GNG5140 Report

Working Winter Accessibility

Submitted by

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Abstract

The design report is a brief of our project work to design a wheelchair equipped with a snow shovel. This design allows our customers to use a wheelchair to clear snow from the road by himself.

After the final model was established, we made a production attempt and adjusted it by analyzing the uncontrollable factors encountered during production and the effects of the test product after production. We tried different versions of the model, searched for information, improved parameters, gradually improved the functionality of the snow shovel, and determined the final version of the improved version.

In this report, at first, we described the final state of our prototype and stated the purpose, function, and interaction; and we detailed and logically planned to complete our model with the remaining time.

According to our original model, we designed systematic testing steps to analyze the performance of the snow shovel, and gave detailed analysis methods and specifications, at the same time, we also test the function and analyze the usability of the snow shovel, and we also provide results that have been considered meticulously during design iterations.

We also analyzed our snow shovel from four aspects: scalability, quality, sustainability, usability, and reliability.

Keywords: snow shovel, V shape, plan, scalability, quality, sustainability, usability and reliability

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1 Introduction

According to functional design, we designed and obtained column parts and overall concepts through 3D printing skills. Through drilling, the parts were assembled in an orderly manner to form a whole that can be applied. The smoothness and safety of the parts were improved by grinding. There are different degrees of testing before and after each part in order to get better and more products that meet customer requirements, such as whether the 3D parts are sturdy enough to meet the drilling standards, the drilling position should be parallel to the wheelchair, and the durability of the screws at the junction and the approximate Life.

In chronological order, we first tested the snow removal efficiency and ruggedness of the previous prototype, and then made some detailed modifications based on this. For example, changing the cross-section of the snow-breaking column from a hexagon to a square, and increasing the filling of the 3D model makes it closer to solid, which can be more substantial. After adding the parts, we can reassemble, drill, and sand the parts with the existing model to form a new prototype.

2 Description of the final state of the prototype

This is the prototype we currently build (Figure 1). We purchased two small plastic snow shovels from our website as our V-shaped snow shovels. A single snow shovel is 30cm wide and 30.5cm high (excluding the aluminum connecting rod above) and weighs 0.5kg. We used 3D printing to make the connection between the two snow shovels. That material is PLC. A metal pole is mounted on the snow shovel, made of aluminum, and the center is empty. The two vertical connecting rods on the snow shovel are made of aluminum, and are connected to the metal iron rod (red) by the screw nuts

Figure 2-1 Current snow shovel

This is the conceptual diagram of our final ideal model (Figure 2). At present, the aluminum pole on the snow shovel is 60cm high. We cut off the upper 30cm and drill a row of parallel holes on each of the two aluminum rods (each hole is 4 cm apart, 2 cm in diameter and 5 holes in each rod). The purpose is to achieve height adjustment. An iron rod (50cm) is connected to the lower hole of the two aluminum rods to increase the stability of the snow shovel and prevent the snow shovel from detaching from the groove to the outside when working. All connection holes are fixed with screws and nuts.

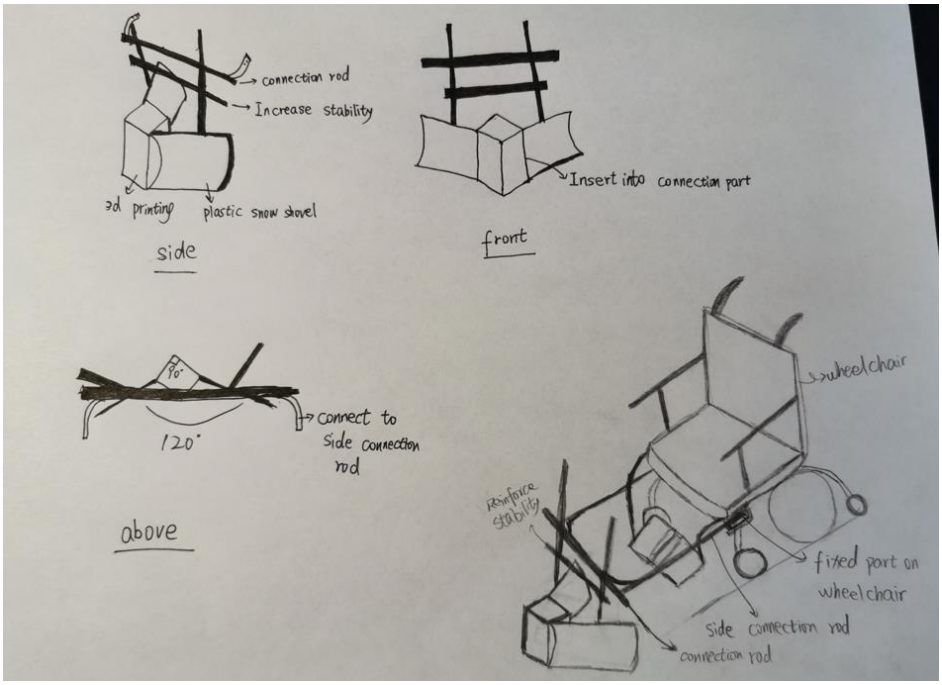
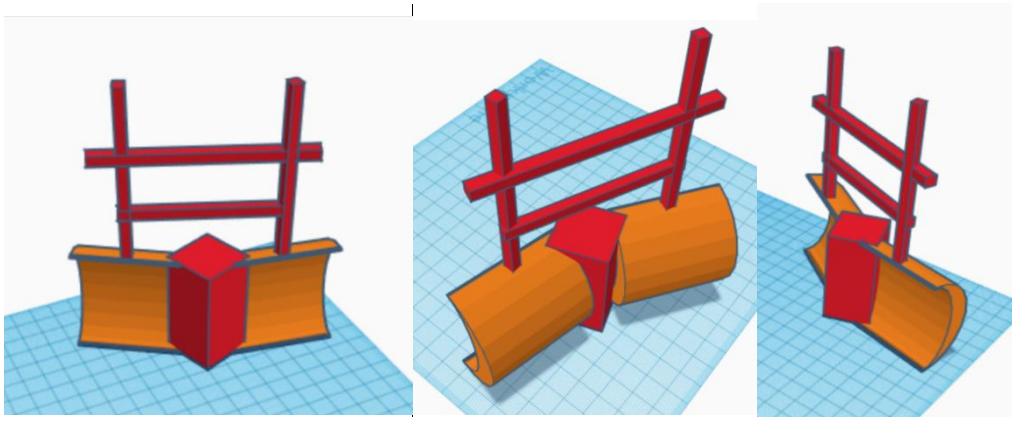


Figure 2-2 Ideal model concept map

In our ideal prototype (Figure 3), the PLC connector in the middle is a cuboid with a filling density of 80%. The angle of the PLC connector is 90 degrees, the side length is 25cm, and the height is 35cm. We have designed grooves on both sides of the diagonal of the connector to match the sides of the snow shovel. The groove is 5cm deep and 30.5cm high. The snow shovel can be inserted into the groove along the diagonal of the connecting body and tightly combined. The angle formed by the two snow shovels is 120 degrees.



