How Design Attempts to Meet Objective	Constraint	How Design Satisfies Constraint
Cost	● Total price of parts: ~$350 (+Ebike battery if required; $500-1000) [26-30]	Cost	● Total cost < $5000
Stability During Unloading	● Inflation time (assuming no load) is ~18.3 seconds. ● Food lifts at an average speed of 4.9cm/s (see Appendix N) [27]	Customer Safety	● Lack of mechanical parts prevents pinching of skin on hinges ● Customer retrieve their food without touching the mattress itself
Light-weight	● Total weight: ~12kg [31][28]	Materials	● Materials exist and easily attainable
Height Reachable	● The mattress reaches a height of ~115cm above the ground [4]	Height Reachable	● Meets the 75cm constraint
Durability	● Mattress is able to support ~272kg of mass [27]	Durability	● The design can support over 5kg of load ● Structure resistant to harsh weather-conditions

6.3.3 Pneumatic Lifting Cylinder

This design utilizes a pneumatic lift cylinder shock piston to lift a food tray. A drawing of the design is provided in Figure 4. A piston rod in the gas cylinder can move vertically due to pressure from compressed nitrogen gas [32-35]. A closed lever applies no force to the button at the end of the piston, thus preventing movement [33]. When the lever is opened, the button unlocks the piston and allows it to be moved by the compressed gas [33]. While the lever is open, the tray can be lowered when the winch and cable attached to the tray applies a downwards force greater than the pressure from the compressed gas. Hence, the functions are satisfied. An attachment plate will be used to secure the lever, tray and gas lift cylinder together. The design will reach a maximum height of approximately 80.63cm from the ground (Appendix O). Table 8 describes how this design meets the objectives and constraints.

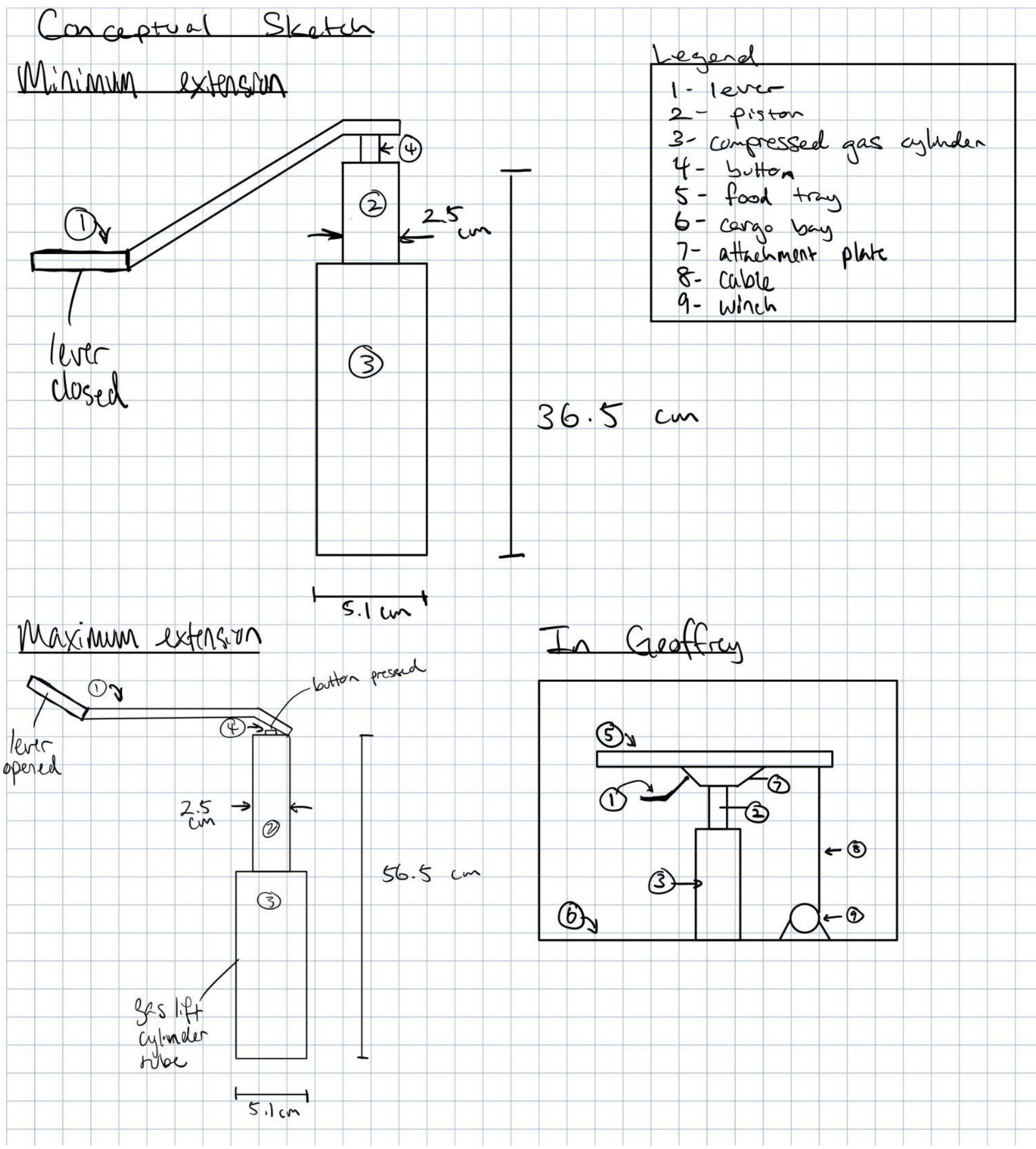


Figure 4. Conceptual drawing of the pneumatic height adjustment mechanism.