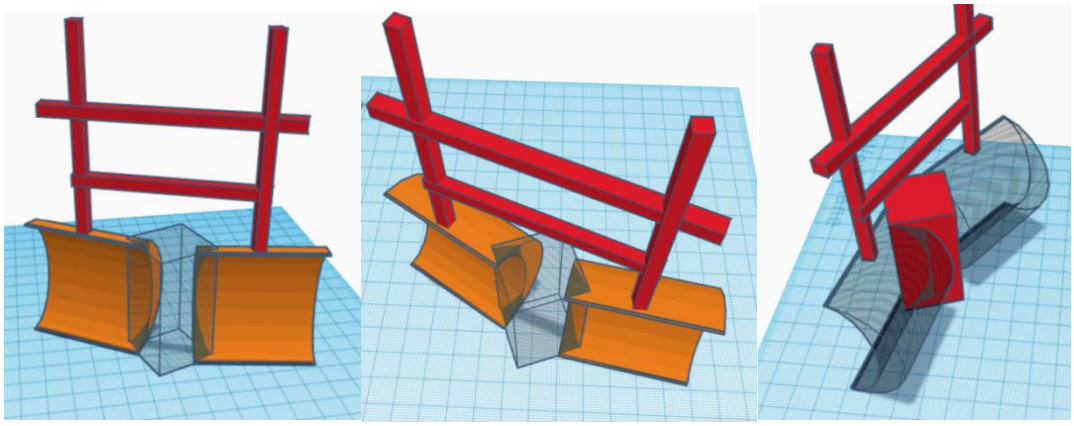


Figure 2-3 Ideal snow shovel

Of the two metal connecting rods, the upper one (55cm) has 5 available holes at each side. The distance between each hole is 4cm. Besides, it uses an aluminum alloy sheet (Figure 4) to connect the rod to the two side connection rods. Three holes are drilled at each end of each side connection rod, and the distance between each hole is 4cm, which can adjust the distance between the wheelchair and the snow shovel.

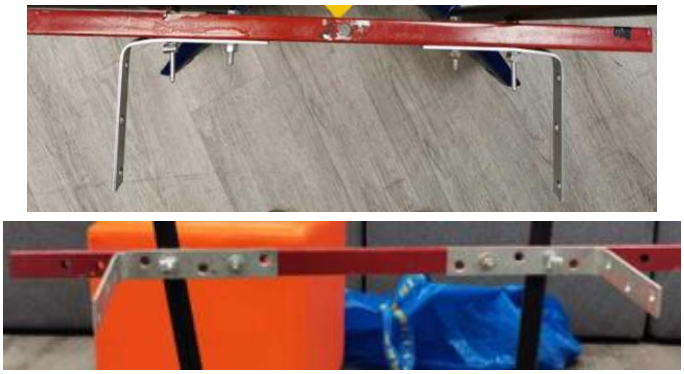


Figure 2-4 Aluminum alloy sheet

At the fixed end of the wheelchair, we use a 15cm iron rod and a 12cm aluminum alloy piece with screw nuts at both ends, and drill a hole at the center of the side of the 15cm iron rod to fix it to the side connection rod with a screw nut (Figure 5).

In our ideal prototype, the iron link used is a hollow rod with a cross section of 2CM. The screws and nuts used are all removable and replaceable. The total width of the snow shovel is 80cm, height 60cm, and weight 5kg.

Figure 2-5 Wheelchair fixed part

3 Purpose, Function and Interaction

3.1 Purpose

The user of our product is a polio patient. He hopes to install a snow shovel on the wheelchair to help the neighbors clear the snow on the walkway near the house by controlling the movement and steering of the wheelchair. Based on the previous experience of a snow shovel, he hopes to get a shovel that does not need to turn and directly push the snow on the road to both sides of the road. Because the door frame of the user's home is narrow, the snow shovel needs to be brought to an adjacent installation (this process is completed by the user ’s weak mother alone), the user and his mother want the snow shovel to be light, portable, and easy to install so that the user ’s mother can spend less time in the snow.

3.2 Function

Based on the needs of users, we decided to use a V-shape snow shovel. The V-shaped tip can increase the pressure by reducing the area of the force and it is easier to break the snowdrift. The V-shaped snow shovel is connected to both sides. The plastic snow shovel is lighter. To meet the needs of users. When the snow shovel moves forward in the snow, the V-shaped tip breaks through the snowdrift, and the snow flows from the V tip to the snow shovel on both sides by the squeezing action between the snow molecules, and the snow shovel on both sides guides the snow to the wheelchair. On both sides. Based on the user's evaluation of the previous two works, we retain the connecting rod part that the user is satisfied with and add a detachable strap to bring the connection between the connecting rod and the wheelchair to increase the stability of the connecting rod.

3.3 Interaction

When the user wants to use a snow shovel to shovel snow, he only needs to fix the connecting rod in a wheelchair and tighten it with a strap. The snow shovel part is fixed on the connecting rod by a nut that can be tightened by hand. The entire connection process only needs It can be completed in about three minutes. After use, you only need to remove the snow shovel, loosen the strap, and then remove it, and then remove the connecting rod. The entire snow shovel and the connecting rod are only 4kg, which can be lifted with one hand, and the installation process is simple and the time required is short. When the user pushes the wheelchair lever forward, the snow in front of the wheelchair can be easily pushed to both sides of the road. No need to turn. The product basically meets the customer's requirements and achieves a good interaction effect.

4 Normal action plan

Task Name	Duration	Start	Finish	Assigne
1.Modification of 3D model	1d	20-03-17	20-03-17	All mem
1.1 Analyze the previous version	1d	20-03-17	20-03-17	All mem
1.2 Modify the 3D model.	1d	20-03-17	20-03-17	Zhijia Zh
1.3 Use a 3D printer	3d	20-03-17	20-03-19	Zhijia Zh
2. Drilling	2d	20-03-18	20-03-19	All mem
2.1 Drill holes	1d	20-03-18	20-03-18	Ziqi Jin a
2.2 Polish	1d	20-03-19	20-03-19	Ziqi Jin a
3.Installation	3d	20-03-19	20-03-21	All mem
3.1 Assembly of 3D printed parts	1d	20-03-19	20-03-19	Jiancon
3.2 Polish 3D prints and parts.	1d	20-03-20	20-03-20	Jiancon
3.3 Assemble the connecting bracket.	1d	20-03-21	20-03-21	Jiancon
4.Test, Analysis ,Interaction and Modify	5d	20-03-22	20-03-26	All mem

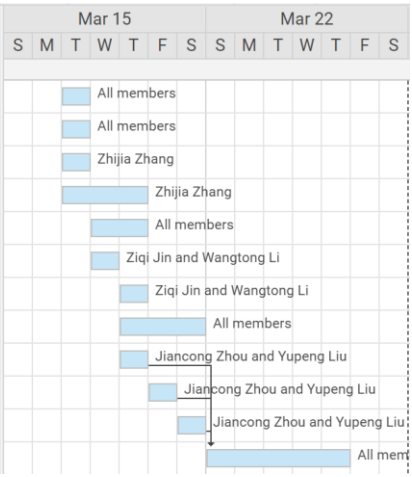


Figure 4-1 Gantt chart

Work is performed by all designers unless noted otherwise.

4.1 Modification of the 3D model

4.1.1 Analyze the defects of the previous version and the reasons.

(1). Compare the test results with the target requirements.

(2). Identify the cause of defects and analyze the reliability and durability of components.

(3). Perform group discussion for the best solution.

(4). Search for ways to improve through the Internet and so on.

4.1.2 Modify the 3D model. (Completed by Zhijia Zhang, Time consumption one day)

(1). Simulate the product durability index to modify the filling degree.

(2). Redesign the card slot and modify the size.

4.1.3 Use a 3D printer to print a new version of the model. (Completed by Zhijia Zhang, Time consumption three days)

4.2 Drilling

4.2.1 Drill holes on the joint bracket to fit the new shovel. (Completed by Ziqi Jin and Wangtong Li, Time consumption one day)

(1). Polish the parts from lathe and milling tasks.

(2). Check the parts and see if they meet requirements.

4.2.2 Drill holes every five centimeters on the shovels to meet different height requirements. (Completed by Ziqi Jin and Wangtong Li, Time consumption one day)

(1). Polish the parts from lathe and milling tasks.

(2). Check the parts and see if they meet requirements.

4.3 Installation

4.3.1 Assembly of the 3D printed parts with snow shovels.(Completed by Jiancong Zhou and Yupeng Liu, Time consumption one day)

(1). Check the assembly parts and check the assembly drawings.

(2). Implement assembly tasks.

(3). Check the fastness of the component.

(4). Adjust components according to the actual situation.

4.3.2 Polish 3D prints and parts. (Completed by Jiancong Zhou and Yupeng Liu, Time consumption one day)

(1). Use laser cutting to polish sharp edges to refine the rough model.

4.3.3 Assemble the snow shovel with the connecting bracket. (Completed by Jiancong Zhou and Yupeng Liu, Time consumption one day)

(1). Check the assembly parts and check the assembly drawings.

(2). Implement assembly tasks.

(3). Check the fastness of the component.

(4). Adjust components according to the actual situation.

4.4 Test, Analysis, Interaction and Modification(Time consumption five days)

Time allocation

Day 1:

(1). Installation and safety(six hours)

(2). Mobility (four hours)

Day 2:

(1). Stability (four hours)

(2). Weight (four hours)

Day 3:

(1). Snow clearing ability(eight hours)

HR allocation

Material and equipment: Zhijia Zhang, Ziqi Jin

Driver: Yupeng Liu

Measurement: Wangtong Li

Record: Jiancong Zhou

Analysis: All team members

Interaction：(From Day 4 to Day 5)

(1). Present the finished product and analysis report to the customer.

(2). Confirm with the customer that all requirements have been met.

(3). Perform modification based on the customer’s needs.

5 Testing, analysis and specifications

In this section, testing and analysis to evaluate prototype performance compared to target specifications are conducted. Due to the impact of the COVID-19, not all tests and analyses can be performed. Instead, we provide a description of a systematic testing and analysis procedure. An expected final prototype specification is also provided even we currently do not have a final prototype.

Installation & Safety

5.1 Target specifications of installation

(1). Installation time should be less than 10 minutes and should be completed by a single person using only a wrench.

(2). The prototype contains no sharp edges to prevent accidental injury.

5.2 Testing procedures of installation

(1). Assemble the snowplow and frame, then attach the snow clearing mechanism in the wheelchair, record the total time. One test personnel complete the installation by himself without assistance, as the client does.

(2). Run a full diagnosis for the prototype. See if there are any sharp edges.

5.3 Testing results of installation

The results are listed in the table below.

Table 5-1 Test results of installation

Specification:	**Case:**	**Results**
1.Installation	1.1.Installation time	The installation time of the final prototype is 5 minutes in total. The client only uses a wrench to install the prototype easily.

	1.2.Sharp edges	There are two exposed sharp edges on both sides of the bracket.

5.4 Testing analysis of installation

(1). Installation time meets customer requirements and design objectives. Installation steps are simple enough for an individual client.

(2). Sharp edges still exist, modification of security is required, the specification need is not met.

Stability

Due to the lack of an actual wheelchair, test and analysis can not be fully performed, so we provide the procedures of test and analysis.

5.5 Target specifications of stability

5.5.1 Up-hill stability

(1). The prototype can stably maintain its position on a 30-degree slope uphill (with snow on the surface).

(2). The maximum speed of the prototype when moving on a 30-degree slope uphill (with snow on the surface) is not less than 8.5KM/hour.

(3). The total mass of this prototype is 170KG, and we assume the static friction coefficient of snow is 0.03, and the slope is 30 degrees. According to Newton's second law, to ensure the stability of the prototype on the slope, the friction force along the incline direction should reach 850N.

5.5.2 Down-hill stability

(1). The prototype can stably maintain its position on a 30-degree slope downhill(with snow on the surface).

(2). The maximum speed of the prototype when moving on a 30-degree slope downhill (with snow on the surface) is not less than 8.5KM/hour and not more than 25km/hour.

(3). The friction force along the incline direction should reach 850N.

(4). The braking distance under the maximum speed does not exceed 1.5 meters, and the braking time shall not exceed 2 seconds when the client is driving downhill.

5.5.3 Turning stability

(1). The prototype makes a sharp turn at full speed (8.5KM/Hour) with a turning radius of 0.5m and a tilt angle of no more than 10 degrees.

(2). Assume that the prototype mass is 170KG, and the angle of inclination is 10 degrees. To prevent the prototype from turning, the static friction force between the inner wheel and the ground does not exceed 1674N.

5.6 Testing procedures of stability

5.6.1 Up-hill stability

(1). Using plywood and steel frames, make a ramp that slopes at an angle of 30 degrees and is 10 meters long and 2 meters wide.

(2). Place the prototype on the ramp in the upward direction, and gradually increase the tilt angle to measure the maximum incline degree.

(3). The tester drove the prototype on the ramp, gradually increasing the power to the maximum and recording the speed.

(4). Use pressure sensors and tension sensors to measure the friction of the prototype in both the vertical and horizontal directions of the ramp.

5.6.2 Down-hill stability

(1). Place the prototype on the ramp in the downward direction, and gradually increase the tilt angle to measure the maximum incline degree.

(2). The tester drove the prototype on the ramp, gradually increasing the power to the maximum and recording the speed.

(3). Use pressure sensors and tension sensors to measure the friction of the prototype in both the vertical and horizontal directions of the ramp.

5.6.3 Turning stability

(1). The tester drives the prototype and increases the speed to 8.5KM/hour, make sharp turns, and records the turn radius. Gyros and sensors are installed on the prototype to record the tilt angle.

(2). Use a tension sensor to test the friction of the inner wheels of the prototype at a 10-degree tilt angle.

5.7 Analysis procedures of stability

5.7.1 Up-hill stability

(1). If the prototype is stable at a gradient greater than or equal to 30 degrees, the requirements are met.

(2). At maximum power, test whether the speed of the prototype can reach 8.5KM/hour on a 30-degree slope. If it can, the requirements are met.

(3). If the friction force along the incline direction reaches 850N, then requirements are met.

5.7.2 Down-hill stability

(1). If the prototype is stable at a gradient greater than or equal to 30 degrees, the requirements are met.

(2). At maximum power, test the speed of the prototype. If the speed can reach 8.5KM/hour but does not exceed 25KM/hour on a 30-degree slope, then the requirements are met.

(3). If the friction along the incline direction reaches 850N, then requirements are met.

(4). If the braking distance under the maximum speed does not exceed 1.5 meters, and the braking time does not exceed 2 seconds when the client is driving downhill, then requirements are met.

5.7.3 Turning stability

(1). Check the turning radius and tilt Angle, if the radius is within 0.5m and the incline angle is less than 10 degrees, the requirements are met.

(2). Check the friction between the inner wheel of the prototype and the surface, see if the number is less than 574N or not.

5.8 Final prototype specifications

The table below illustrates all final prototype specifications.

Table 5-2 Final prototype specifications

Metrics:	**Units:**	**Targets:**
Weight (with the snow plow)	KG	170
Seat Height	Inch	20
Seat Width	Inch	17
Backrest Height	Inch	15
Backrest Width	Inch	16
Wheel	Inch	16
Battery Weight	lbs	7.5*2
Battery Voltage Output	V	12
Battery Capacity	AH	6*2
Battery Charging Time	Hour	6-8
Maximum Speed	KM/hour	25
Weight Capacity	lbs	265
Braking Distance	M	1.5
Braking Time	S	2
Turning Radius	M	0.8
Climbing Ability	Degree	30
Snow Clearing Width	Inch	31
Snow Clearing Depth	Inch	12
Installation Time	Minute	5

6 Functional Testing and Usability Analysis

A detailed testing and analysis procedure for functionality is provided, along with the method for documenting the usability of the final solution. The process of going through the iterative round with the user to ensure optimal usability is also included. The table below shows the function, specification, and case of the functional testing procedure.