Table 8: How Design meets Objectives/Constraints (Appendix O)

Objective	How Design Attempts to Meet Objective	Constraint	How Design Satisfies Constraint
Cost	• Estimated total cost: $133.00 [36-39]	Cost	• Total cost < $5000

Stability During Unloading	• Food tray will be a level surface during unloading to prevent spillage. • Well-oiled parts ensure smooth ascent and descent [34].	Customer safety	• Customers can remove their food without physically touching the mechanism.
Lightweight	• The mass of the design is approximately 1.38kg [38-40].	Materials	• Only existing materials are used (e.g. steel cylinder with compressed gaseous nitrogen)
Height reachable	• The tray can be lifted to 80.63cm from the ground [4][38].	Height reachable	• Capable of reaching a height of 80.63cm relative to the ground.
Durability	• Design can support approximately 204kg of weight [38].	Durability	• Design can easily support 5 kg of weight • Structure counteracts harsh weather-conditions

7.0 Proposed Conceptual Design

Through the multi-step design selection process, including the Pugh decision matrix (Appendix M), the scissor lift design was determined to be the best solution to address the gap and fulfill the client's needs. It does so by raising food packages to within arm's reach of the customer, where they can be retrieved with minimal effort. The scissor lift satisfies every constraint and meets the objectives more extensively than the alternatives. While the scissor lift is the heaviest of the designs, it significantly outperforms the rest in regards to more important objectives, such as maximum height achievable and stability during unloading. As detailed in previous sections, the scissor lift achieves a maximum height of 127cm, superior to the pneumatic height adjustment mechanism (~80cm) and the inflatable mattress (~115cm). Moreover, the scissor lift includes a 3.4in barrier around the loading deck to prevent food from being knocked off during unloading by external circumstances (e.g. outside collisions, inclement weather, etc). The lift is pneumatically powered, and the smooth extension of its support rods facilitates the stable ascension of the loading deck. The scissor lift mechanism itself will cost between $800 and $1200, ensuring the total cost of the robot will not exceed 1.5x the original cost of $2500. Also, the design is compact and fits entirely within Geoffrey's current cargo bay design.

8.0 Measures of Success

This section describes the tests the team will perform to measure the performance of the proposed conceptual design.

To test the stability of the design, the maximum angle off the horizontal throughout the unloading process will be measured. An estimation for this angle can be achieved through recording videos of the lift in action and then analyzing it frame by frame to determine the maximum slant. Refining the stability of the design is crucial to a safe delivery.

To test the durability of the design, simulations will be run on the SolidWorks model to test the maximum supportable load. An estimation for the maximum load will be derived from the material properties of the materials being used(e.g. stress-strain data for Al 3003) and calculations performed based on these values and the geometry of the design. This will ensure customer safety and the design's efficacy.

9.0 Conclusion

The project goal is creating a design that enables Geoffrey to deliver food to within arm's reach of the customer. A diverse solution space was generated through the extensive use of brainstorming methods, and the three most optimal designs were identified through feasibility checks, multi-voting, and a graphical decision chart. These were selected as the alternative designs, which were then individually refined. Using a Pugh Matrix (Appendix M), the design that best fit the objectives and constraints was determined to be the scissor lift. Measures of success for judging the performance of the design were described in detail. This report will be submitted by November 29, 2021 for review.

10.0 Reference List

[1] Engineering Strategies and Practice, “Client Statement: Design the Future of Home Delivery,” 2021. [Online]. Available: https://q.utoronto.ca/courses/238537/pages/client-statement?module_item_id=2926941. [Accessed: Oct. 19, 2021.]

[2] Tiny Mile, *Tiny Mile*, 2021. [Online]. Available: https://tinymile.ai./ [Accessed Oct. 20, 2021].

[3] CBC News, “Canadians still getting taller, but not as fast as others,” *CBC*, Jul. 26, 2016. [Online]. Available: https://www.cbc.ca/news/health/height-growth-canada-1.3695398. [Accessed: Oct. 18, 2021.]

[4] Tiny Mile, *Robot Drawing Model*. 2021.

[5] Centers for Disease Control and Prevention, “Disability and Health Disability Barriers,” *Centers for Disease Control and Prevention*, 04-Sep-2019. [Online]. Available: https://www.cdc.gov/ncbddd/disabilityandhealth/disability-barriers.html. [Accessed: Nov. 28, 2021]

[6] N. Prieto, “Home delivery services improve accessibility of food, medications, and medical care for people with transportation issues,” *Assistive Technology at Easter Seals Crossroads*, Oct. 01, 2014. https://www.eastersealstech.com/2014/10/01/delivery-services-improve-accessibility-food-medications-medical-care-people-transportation-issues/. [Accessed Oct. 18, 2021].

[7] Americans with Disabilities Act National Network, “Food Service: Accommodating Diners with Disabilities,” *ADA National Network*, 2017. https://adata.org/factsheet/food-service. [Accessed Oct. 18, 2021].

[8] “Toronto temperatures: Averages by month,” *Toronto ON Average Temperatures by Month*, 2019. [Online]. Available: https://www.currentresults.com/Weather/Canada/Ontario/Places/toronto-temperatures-by-month-average.php. [Accessed: Oct. 19, 2021].

[9] “Average monthly rainfall and Snow in Toronto (Ontario), Canada (millimeter),” *World Weather & Climate Information*, Jan. 24, 2021. [Online]. Available: https://weather-and-climate.com/average-monthly-precipitation-Rainfall,toronto,Canada. [Accessed: Oct. 20, 2021].

[10] “Toronto, Canada - detailed climate information and monthly weather forecast,” *Weather Atlas*, Aug. 23, 2021. [Online]. Available: https://www.weather-atlas.com/en/canada/toronto-climate#wind. [Accessed: Oct. 15, 2021].

[11] “Toronto snowfall totals & accumulation averages,” *Toronto ON Snowfall Totals & Snow Accumulation Averages*, Jan. 2021. [Online]. Available: https://www.currentresults.com/Weather/Canada/Ontario/Places/toronto-snowfall-totals-snow-accumulation-averages.php. [Accessed: Oct. 22, 2021].

[12] City of Toronto, “When/how we clear snow & ice,” *City of Toronto*, Jan. 28, 2021. [Online]. Available: https://www.toronto.ca/services-payments/streets-parking-transportation/road-maintenance/winter-maintenance/levels-of-snow-clearing-service/. [Accessed: Oct. 15, 2021].

[13] “Toronto topographic map, elevation, relief,” *Topographic Map*. [Online]. Available: https://en-ca.topographic-map.com/maps/q4v/Toronto/. [Accessed: Oct. 20, 2021].

[14] D. Flack, “How many cellular towers are there in Toronto?,” *blogTO*, Dec. 23, 2010. [Online]. Available: https://www.blogto.com/city/2010/12/how_many_cellular_towers_are_there_in_toronto/. [Accessed: Oct. 23, 2021].

[15] “What are 4G LTE frequencies & bands of telus, Rogers, Bell?,” *SignalBooster.com*, 2021. [Online]. Available: https://www.signalbooster.com/pages/what-are-4g-lte-frequencies-bands-of-telus-rogers-bell. [Accessed: Oct. 20, 2021].

[16] S. Albano, “WIFI frequency bands,” *Minim*, Apr. 1, 2019. [Online]. Available: https://www.minim.com/blog/wifi-frequency-bands-2.4-ghz-and-5-ghz. [Accessed: Oct. 15, 2021].

[17] J. Herman, “Why everything wireless is 2.4 GHz,” *Wired*, Sep. 7, 2010. [Online]. Available: https://www.wired.com/2010/09/wireless-explainer/. [Accessed: Oct. 23, 2021].