Table 6-1 Function, specification and case

Function	Specification	Case
1.Snow clearing ability	1.1 Dry snow	Test prototype on the sand
	1.2 Wet snow	Test prototype on the wet sand(with different terrain)
	1.3 Clearing width	Measure the width of ruts left by the prototype in the snow or the sand(with different terrain)
	1.4 Clearing depth	Measure the depth of ruts left by the prototype in the snow or the sand(with different terrain)
	1.5 Slop surface	Set different incline angles, perform all cases above
	1.6 Snow clearing efficiency	Test the speed of prototype on dry snow, wet snow, and slop surface

2.Mobility	2.1 Bituminous street(with snowy surface)	Use sand to simulate snow, test mobility factors of prototype on the bituminous street
	2.2 Sidewalk(with snowy surface)	Use sand to simulate snow, test mobility factors of prototype on the Sidewalk
	2.3 Obstacle crossing ability	Set up different obstacles(bricks, bottles, cardboard boxes) to test the prototype's obstacle crossing ability
3.Weight	3.1Weight of the snowplow	Use a variety of electronic scales to measure the weight of the snowplow
	3.2Weight of the attachment bracket	Use a variety of electronic scales to measure the weight of the attachment bracket

Testing procedure

6.1 Snow clearing ability

6.1.1 Dry snow

(1). Use sand to simulate the snow on the surface, or take the prototype to a ski resort for testing.

(2). The tester operates the prototype on the test filed.

(3). Measure the speed at which the prototype is moving, check for loose components, and check if the prototype is impassable. Check the steering of the prototype on the test site.

(4). If running continuously for 100 meters (round trip) without failure, close the prototype.

(5). Check the snow clearing width, check the snow clearing depth.

6.1.2 Wet snow

(1). Use sand to simulate the snow on the surface, or take the prototype to a ski resort for testing. Mix the water and sand well and spread them evenly on the test site to simulate the wet snow scene.

(2). The tester operates the prototype on the test filed.

(3). Measure the speed at which the prototype is moving, check for loose components, and check if the prototype is impassable. Check the steering of the prototype on the test site.

(4). If running continuously for 100 meters (round trip) without failure, close the prototype.

(5). Check the snow clearing width, check the snow clearing depth.

6.1.3 Clearing width

(1). The tester operates the prototype on the test filed.

(2). The tester shuts down the prototype after continuous operation for 100 meters (round trip).

(3). Measure the width of the track.

6.1.4 Clearing depth

(1). The tester operates the prototype on the test filed.

(2). The tester shuts down the prototype after continuous operation for 100 meters (round trip).

(3). Measure the depth of the track.

6.1.5 Slop surface

(1). Using plywood and steel frames, make a ramp that slopes at an angle of 30 degrees and is 10 meters long and 2 meters wide.

(2). Perform all testing procedures from 1.1.1 and 1.1.2.

6.1.6 Snow clearing efficiency

(1). Perform all procedures from 1.1.1, 1.1.2, 1.1.3, 1.1.4, and 1.1.5.

(2). Check the time consumption.

6.2 Mobility

6.2.1 Bituminous street(with snowy surface)

(1). Spread the sand evenly on the bituminous street to simulate the wet snow scene.

(2). Test the speed, braking time, and turning radius.

6.2.2 Sidewalk (with snowy surface)

(1). Spread the sand evenly on the sidewalk to simulate the wet snow scene.

(2). Test the speed, braking time, and turning radius.

6.2.3 Obstacle crossing ability

(1). Set up different obstacles(bricks, bottles, cardboard boxes) to test the prototype's obstacle crossing ability.

6.3 Weight

6.3.1 Weight of the snowplow

(1). Use a variety of electronic scales to measure the weight of the snowplow

6.3.2 Weight of the attachment bracket

(1) . Use a variety of electronic scales to measure the weight of the attachment bracket.

Testing analysis procedure

This sector lists all requirements that the prototype needs to meet for optimal usability and functionality.

6.4 Snow clearing ability

6.4.1 Dry snow

(1). Snow clearing width: 31 inches.

(2). Snow clearing depth: 12 inches.

(3). The structure remains stable during operation.

(4). The maximum operating speed is no less than 8.5KM/hour.

6.4.2 Wet snow

(1). Snow clearing width: 31 inches.

(2). Snow clearing depth: 12 inches.

(3). The structure remains stable during operation.

(4). The maximum operating speed is no less than 8KM/hour.

6.4.3 Clearing width

(1). Snow clearing width: 31 inches.

6.4.4 Clearing depth

(1). Snow clearing depth: 12 inches.

6.4.5 Slop surface

(1). The prototype is stable at a gradient greater than or equal to 30 degrees.

(2). At maximum power, the speed of the prototype can reach 8.5KM/hour on a 30-degree slope.

(3). Snow clearing width: 31 inches.

(4). Snow clearing depth: 12 inches.

(5). The structure remains stable during operation.

(6). The maximum operating speed is no less than 5KM/hour.

(7). The friction force along the incline direction reaches 850N

6.5 Mobility

6.5.1 Bituminous street(with snowy surface)

(1). Maximum speed reaches 8.5KM/hour.

(2). Turning radius is less than 0.9m.

(3). Incline angle is less than 12 degrees.

(4). The friction between the inner wheel of the prototype and the surface is less than 500N.

6.5.2 Sidewalk (with snowy surface)

(1). Maximum speed reaches 8KM/hour.

(2). Turning radius is less than 0.9m.

(3). Incline angle is less than 8 degrees.

(4). The friction between the inner wheel of the prototype and the surface is less than 300N.

6.5.3 Obstacle crossing ability

The prototype can move across:

(1). Steps(5cm)

(2). Bricks(5cm)

(3). Water bottle

(4). Branches

Or any other obstacles that are similar in size.

6.6 Weight

6.6.1 Weight of the snowplow

(1). The weight of the snowplow is less than 2.5KG.

6.6.2 Weight of the attachment bracket

(1). The weight of the attachment bracket is less than 5KG.

Usability analysis procedure

The picture below provides a full illustration of our usability analysis procedure.

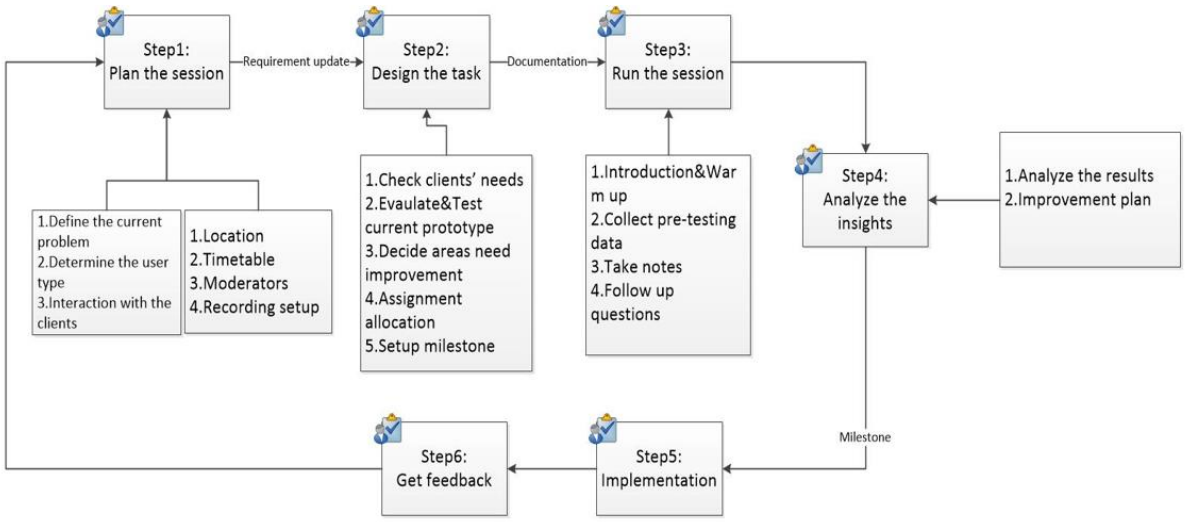


Figure 6-1 Usability analysis procedure

Iterative design procedure

To ensure optimal usability, we utilize Iterative Engineering Design Process(IEDP) and iteratively interact with our clients to update their new requirements. The picture below is our design process.