[18] L. Cumming, “Map shows busiest pedestrian intersections in downtown Toronto,” *blogTO*, Apr. 28, 2018. [Online]. Available: https://www.blogto.com/city/2018/04/map-busiest-pedestrian-intersections-downtown-toronto/. [Accessed: Oct. 20, 2021].

[19] S. McCahan, Designing Engineers : an introductory text . Hoboken, NJ: Wiley, 2015.

[20] *Toronto complete streets guidelines: Making streets for people, placemaking and prosperity*.1st ed. Toronto, Ont: City of Toronto., 2017 [Accessed: Oct. 22, 2021].

[21] “Coronavirus disease (COVID-19) and food safety ,” *Government of Canada*. https://www.canada.ca/en/health-canada/services/food-nutrition/food-safety/covid19.html. [Accessed: Oct. 22, 2021].

[22] “Consumer Packaging and Labelling Act.” *Health Canada.* https://laws-lois.justice.gc.ca/eng/acts/C-38/page-2.html#h-95994. [Accessed: Oct. 22, 2021].

[23] “The Act (AODA),” *AODA.ca*, 2019. https://www.aoda.ca/the-act/ [Accessed Nov. 27, 2021].

[24] *Public Health Ontario*, Oct. 24, 2021. https://www.publichealthontario.ca. [Accessed: Oct. 24, 2021].

[25] “Southworth Lift-Tool™ Aluminum Scissor Lift Table, 300 Lb. Capacity,” *Global Industrial*. https://www.globalindustrial.ca/p/southworth-li-tool-aluminum-scissor-li-table-300-lb-capacity [Accessed: Nov. 27, 2021].

[26] “Intex elevated 18" premium comfort queen air mattress with internal pump.” https://www.target.com/p/intex-elevated-18-34-premium-comfort-queen-air-mattress-with-internal-pump/-/A-79812931 [Accessed: Nov. 25, 2021].

[27] “Electric Air Pump, 12V DC Air Pump for Inflatables, Portable Inflator/Deflator Pumps for Kayaks, Outdoor Camping, Air Mattress, Air Bed Raft Pool Toys, with 3 Nozzles(car use) : Amazon.ca: Everything Else,” Aug. 14, 2018. https://www.amazon.ca/xrime-Electric-Portable-inflator-Swimming/dp/B07GGTT39Z/ref=asc_df_B07GGTT39Z/?tag=googleshopc0c-20&linkCode=df0&hvadid=315294598288&hvpos=&hvnetw=g&hvrand=5899117882276189265&hvpone=&hvptwo=&hvqmt=&hvdev=c&hvdvcmdl=&hvlocint=&hvlocphy=9061009&hvtargid=pla-613727835812&psc=1 [Accessed: Nov. 25, 2021].

[28] Ben, “How Much Does an Ebike Battery Weigh?,” *eBike Pursuits*, Feb. 03, 2020. https://ebikepursuits.com/how-much-does-an-ebike-battery-weigh/ [Accessed: Nov. 25, 2021].

[29] Alex, “How Much Does an Electric Bike Battery Cost?,” *eBikesHQ.com*, Dec. 06, 2019. https://ebikeshq.com/electric-bike-battery-cost/ [Accessed: Nov. 25, 2021].

[30] “Reinforced Poly Sheeting - 6 Mil, 8’ x 100’,” *Uline*. https://www.uline.ca/Product/Detail/S-17863/Plastic-Sheeting/Reinforced-Poly-Sheeting-6-Mil-8-x-100?pricode=YD322&gadtype=pla&id=S-17863&gclid=CjwKCAiAnO2MBhApEiwA8q0HYXiyPM-gJVbPQRZffzKVdVVDFSA2H4Q8cpv6MzZkeGxOnchu0q6orxoC-jIQAvD_BwE&gclsrc=aw.ds [Accessed: Nov. 25, 2021].

[31] Hebei Hengtai Machine Tool Accessories Manufacturing Co., Ltd., “Inside Machinery Tool Accordion Bellow Cover/ Guards/bellow,” *Buy Vmc Inside Bellows,Cnc Machine Bellow Covers For Dmg Mori,Vertical Protective Bellow Covers Product on Alibaba.com*. https://www.alibaba.com/product-detail/inside-machinery-Tool-Accordion-Bellow-Cover_60554775226.html [Accessed: Nov. 27, 2021].

[32] Vance, “How Does An Office Chair Cylinder Work? 2 Types Of Cylinders - To Ergonomics,” *To Ergonomics*, 06-Aug-2020. [Online]. Available: https://toergonomics.com/how-does-a-chair-gas-cylinder-work/. [Accessed: Nov. 26, 2021]

[33] V. Vaughan, “How Do Office Chair Hydraulics Work?,” *Manutan UK Blog*, 12-Mar-2020. [Online]. Available: https://www.manutan.co.uk/blog/office-chairs/how-do-office-chair-hydraulics-work/. [Accessed: Nov. 26, 2021]

[34] T. Sangster, “How Does A Pneumatic Office Chair Work?,” *Topaz Furniture*, 06-Sep-2012. [Online]. Available: https://topazfurniture.com.au/blog/how-does-a-pneumatic-office-chair-work/. [Accessed: Nov. 26, 2021]

[35] D. S. Teppo and R. T. Holdredge, “Chair height adjustment mechanism,” 10-Aug-1993 [Online]. Available: https://patents.google.com/patent/US5234187A/en. [Accessed: Nov. 26, 2021]

[36] Ainilaily, “4"Short Stroke Adjustable Gas Lift Cylinder Tube for Office Chair Stool Replacement Parts,Heavy Duty Hydraulic Pneumatic Cylinder Shock Piston (9.7" to 13.7"Long),” *Amazon.com*. [Online]. Available: https://www.amazon.com/dp/B0946BKD7Q/ref=sspa_dk_detail_3?psc=1&pd_rd_w=iHyhb&pf_rd_p=9fd3ea7c-b77c-42ac-b43b-c872d3f37c38&pd_rd_wg=ZHHkW&pf_rd_r=5ZY5VSX21MGY75R7C22D&pd_rd_r=2a941ae2-7e77-4df6-a5cb-bc28701ec59f&spLa=ZW5jcnlwdGVkUXVhbGlmaWVyPUEzNkc1WVVNNVdTN1omZW5jcnlwdGVkSWQ9QTA3Nzg1OTQxTEZDN1gyQUhCWEZWJmVuY3J5cHRlZEFkSWQ9QTAyMjU2NzdPOVkzRDZRU0I0SjImd2lkZ2V0TmFtZT1zcF9kZXRhaWwmYWN0aW9uPWNsaWNrUmVkaXJlY3QmZG9Ob3RMb2dDbGljaz10cnVl. [Accessed: Nov. 28, 2021]

[37] Foshan MAC Chairs and Components, “Chair Height Adjustment Mechanism Chair Mechanism Making Machine,” *Alibaba.com*. [Online]. Available: https://www.alibaba.com/product-detail/chair-height-adjustment-mechanism_60815620050.html. [Accessed: Nov. 25, 2021].

[38] Ainilaily, “14" to 22" Long Adjustable Gas Lift Cylinder Tube for Office Chair Stool Replacement Parts,Heavy Duty Hydraulic Pneumatic Cylinder Shock Piston (8" Stroke),” *Amazon.com*. [Online]. Available: https://www.amazon.com/dp/B08F22VM99/ref=sspa_dk_detail_2?psc=1&pd_rd_i=B08F22VM99&pd_rd_w=5mpDK&pf_rd_p=9fd3ea7c-b77c-42ac-b43b-c872d3f37c38&pd_rd_wg=WcAtE&pf_rd_r=WE36ZAB6SM5VTK2EC12D&pd_rd_r=477c6df9-1b29-4e74-9063-a0bc1e8fe96d&spLa=ZW5jcnlwdGVkUXVhbGlmaWVyPUEyNTNFTlgzUFpIU0syJmVuY3J5cHRlZElkPUEwMzA5MjA3M00xOEtOUFczTjNQNiZlbmNyeXB0ZWRBZElkPUEwMTIwNzAyMUtKVzRTRVhQWEU3UCZ3aWRnZXROYW1lPXNwX2RldGFpbCZhY3Rpb249Y2xpY2tSZWRpcmVjdCZkb05vdExvZ0NsaWNrPXRydWU=. [Accessed: Nov. 28, 2021].

[39] RC4WD, “RC4WD 1/10 Mini Warn 9.5cti Winch Z-S1571,” Amazon. [Online]. Available: https://www.amazon.com/RC4WD-Mini-9-5cti-Winch-Z-S1571/dp/B016N5IKAW/ref=sr_1_5?keywords=mini+winch&qid=1638040921&qsid=144-6091655-5705446&sr=8-5&sres=B087JV2Z2Z%2CB07Y2QPR7V%2CB016N5IKAW%2CB09484B9ZR%2CB087JKBVZC%2CB00361WUV2%2CB082N5Y2R4%2CB00BKW4440%2CB07XDYVZPQ%2CB002PNOKKQ%2CB097P4CYJQ%2CB08CXMNS6Y%2CB07FPN64Z9%2CB08BL9FMGW%2CB07VPPRP8J%2CB07WC4BXMH. [Accessed: Nov. 27, 2021]

[40] Walmart, “Plastic Trays,” *Walmart.com*. [Online]. Available: https://www.walmart.com/c/kp/plastic-trays. [Accessed: Nov. 27, 2021]

[41] L. Cumming, “Map shows busiest pedestrian intersections in downtown Toronto,” *blogTO*, 28-Apr-2018. [Online]. Available: https://www.blogto.com/city/2018/04/map-busiest-pedestrian-intersections-downtown-toronto/. [Accessed: Oct. 20, 2021].

[42] Premier Plant Hire, *Boom Lift*. 2018 [Online]. Available: https://www.premierplanthire.co.uk/wp-content/uploads/2018/12/10250_Z45-25JBoomLift.jpg. [Accessed: Nov. 28, 2021]

[43] pngimg.com, *Scales PNG image with transparent background*. [Online]. Available: https://pngimg.com/image/52965. [Accessed: Nov. 28, 2021]

[44] S. Hendricks, *Lifting mechanism video*. 2016 [Online]. Available: https://www.youtube.com/watch?v=GLTzE4ws-aY&ab_channel=SjoerdHendriks. [Accessed: Nov. 28, 2021]

[45] Foodora Canada, "Meet Geoffrey, the autonomous delivery robot: foodora teams up with Tiny Mile on artificially intelligent delivery," *foodora Canada*, Mar. 11, 2020. Accessed: Nov. 25, 2021. [Online]. Available: https://www.globenewswire.com/news-release/2020/03/11/1998676/0/en/Meet-Geoffrey-the-autonomous-delivery-robot-foodora-teams-up-with-Tiny-Mile-on-artificially-intelligent-delivery.html

Appendices

Appendix A: Map of Pedestrian traffic at each intersection in downtown Toronto (measured in 24 hour time frames, 2015) [41]