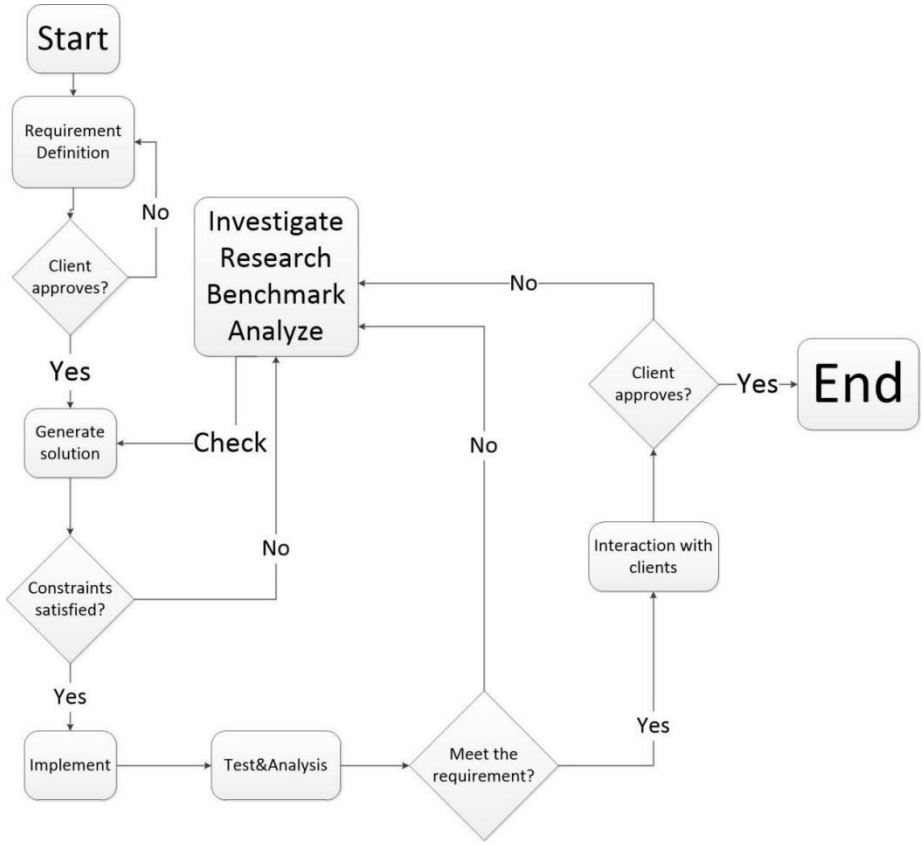


Figure 6-2 Iterative design procedure

7 Scalability

Based on the definition of scalability, we analyze three aspects: scaling production or manufacturing, scaling functionality, and scaling user population.

7.1 Scaling Production or Manufacturing

In order to analyze this aspect, we analyze from six aspects: material supply and material selection, part features, part handling, tolerances, and precision, tools, processes.

7.1.1 Material Supply and Material Selection

In our snow shovel, except for the 3D printed part of the intermediate connector, other parts are available on the market, and it is universal. Except for the snow shovel, there have fluctuations in production and prices due to seasonal problems. Other parts are available all year round. Availability. In the installation, we used milling, lathe, laser cutting, and welding techniques, all of which are often used in traditional handicrafts. In the 3D printing part, we use a more common cuboid to make a V-shape snow-breaking connector and transform the cuboid to form a groove to insert a snow shovel, which is also the only part in the design that is not standardized. The materials we use are mostly two common materials, plastic and iron, according to customer needs. A plastic snow shovel can achieve on Amazon. Well-known sellers have mass-produced, and the production line is guaranteed. For some connection rods which are made by iron, customers can find the mass-produced stocks at Canadian Tire and IKEA; the nuts and screws used for the connection can also be purchased from Canadian Tire and IKEA.

7.1.2 Part Features

We spliced the snow shovel into two parts, the snow shovel and the connecting rod, and only four sets of screws and nuts were used in the assembly. The materials we used this time are all available in Canada, the shapes are standardized, the surface does not need

to be too smooth, and the edges do not need fine processing. The requirements for sanding processing are not high, which can reduce the cost.

7.1.3 Handling Parts

Our snow shovel can stand on the ground by itself, and its weight is very light. The user can preferentially fix the connecting rod to the electric wheelchair, place the snow shovel in a suitable place, and fix it with screws. No need to lift the snow shovel, so the user does not need to take extra effort to assemble; it's very easy.

7.1.4 Tolerance and Precision

Have none of the tolerance requirements, the operation is very simple, you can adjust the depth of the connector slot and the height of the connector according to different snow shovel sizes. The measurement also mainly measures some basic parameters around the electric wheelchair. Customers can use it immediately without additional adjustment.

7.1.5 Tools

During the production process we used 3D printing, milling, lathe, welding and laser cutting. These are standard tools, and customers only need to install nuts when fixing, and they can be fixed with rolled strip, which can be done by hand without additional tools.

7.1.6 Processes

It only takes three to five minutes for one person to install, and the installation process is simple.

7.2 Scaling Functionality

7.2.1 Simplicity

Each mechanism only one function; Each component is strong enough; And the structure is simple, no unnecessary features

7.2.2 Clarity

All service operations are immediately accessible on the outer surface of the snow shovel and the user can easily reach. When component fail, for example, the screws broken, users can easily buy a new one in Canadian Tire or IKEA, they are cheap and can easily access. And our snow shovel is an open concept design, it can be easily control and repair. As for V-shape, the theory can be searched on google, and some products are still sold on Amazon.

7.2.3 Unity

Each component is strong enough to resist the static and dynamic loads. When the electric wheelchair is in motion, the snow shovel is subject to resistance from the snow and gradually increases with increasing speed. So when we do the testing, we will add 'some 'margin speed, which means a little faster than the maximum speed of the wheelchair to make sure it can work properly.

7.3 Scaling User Population

7.3.1 Supporting More Users

On our connection rod, there has several holes, users can select which pair of holes they want based on the width of their wheelchair. Moreover, there have several holes on the snow shovel's rod, and users can adjust the height as they want. The connection design is suitable for most wheelchairs.

7.3.2 Use in More Cases

In our test, we use sand instead of snow, so it can be used to clean sand. When the road is clear of snow, the sidewalks, narrow paths, and other places where snow shoveling is not easy to handle, it is prolonged to use manual snow shoveling, and the staff can use our wheelchair to clean up with our snow shoveling.

8 Quality

8.1 The customer requirements and their importance.

Our customer requirements are determined by investigating existing snow shovels on various websites with more purchase records as our market research and by communicating with customers.

In the process of talking with customers, because this product is mainly targeted at polio patients and this group is relatively small. So we mainly communicated with our customers to listen and understand his main needs, and asked him to help us fill out a customer survey (refer to Appendix 1). The main purpose is to determine what he thinks the importance of customer requirements. We use this questionnaire as the main criterion for determining which needs are more important. In the process of market research, we recorded and summarized the customer requirements expressed in user reviews and the number of mentions as one of the criteria for determining importance of customer requirements. But since there are almost no snow shovels for wheelchairs on the website with many reviews, we found snow shovels that can be installed on other tools such as cars. The customer requirements of these snow shovels are still a little different from those used in wheelchairs, so we take this as a small assessment of user needs and importance. Through the above comprehensive analysis, the customer requirements we identified are as follows:

Table 8-1 Customer attributes and bundles of CAs

Customer attributes and bundles of CAs		
Primary	**Secondary**	**Tertiary**
Good user experience	User safety	Stay stable while uphill
		Stay stable while downhill
		Stay stable while turning
		Doesn't scratch by sharp edges during installation
	Assembly	Easy to install and use
	Portable	The structure is lightweight
		No additional electrical device
Good performance for product	Ability to clean snow	Snow clearing efficiency is good
		Easy to clean deep and shallow snow
		Easy to clean dry and wet snow
	Mobility	Can smoothly pass through various roads while clear snow
		Can smoothly pass through various obstacles
Budget	Material price	Budget is below 100 dollars

Table 8-2 The importance of customer requirements

Bundles	Customer requirements	Relative importance (%)
User safety	Stay stable while uphill	11
	Stay stable while downhill	11
	Stay stable while turning	9
	Doesn't scratch by sharp edges during installation	5
Assembly	Easy to install and use	10
Portable	The structure is lightweight	5
	No additional electrical device	4
Ability to clean snow	Snow clearing efficiency is good	10
	Easy to clean deep and shallow snow	8
	Easy to clean dry and wet snow	7
Mobility	Can smoothly pass through various roads while clear snow	9
	Can smoothly pass through various obstacles	8
Material price	Budget is below 100 dollars	3
		total 100

8.2 Design specifications and how to change the design

In order to satisfy our customer requirements, we intend to make changes to the structure of snow shovel and the structure of the connecting cod in our design specifications. After discussions among our team members, we came up with the specifications are reduce the weight of snow shovel, lower the center of gravity and etc. in table 3. We use +and – to represents for the change. And + represents for the increase and – represents for the decrease.

Table 8-3 Design specifications how to change the design

Engineering characteristics	Structure on snow shovel	(+) Reduce the weight of snow shovel
		(+) Lower the center of gravity
		(-) sharp metal edges
		(-) Distance between the snow shovel and the ground
		(+) Struture made of PLC
		(+) V shape angle
	Structure on the connecting rod	(-) Number of metal connecting rods
		(-) Number of screws and nuts used

8.3 The relationship between customer requirements and design specifications and the strength of the relationship

We use numbers to establish the strength of relationships.

In table 4, we use 4 numbers to illustrate the strength of the relationship. The correspondence between four numbers and strength is shown in table 5.

Table 8-4 Relationship matrix

				Engineering characteristics								
				Structure on snow shovel							Structure on the connecting rod	
				(+) Reduce the weight of snow shovel		(+) Lower center of gravity	(-) sharp metal edges	(-) Distance between the snow shovel and the ground	(+) Struture made of PLC	(+) V shape angle	(-) Number of metal connecting rods	(-) Number of screws and nuts used
			Relative importance									
Customer requirement	User safety	Stay stable while uphill	11	1	2							
		Stay stable while downhill	11	1	2							
		Stay stable while turning	9	1	2							
		Doesn't scratch by sharp edges during installation	5			2						
	Assembly	Easy to install and use	10									
	Portable	The structure is lightweight	5	2					1		1	
		No additional electrical device	4						2			
	Ability to clean snow	Snow clearing efficiency is good	10					2				
		Easy to clean deep and shallow snow	8							2	2	
		Easy to clean dry and wet snow	7							2		
	Mobility	Can smoothly pass through various roads while clear snow	9					-1				
		Can smoothly pass through various obstacles	8					-1				
	Price	Budget is below 100 dollars	3						1		1	1

Table 8-5 Strength of relationships

relationships	
2	Strong positive
1	Medium positive
-1	medium negative
-2	Strong negative

8.4 Objective metrics and comparison to competitive products

We first determined the metrics according to the design specifications, and then we determined the product information of competitors by querying the official website information and customer reviews and asking the product customer service. Finally we set our target specification values in table 6.

Table 8-6 Objective measures

		Engineering characteristics							
		Structure on snow shovel						Structure on the connecting rod	
		(+) Reduce the weight of snow shovel	(+) Lower the center of gravity	(-) sharp edges	(-) Distance between the snow shovel and the ground	(+) Struture made of PLC	(+) V shape angle	(-) Number of metal connecting rods	(-) Number of screws and nuts used in installation
Objective measures	Measurement units	kg	cm	number	cm	number	degree	number	number
	Ideal snow shovel	5	15.75	1	0.8	3	90	6	6
	Competitor 1	2.6	6.6	4	0.5	2	180	2	8
	Competitor 2	37.2	24.05	12	0.3	0	180	10	0

In the comparison of competing products, there is almost no snow shovel for wheelchairs which have some sales on the market. Therefore, we compared the snow shovel in our prototype with other snow shovels that can be used in vehicles and other vehicles to compare its performance in snow removal and other aspects, and compared the basic performance of a wheelchair with a snow shovel and the performance of an ordinary wheelchair. To verify that the final prototype has good mobility.

Figure 8-1 Competitor 1 and 2

Table 8-7 Comparison between snow shovels

		Ideal shovel	Competitor 1	Competitor 2
Climbing Ability	Degree	30	Depends on the structure of the connected vehicle	
Snow Clearing Width	Inch	20	20.59	60.8
Snow Clearing Depth	Inch	12	5.2	18.9
Installation Time	Minute	3	3	5
Snow shovel Weight	Kg	5	2.6	37.2
Adjustable height	Inch	10	3	1
Average Snow removal speed	Km/hour	6	Depends on the power of the connected vehicle	

These two competitive products are the two products with the highest scores in our previous benchmark. The parameters of the competing products we check the merchant description on the website and ask the seller on the Amazon [1][2]and other websites for some parameters such as installation time. Besides, we inquired the customer and found out on the website the type and performance of the wheelchair [3] he is currently using.

Figure 8-2 Wheelchair

Table 8-8 Comparison between wheelchair and with shovel

		Wheelchair with ideal snow shovel	Wheelchair
Weight(with the snow plow)	KG	170	166
Maximum Speed	KM/hour	9.8	9.9
Weight Capacity	lbs	265	300
Turning Radius	M	1	0.8
Braking Distance	M	1.5	1.6
Braking Time	S	2	2.5
Obstacle crossing ability	CM	5	5

8.5 Comparison of competitive products and the perception of how much they satisfy customer needs

Based on the test results and querying the customer reviews and rating status of two competing products on the website, we have calculated customer perceptions for the ideal model and two competitors in table 8. It can be seen from the results that our ideal snow shovel has a higher score compared with competitors' products, meets customer needs more, and has a greater competitive advantage.

Table 8-9 Customer perceptions

Bundles	Customer requirements	Relative importance (%)	Customer perceptions 5-best 1-worst		
			Our ideal shovel	Competitor 1	Competitor 2
User safety	Stay stable while uphill	11	4	4	4.5
	Stay stable while downhill	11	4	3.5	4
	Stay stable while turning	9	4	4	4.5
	Doesn't scratch by sharp edges during installation	5	4.5	4	2.5
Assembly	Easy to install and use	10	4.5	4	3
Portable	The structure is lightweight	5	5	4.5	1.5
	No additional electrical device	4	5	3.5	3
Ability to clean snow	Snow clearing efficiency is good	10	3.5	4	4.5
	Easy to clean deep and shallow snow	8	3.5	3.5	4
	Easy to clean dry and wet snow	7	3.5	3.5	4.5
Mobility	Can smoothly pass through various roads while clear snow	9	4	3.5	4
	Can smoothly pass through various obstacles	8	3.5	3.5	4
Price	Budget is below 100 dollars	3	5	3.5	1
		Total value	4.03	3.775	3.755

8.6 Comparison between each design specification and how changes in these specifications may affect each other

Table 8-10 Relationship between specifications

		Engineering characteristics											
		Structure on snow shovel								Structure on the connecting rod			
		(+) Reduce the weight of snow shovel	(+) Lower the center of gravity	(-) sharp metal edges	(-) Distance between the snow shovel and the ground	(+) Struture made of PLC	(+) V shape angle	(-) Number of metal connecting rods	(-) Number of screws and nuts used	(+) Reduce the weight of snow shovel	(+) Lower the center of gravity	(-) sharp metal edges	(-) Distance between the snow shovel and the ground
Engineering characteristics	Structure on snow shovel	(+) Reduce the weight of snow shovel		-1				2					
		(+) Lower the center of gravity	-1					1		1			
		(-) sharp metal edges											
		(-) Distance between the snow shovel and the ground		1									
		(+) Struture made of PLC	1										
		(+) V shape angle											
	Structure on the connecting rod	(-) Number of metal connecting rods	2	1									
		(-) Number of screws and nuts used											

In table10, we analyzed the relationship and impact between these specifications, we use 4 numbers to illustrate the strength of the relationship. The correspondence between four numbers and strength is shown in table 5.