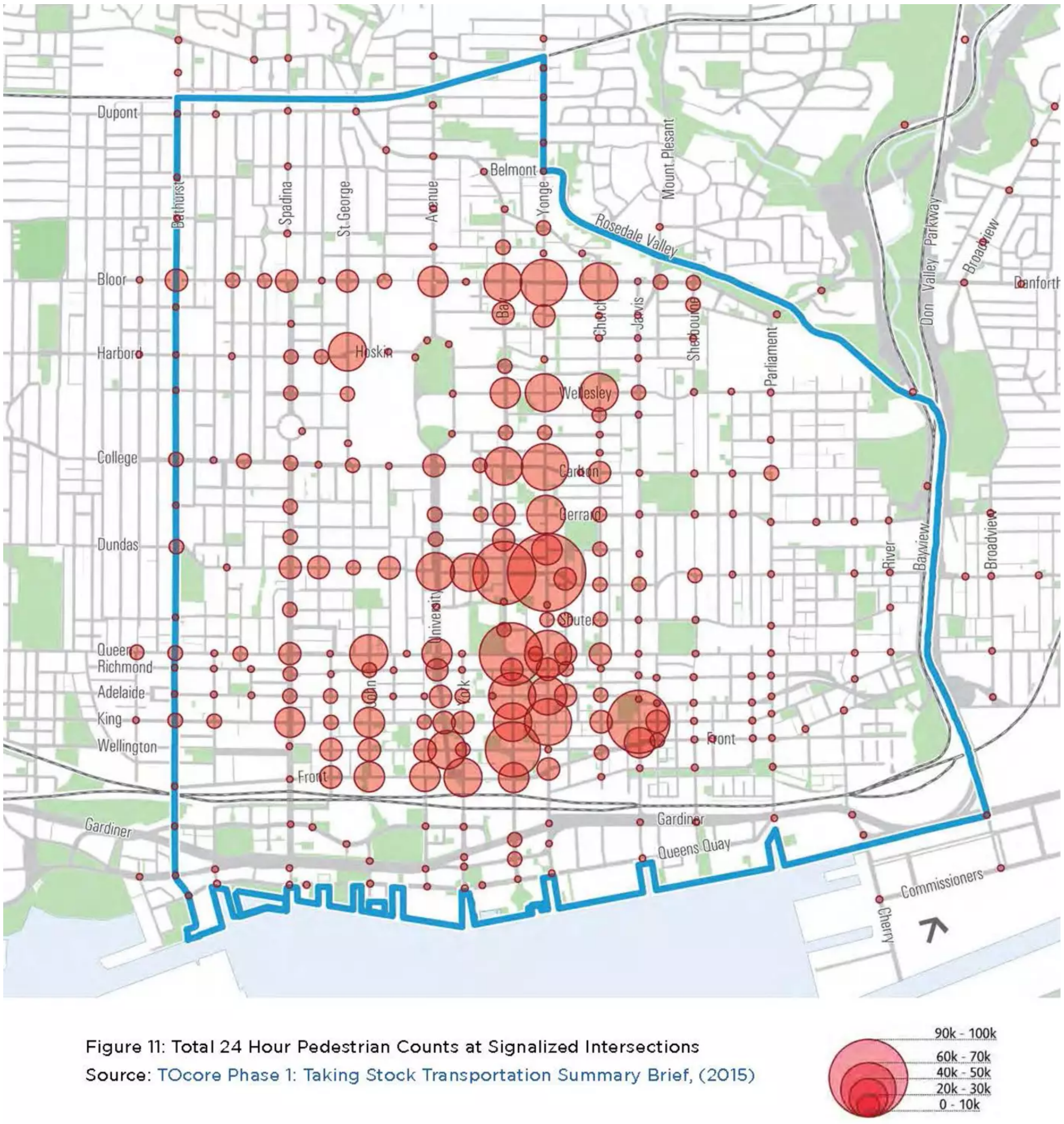


Figure 11: Total 24 Hour Pedestrian Counts at Signalized Intersections
Source: TOcore Phase 1: Taking Stock Transportation Summary Brief, (2015)

Appendix B: Pairwise comparison table for stakeholders.

The table below represents the pairwise comparison table for the stakeholders. Each individual stakeholder was listed and then compared to its respective counterpart.

---	Health Canada	City of Toronto's Pedestrian Safety Committee	Accessibility for Ontarians Act (AODA)	Total
Health Canada	-	0	1	1
City of Toronto's Pedestrian Safety Committee	1	-	1	2
Accessibility for Ontarians Act (AODA)	0	0	-	0

Appendix C: Pairwise comparison table for objectives

The following pairwise comparison table showcases the method used to rank the different objectives by importance. 1 denotes that the objective on the row was determined to be more important while a 0 denotes that the objective on the column was determined to be more important.

-	Functionality	Expense	Durability	Safety	**Total:**
Functionality	-	1	1	0	**2**
Expense	0	-	0	0	**0**
Durability	0	1	-	0	**1**
Safety	1	1	1	-	**3**

Appendix D: Functional Basis for Functions

The functional basis model for generating functions takes the most 'bare-bones' set of functions in which a generated design model is expected to carry out. In the case of the Geoffrey bot, the Functional Basis and Functions are particularly succinct due to the simplicity behind the generalized functions in which the created technology is expected to carry out.

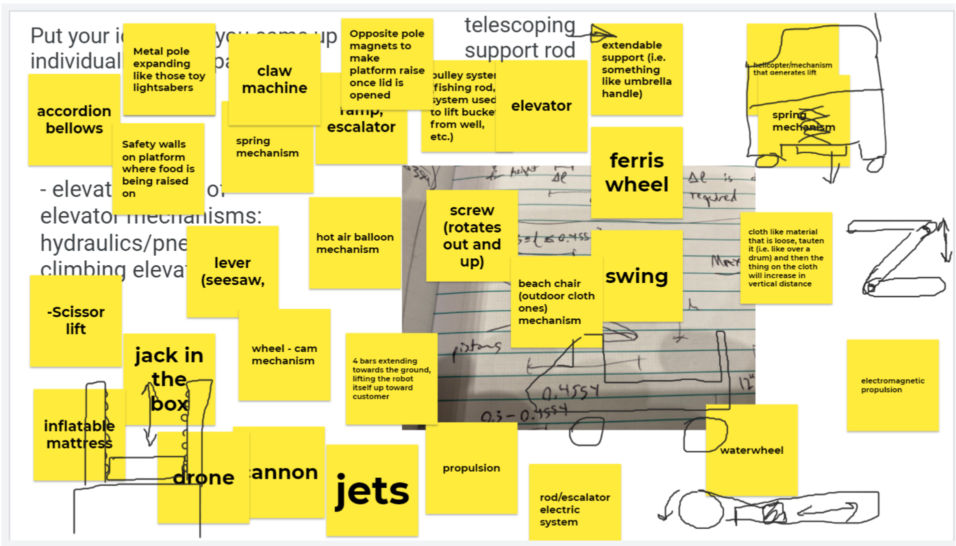
Functional basis:

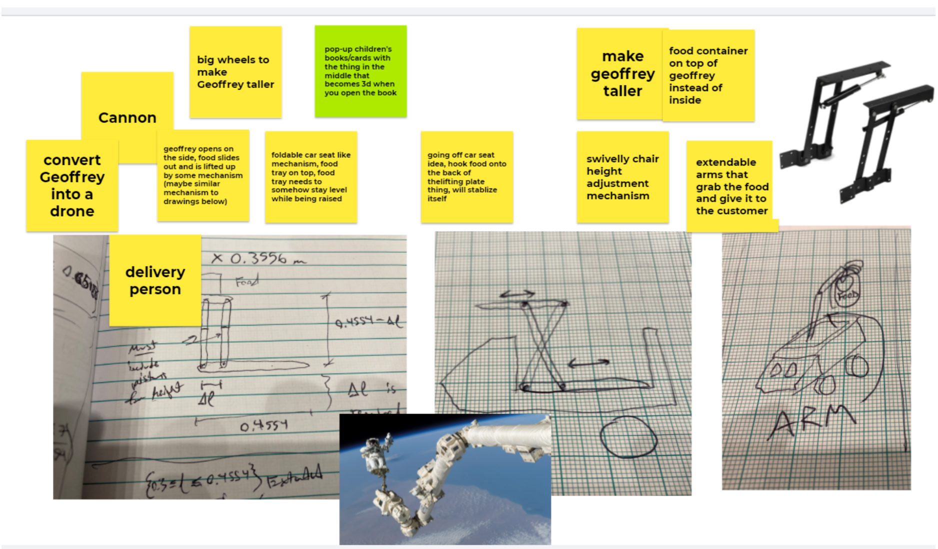
- Lifts mass
- Lowers mass

Functions:

- Lifts mass in a stable manner which does not launch the mass (ultimately does not pose a danger to those in the surrounding area of operation)
- Lifts food to a suitable height for the customer.
- Lowers mass in a stable manner which does not pose a danger to pedestrians/passers-by
- Lowers the mechanism so that the cargo bay is able to close.