8.7 Constraints

In this design, we have some inevitable constraints.

(1) Budget

We have 100 Canadian dollars in total for our budget, thus we should limit the expense and drop the cost overruns materials and designs.

(2) Time

We need to design, make and test our product in no more than 3 months.

(3) Technical limits

The techniques we use such as 3D printing and all the machines we can use are in makerlabs. If we print with a free 3D printer, we will be limited by the size of the printer and cannot print a product that meets the requirements at one time. If we use a large paid printer, we will also be limited by the long printing time and price.

(4) Wheelchair-power

This whole structure is powered by the battery in the wheelchair which is limited, thus the structure for snow shovel should not be overweight or cost too much power.

(5) Manpower

All tasks in this project will be done by our 5 members, thus we need to balance the task volume for each of us.

9 Sustainability Analysis

9.1 Sustainable Development

9.1.1 Social Impact

A large proportion of people in society need wheelchairs, and they often cannot participate in social life and work. The improvement creation of this wheelchair gives a working opportunity to disabled people who usually can't find a job. They feel involved and needed by society through work, and they learn to take social responsibility and cooperate with others through communication with colleagues and employers. Using a wheelchair to work can increase the amount of activity and reduce the possibility of users suffering from health complications. Besides, other family members can also be freed to participate in community activities and employment. It increases the diversity of the workplace because disabled people can also help to shovel snow and also reflects the fairness and universal human rights of society for all practitioners.

But at the same time, competition for jobs will increase. Because the society's employment system for the disabled is inadequate, their benefits cannot be guaranteed and may face discrimination.

9.1.2 Environmental Impact

The snow shoveling wheelchair can reduce the use of snow shoveling to a certain extent, and in the short term, the frequency of industrial salt spraying and snow shoveling can be reduced. At the same time, there is no need for professional personnel to shovel snow. Instead, residents in residential areas are allocated to corresponding fields, which reduces the carbon emissions of transportation caused by snow shovel trucks and the waste of human resources of snow shovel personnel. In the long run, it can reduce the production volume of related equipment such as snow shovels and save the manufacturing of non-recyclable consumables. Relevant departments can also reduce

the environmental maintenance funds invested in this part to develop other beneficial causes.

9.2 Risk assessment

9.2.1 Frostbite Risk

Prolonged outdoor low-temperature work may cause discomfort and frostbite. Therefore, it is necessary to pay attention to the sufficient number of breaks and rest time. At the same time, users should try to wear materials with low thermal conductivity and low hygroscopicity to make cold-proof clothing, and wear warm gloves and hats. Avoid binding hands and feet to affect blood circulation. In the later modification, consider adding a snow-proof roof or adding heating to the seat cushion.

9.2.2 Cold metal sticky skin damage

In winter, outdoor metal is already extremely cold, and human hands are at high temperatures. When people touch the metal, cold and heat exchange occurs. The temperature on the hand suddenly drops, and the skin and the metal stick together, so there will be The skin is sticking off. We try to replace cold metal with other materials such as plastic during our own tests and add a layer of protection to all metal parts that may encounter users. Remind the user to wear gloves when writing the user manual.

9.2.3 Security risk

There is a danger of overturning when there is too much snow on the snow shovel or problems with the operation of the wheelchair, such as skidding. So we need to increase the weight of the wheelchair itself, and put some straps on the chair that can hold the user. Add anti-skid measures to the wheel if possible and test multiple times.

9.2.4 Scratch hazard

Due to the shape chosen, the user is at risk of being scratched by sharp edges. Therefore, in the test, various angles were tried to achieve the purpose that the shovel did not contact the user as much as possible. Purchased snow shovel material is also edge passivated.

9.3 Life cycle assessment

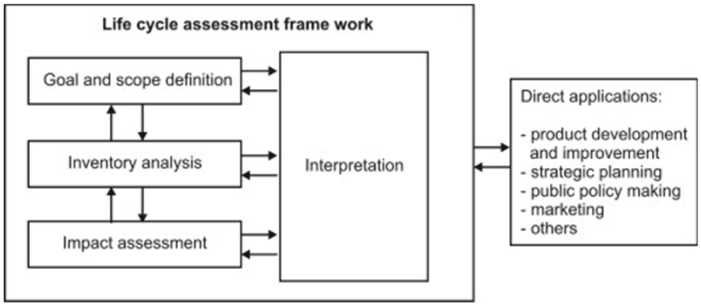


Figure 9-1 Life cycle assessment frame work

9.3.1 Goal and scope definition

Allows users to use a snow shovel on a wheelchair to complete snow removal. On the basis of ensuring safety, the optimized design makes it more lightweight, sustainable and portable and keeps the budget within a controllable range.

Shovel dry wet snow and snow of different thicknesses are used as test conditions. From the design of the snow shovel production to the snow shovel can no longer complete the snow removal function for the entire life cycle of the product. All inputs take account of incidental environmental, energy, and economic factors, which are indirect emissions of pollution and indirect energy consumption. The design is based on a reasonable technical environment.

9.3.2 Inventory analysis

Table 9-1 Inventory

Item	Cost ($)
Snow shovel	68
Strapping tape	5
Glue gun	25
Glue stick	5
Labor	0

Bus fare	0
Sustainable parts from old model	0
3D print part	0
Wheelchair from client	0
Screw set	12
Tool kit	10
Total	125

9.3.3 Impact assessment

(1) Evaluation of environment impact

In contrast to snowplow cars, which use large amounts of gasoline, wheelchairs need only be recharged on a regular basis. This reduces large amount of carbon emissions and is environmentally friendly.

(2) Evaluation of energy impact

Snow-plowing vehicles takes less time to remove per unit snow compared with snow-plowing wheelchair and are more efficient.

(3) Evaluation of economy impact

The implementation of the wheelchair can promote the employment of the disabled, place a large number of jobs, and enable users to obtain economic benefits instead of subsidies, which will increase the output of related industries and thus stimulate economic growth. However, it has reduced the expenditure of the municipal government department on the maintenance of the public environment, which has caused some positions to no longer need to be hired.

（4）Interpretation

Reduce the cost required for a unit of snow shoveling wheelchairs and increase the investment in technology to continuously upgrade the model;

Make most of the advantages of the residents' communities widespread distribution, vigorously promote the product;

Conduct more research and experiments to make the product more in line with consumer expectations;

Improve related disabled people Employment laws and regulations.