Appendix E: Sample of first free brainstorming session (hosted on Google Jamboard) with a list of 65 ideas (considered independent of constraints.)





Consolidated Ideas

1. Claw machine
2. lever/seesaw
3. Scissor lift
4. Jack in the box
5. Jet
6. Drone accompaniment lifts food from Geoffrey
7. Cannon
8. Swing
9. Rotating wheel
10. Ramp
11. Escalator
12. Extendable support which lifts Geoffrey up from the base
13. Spring mechanism
14. Wheel cam mechanism
15. Propulsion
16. Waterwheel
17. Electromagnetic propulsion
18. Inflatable mattress
19. Accordion bellows
20. Screw
21. Telescoping support rod (metal pole expanding like a toy lightsaber)
22. Helicopter mechanism
23. Rack and pinion mechanism
24. Elevator (types of elevator mechanism: hydraulics/pneumatics)
25. Pneumatic elevator
26. Pulley elevator
27. Geared traction elevator
28. Hydraulic elevator
29. Crane
30. Opposite pole magnets to make platform raise once lid is opened
31. Rod/escalator electric system
32. Z-mechanism
33. Cloth like material that is loose, tighten it (like over a drum)- hammock/net
34. 4 bars extending towards the ground lifting the robot itself up toward customer
35. Helium balloons
36. Hot air balloon mechanism
37. Big wheels to make Geoffrey taller
38. Convert Geoffrey into a drone
39. Delivery person hands the food from Geoffrey to the customer
40. Geoffrey opens on the side, food slides out and is lifted up by a compact scissor lift mechanism; hook food onto the back of the lifting mechanism so it will stabilize itself

41. Foldable car seat mechanism-- Drawbridge
42. Swivelly chair height adjustment mechanism attached to the tray the food is on
43. Extendable arms that grab the food and give it to the customer
44. Reduce Geoffrey's size so that he can jump into the customers hands
45. Pop-up children's book mechanism
46. Give Geoffrey legs
47. Slingshot
48. Solenoids to raise food with a magnetic base
49. Ratchet and pawl
50. Push food up a slide with a fan
51. Geoffrey always floats at arm's reach using propellers
52. Hoist attached to Geoffrey that hoists the food up
53. Convert Geoffrey to a forklift
54. Winch system to lift food (installed on a high part of Geoffrey's frame directly above the cargo bay)
55. A forklift in Geoffrey that lifts the food
56. Conveyor belt ramp (internal)
57. Pulley that customer pulls to get food out of compartment
58. Fill Geoffrey with water, which raises the water level and the food that is floating will increase in height
59. Geoffrey carries a conveyor belt ramp with him, when he arrives he places the food onto the ramp which carries the food up
60. Elongating poles on Geoffrey's exterior coupled with a scissor lift mechanism inside cargo bay lifting the food up
61. Safe catapult with food held in a container (e.g. net) so that it is not flung out (also try to slow speed of lift so that there isn't enough force to fling to the food)
62. Fire truck ladder
63. Cherry picker, the non-scissor lift kind  [42]
64. Geoffrey brings a ramp with him and drives up the ramp
65. Scales  [44]

Appendix F: SCAMPER method

Modify an existing idea using each aspect of the acronym.

<u>With scissor lift in mind</u>

Substitute:

- Lighter material for frame
- Wood, some sort of strong plastic

Combine:

- Increase height of Geoffrey using something else like support rods then have scissor lift food out of cargo bay

Adapt:

Modify:

- Have cargo bay open from side, scissor lift slide out and then lift
- Add a sensor so that the scissor lift can automatically detect when to stop

Magnify:

Minify:

- Reduce the size of an industrial scissor lift to fit inside of Geoffrey's cargo bay

Put to other uses:

Eliminate:

- Geoffrey

Rearrange or reverse:

- Lift Geoffrey's entirety with the scissor lift

Appendix G: Analogy Method

The ideas listed below were generated by adapting and using ideas from nature or the surrounding environment to generate solutions.

- Waterwheel
- Pulley system for sails on sailboat
- Ferris wheel
- Elevator system
- Catapult
- Like poles (magnets) repulsing one another

Appendix H: Morphological Chart

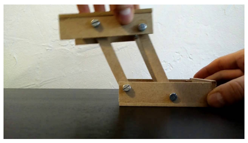
A morphological chart represents a breakdown of solutions into a variety of different components with several variations in each section. Essentially, the final solution is broken down into simpler parts such as devices to hold/store the food, the power of the design, the operation behind the design, et cetera. The table below represents the morphological chart generated for the purposes of this design where the final solution can be almost any solution that incorporates at least one variation from each column.

Hold food	**Power behind design**	**Increase height of food holder**	**Extending motion of offloading (combinations if applicable)**	**Operation**
Tray	Electric Design (Battery)	Mechanical Design (ie: scissor lift)	Rotational	Fully-autonomous (requiring only the “push of a button”)
Hook	Pneumatic Design	Make Geoffrey taller	Vertical translation	Partially-autonomous (requires a selection of preset functions)
Arm	Hydraulic Design	Propelled Design (food is projected)	Horizontal translation (to the sides or back/front)	Not-autonomous (requires full management and monitoring from operator)
External unit	Solar-powered Design	Use of External arms/extensions	No motion (consistent with food at a constant height)	No operation (consistent with food at a constant height)
Food is not in a container	Combustion Engine-powered design	Redesigning Geoffrey without the current “cargo bay design”		Operated by client (consistent with ‘human-powered’ design)
	Buoyancy-dependent design	Airborne Design		
	Wind-turbine powered design	Box is at a constant height supported by a column underneath		
	Human Powered	Pulley Design		

Appendix I (for Feasibility Check)

2. Feasible ideas
*Unfeasible in yellow

Classifications:

1. Claw machine
2. lever/seesaw
3. Scissor lift
4. Jack in the box (*too dangerous to passing pedestrians, potentially projectile*)
5. Jet (*too dangerous to passing pedestrians, potentially projectile*)
6. Drone accompaniment lifts food from Geoffrey
7. Cannon (*too dangerous to passing pedestrians, potentially projectile*)
8. Swing (*too dangerous to passing pedestrians, potentially projectile*)
9. Rotating wheel
10. Ramp (what does this mean)
11. Escalator
12. Extendable support which lifts Geoffrey up from the base
13. Spring mechanism (*too dangerous to passing pedestrians, potentially projectile*)
14. Wheel cam mechanism
15. Propulsion
16. Waterwheel (*impractical in nature; inefficient, expensive*)
17. Electromagnetic propulsion (*too dangerous to passing pedestrians, potentially projectile*)
18. Inflatable mattress
19. Accordion bellows
20. Screw (rotations out and up; similar to a barber pole)
21. Telescoping support rod (metal pole expanding like toy lightsaber)
22. Helicopter mechanism (*too dangerous to passing pedestrians*)
23. Rack and pinion mechanism (elevator system with gears instead of hydraulics)
24. Elevator (types of elevator mechanism: hydraulics/pneumatics)
25. Pneumatic elevator
26. Pulley elevator
27. Geared traction elevator
28. Hydraulic elevator
29. Crane
30. Opposite pole magnets to make platform raise once lid is opened
31. rod/escalator electric system
32. Z-mechanism  [44]
33.
34. Cloth like material that is loose but is tightened (like a drumhead skin)
35. 4 bars extending towards the ground lifting the robot itself up toward customer

36. Helium balloons
37. Hot air balloon mechanism (*impractical in nature; inefficient, expensive*)
38. Bigger wheels to make Geoffrey taller
39. Convert Geoffrey into a drone (four horizontal propellers instead of the helicopter method)(*impractical in nature; expensive; potentially dangerous to passing pedestrians and customer*)
40. Accompanying delivery person hands the food from Geoffrey to the customer (*impractical in nature; expensive*)
41. Geoffrey opens on the side, food slides out and is lifted up by a compact scissor lift mechanism; (make the second one a new idea) hook food onto the back of the lifting mechanism so it will stabilize itself
42. Foldable car seat mechanism-- Drawbridge (the food is latched on to a hook which is on the undercarriage of drawbridge and on the opposite side of the hinge; the mechanism is powered such that the "bridge" is lifted by the mechanism, lifting the food as well)
43. Pneumatic desk chair height adjustment mechanism attached to the tray the food is on
44. Extendable arms that grab the food and give it to the customer
45. Reduce Geoffrey's size so that he can jump into the customers hands (*impractical in nature; expensive; potentially dangerous to passing pedestrians and customer*)
46. Pop-up children's book mechanism
47. Give Geoffrey legs (*impractical in nature; expensive, less efficient*)
48. Slingshot (*potentially dangerous to passing pedestrians and customer*)
49. Solenoids to raise food with a magnetic base
50. Ratchet and pawl
51. Push food up a slide with a fan
52. Geoffrey always floats at arm's reach using propellers (*impractical in nature; expensive; potentially dangerous to passing pedestrians and customer*)
53. Hoist attached to Geoffrey that hoists the food up
54. Convert Geoffrey to a forklift
55. Winch system to lift food (installed on a high part of Geoffrey's frame directly above the cargo bay)
56. A forklift in Geoffrey that lifts the food
57. Conveyor belt ramp (internal)
58. Pulley that customer pulls to get food out of compartment
59. Fill Geoffrey with water, which raises the water level and the food that is floating will increase in height
60. Geoffrey carries a conveyor belt ramp with him, when he arrives he places the food onto the ramp which carries the food up
61. Elongating poles on Geoffrey's exterior coupled with a scissor lift mechanism inside cargo bay lifting the food up
62. Safe catapult with food held in a container (e.g. net) so that it is not flung out (also try to slow the speed of lift so that there isn't enough force to throw to the food)
63. Fire truck ladder

64. Cherry picker, the non-scissor lift kind [42]
65. Geoffrey brings a ramp with him and drives up the ramp

66. Scales (e.g. for measuring mass) [43]

Appendix J: Multivoting process

Each team member had 10 votes to cast. The numbers in the table below correspond to the numerical order of the idea in the master list, and the coloured cells indicate which ideas had two or more votes.

Matthew	**Cameron**	**Safiyyah**	**Erie**	**Tanya**	**Joyce**
3	1	1	1	3	3
6	3	3	3	9	18
20	11	18	12	18	20
32	20	20	18	20	23
34	32	28	24	23	29
35	42	32	26	28	32
38	57	34	42	32	37
44	60	43	43	34/12	39
49	63	56	56	37	55
63	64	63	60	58	56

Appendix K: Top 10 Ideas

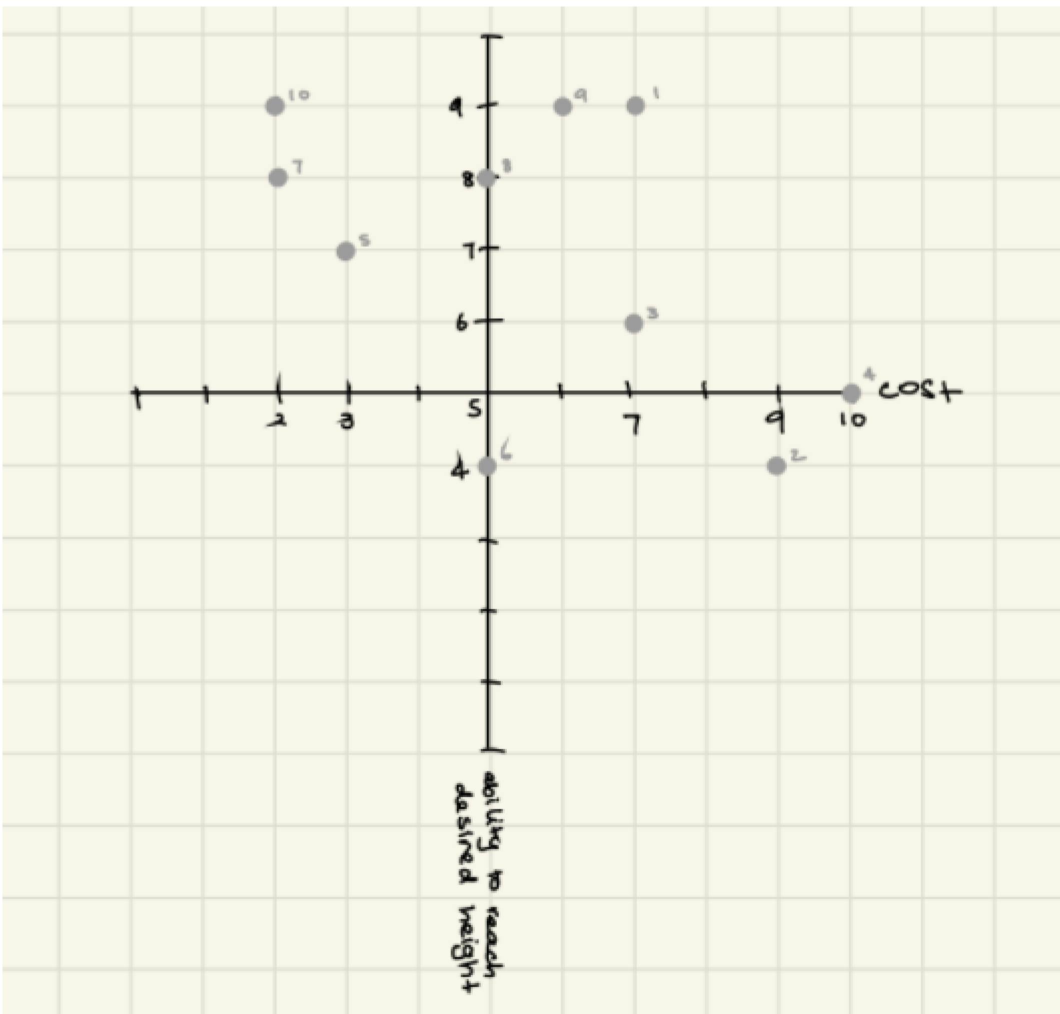
The following ideas were chosen through multivoting. Each team member had 10 choices they could pick. This list is in accordance with the multivoting process listed in Appendix H.

Top 10 list

1. Idea 3: Scissor lift (6)
2. Idea 20: Screw (5)
3. Idea 32: Z mechanism (5)
4. Idea 18: Inflatable mattress (4)
5. Idea 1: Claw machine (3)
6. Idea 56: Conveyor belt (3)
7. Idea 63: Cherry picker (3)
8. Idea 28: hydraulic elevator (2)
9. Idea 42: Pneumatic chair height adjustment mechanism attached to food tray (2)
10. Idea 60: Elongating poles on Geoffrey’s exterior coupled with a scissor lift mechanism inside cargo bay lifting the food up (2)

Appendix L: Graphical Decision Analysis

The graph below represents a plot of each idea with reference to two specific axises. In this case, the two most important objectives/constraints were chosen to be a measure of the successfulness of each design. On the x-axis, the rough calculated cost to build the design was chosen (where 0 equates to a very expensive design and 10 represents the most inexpensive design). On the y-axis, the ability for the design to reach the desired height (listed in the Objectives section) was chosen (where a 0 means that the design is completely incapable of reaching this height and a 10 means that the design exceeds this desired height). The final designs chosen on the basis of this Graph were those that fell the closest to the coordinate (10, 10) (representing the optimal solution).



Finalists: 1, 9, 4
Scissor lift, pneumatic chair height adjustment mechanism, inflatable mattress.

Appendix M: Pugh Decision Matrix

The table below represents a decision matrix in which a datum solution, or base solution was picked; from there, the team listed the other two, top solutions to compare to the datum solution with respect to the design's objectives. Solution 2 and 3 were given a score ranging from -1 to +1 (-1 indicates that the solution is below the datum solution for that respective objective, 0 indicates it is the same, +1 indicates that it is superior). The score for each solution was then summed up in the final row. The team used this to pick the proposed conceptual design.

Objectives	**Datum solution: Pneumatic seat** adjustment mechanism	**Solution 2: Scissor lift**	**Justification**	**Solution 3: Inflatable mattress**	**Justification**
Cost ($)	0	-1	More materials needed, more sophisticated design.	+1	Inflatable mattresses and pneumatics can be procured for a relatively low price.
Functionality(Maximum height reachable)	0	+1	Support rods (the scissors) allow mechanism to reach higher	-1	The inflatable mattress cannot lift things as high, particularly if there is a time constraint to the inflation time
Maximum load supportable	0	+1	Stronger lifting force and support rods with the scissor lift	-1	The inflatable mattress cannot lift heavy objects and deliveries.
Safety- COVID, dropping/spilling food, hurling food, injuring customer	0	0	The scissor lift is similarly safe to the seat adjustment, because it just lifts and lowers a platform.	-1	Potentially uneven surface as the mattress is filled with air can cause food to spill

The design will not increase the weight of the overall robot to more than 125% of the original weight	0	-1	Since the scissor lift is a more condensed version of a seat lift, more materials will be required and thus increasing the weight	+1	The inflatable mattress has little weight of its own, the main weight will be coming from the pump whose weight is lower than that of the adjustment mechanism.
Sum	0	0	-	-1	-

Appendix N: Calculations for inflation rate and operating speed for the 'air-mattress' design.

Below, the unit subscript 'B' represents data collected for the air-mattress advertised online [27]. The subscript 'M' represents that of the designed mattress.

Volume of Bed (V_B):

$$V_B = L \times W \times H$$

$$V_B = 2.032m \times 1.524m \times 0.4572m$$

$$V_B \doteq 1.416m^3$$

Inflation Time:

$$t_B = 4 min$$

$$t_B = 240 s$$

Volume of Geoffrey's Mattress (V_M):

$$V_M = L \times W \times H$$

$$V_M = 0.90 \times 0.40 \times 0.30$$

$$V_M \doteq 0.108 m^3$$

Inflation Time:

$$\frac{V_B}{t_B} = \frac{V_M}{t_M}$$

$$t_M = \frac{V_M t_B}{V_B}$$

$$t_M \doteq 18.31 s$$

Average speed of parcel on the platform:

$$v = \frac{d}{t_M} \quad \text{(Height)}$$

$$v = \frac{0.9}{18.31}$$

$$v \doteq 0.049 m/s$$

← Insufficient in projecting the food (won't leave platform)

Appendix O: Estimations for pneumatic lifting cylinder

The calculations listed below describe the estimations for the cost, height reachable, durability, and mass of the pneumatic lifting cylinder.

<u>Cost:</u>

- Gas lift cylinder costs approximately $16.00-$30.00 [36][37]
- Lever attachment approximately $12.45 [37]
- Mini winch, remote and cable approximately $80.00 [38]
- Plastic food tray from $4.00-$11.00 [40].

Total (using highest number of range): $133.00

<u>Height reachable:</u>

Since the height from the ground to the base of Geoffrey's cargo bay is approximately 24.13cm [4] and the cylinder has a maximum height of 56.5cm, the design will reach a maximum height of approximately 80.63cm from the ground

<u>Durability:</u>

Conversion of 450 pounds to kg = 204 kg

<u>Mass:</u>

Mass of gas cylinder + mass of winch and cable + mass of food tray and lever attachment = approx. 1.38 kg.