9.4 Sustainable materials

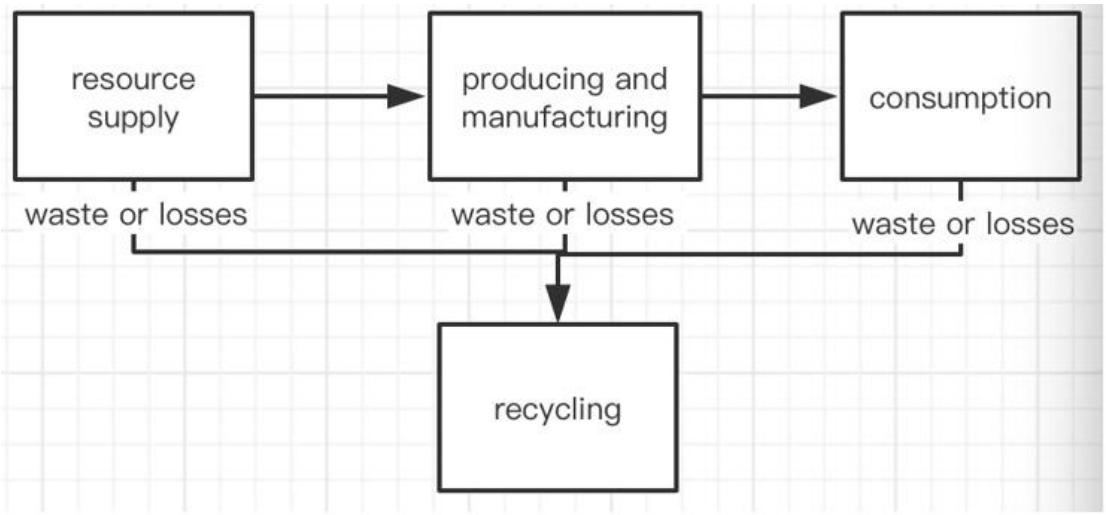


Figure 9-2 Material flow

The waste or loss in manufacturing and assembling snow-plows and wheelchair can be recycled and reused. When the life of the snow shovel wheelchair is over, his various parts can be removed for recycling.

9.5 Design for sustainability

Consider more about user need instead of outcome;

Have group meetings from time to time to maximize mass, energy, space, time efficiency;

Make sure there is no risk before putting into implementation;

Before completing the model, discuss and modify the drawing multiple times to pick the best answer instead of all put into implement;

Minimize the number of parts to control waste of raw materials and shorten assembly time to extend service life;

Choose a wheelchair with low energy consumption for experiments and try to simulate on snowy days to reduce waste of resources caused by environmental simulation;

9.6 Cradle to Cradle

The whole design process follows the 3R principle——Reduce, Reuse, Recycle;

Try to use model parts from old design;

Reuse surplus materials from school laboratory;

Use degradable materials or reusable metals to extend usage time;

Never use raw materials that cause environmental pollution;

Collect e-waste generated in the design, and carry out unified harmless treatment and resource recycling;

10 Usability and reliability analysis

10.1 Usability analysis

The usability design of our products is discussed from the following five points:

• Effectiveness: V-shaped snow shovel is applied to help customers shove more than 85% of snow on the walking surface to meet expectations

• Efficiency: V-shaped light snow shovel is used to help customers to remove 70% of the snow when the wheelchair is moving fast, that is, snow at a speed of 20 kilometers per hour

• Engagement: Our snow shoveling equipment is mainly in dark tones, and the central prism can be changed to different colors, which can give people a pleasant viewing experience in the snow.

• Error Tolerance: The connection of our products is tightened with screws, and there are small parts connected between each module. If the parts are broken, you can use a wrench to remove and update

• Ease of Learning: Because the material is light and the pieces are simple, it is easy to load and unload. One person tightens the screws on both sides for less than 5 minutes. And as long as the integrated snow shovel has completed the steps of installing it to the wheelchair, it can be used directly by activating the wheelchair.

10.1.1 Understand users

Users are people who suffer from disability and need to use a wheelchair. The age can vary from teenagers to elderly. They want to do something for the society by helping snow plowing.

10.1.2 Understand tasks

Users know their own needs and learn how to operate;

Users who have trouble assembling the wheelchair;

Users can’t express their own needs clearly;

Users who have trouble in using the wheelchair;

Users who have needs other than snow-plowing;

Users who have a small figure or light weight are easily to fall off wheelchair;

Users who have difficulty in staying outside for a long time;

10.1.3 Pick representative sets of tasks

Users want the wheelchair weight to be as light as possible;

The wheel chair needs to be able to be assembled quickly and easily;

Try to add a heating equipment;

Add some straps for fixing seats;

The wheelchair remains stable even hits something hard;

The wheelchair will not slip in the snow;

Most importantly, the snow-plowing wheelchair has to be able to shovel snow under different conditions;

10.1.4 Pick a representative set of users

We focus on disabled people who have basic ability to operate a wheelchair, most likely young people who have more access to modern technology. We will test different kind of people later. But first we focus on that type since our first client is a teenager who wants to help plow neighbourhood snow and we have a clear mind of what he wants.

10.1.5 Determine what questions need to be answered about usability

How long they need to be able to operate the wheelchair?

Can they do all installation themselves?

How long do they need to assemble the parts together?

Do they need to memorize anything before use?

Are there any kind of people who should be forbidden from using?

How long can they use snow shovel for once?

Will they able to snow plow in different kinds of area?

Will they feel unsatisfied and return the wheelchair?

What function they like most?

Do they enjoy sitting on the snow-plowing shovel?

Are the snow-plow able to operate under different weather conditions?

10.2 Reliability analysis

The design can be divided into two large blocks, snow shovel and wheelchair. For the snow shovel, the connection stability of its components needs to be tested to a certain degree, and the selected materials must also have certain evaluation standards. And the connection and assembly of snow shovel and wheelchair are also critical. So we will discuss it in three parts.

10.2.1 Stability from the connection

(1) Connection of snow shovel face with cross bar

Because the connection is made of screws, it is easy to replace, and the price is low. The situation where damage may occur is the collision of the link, so artificial shaking is used to test the time when the connection reaches an unstable state, and then the actual time is used to estimate the real Life.

Test results: We tried to make each group member perform an experiment because the magnitude of the strength is different; the average value of the loosening time is selected. After about 30 minutes of hand-cranking, the connection between the snow shovel and the crossbar is loose. The service life is estimated according to the usual frequency of use, two days one time, and once for half an hour. And because the actual anti-vibration strength between the snow shovel and the ground is smaller, it is basically equivalent to changing the screws once a week. This is not bad for a frequent snow shovel.

(2) Connection of snow shovel and wheelchair

The method and result go same as before.

(3) Deformation resistance of snow shovel material

Due to the high price of a snow shovel, in order to control the budget, we cannot use the destructive test method to estimate the service life. Therefore, we need to search the snow shovel's official website to search its service life. The specific service life was checked through the purchase website for two years. However, this design is different

from simply using a snow shovel. Bundling with a wheelchair means longer exposure to low-temperature environments or friction damage to the ground, and may shorten the time. Therefore, the estimated service life is one year, in winter and early spring. Use, the use time is about half a year, so based on the natural year, the reliability within two years is guaranteed.

10.2.2 Wheelchair reliability

(1) Wheelchair battery

The battery of the wheelchair is rechargeable, and the specific parameters and life can be obtained by querying the useful life data of the official website. You can get it by reading the instruction manual of the wheelchair. As long as you pay attention to charging and maintenance, do not keep the switch on for a long time, which will cause the battery to continue to discharge and cause the battery to run out. You can reach the standard service life.

(2) Wheelchair tire

Wheelchair tire life can be obtained by querying the official website data, but if long-term exposure to low temperature environments or friction damage to the ground, and based on the actual conditions of the use environment, industrial salt may be sprinkled on the ground to melt snow, which will lead to tire use The time is shortened, so we can add rubber sleeves to achieve anti-skid and anti-freeze purposes, increasing reliability and service life.

11 Conclusions and Recommendations for Future Work

The process of starting and delivering the project was a complex learning process for members of the design team. Teamwork, time management, problem-solving, and budgeting skills must be developed in order to achieve design solutions for design days. Time management was a particularly difficult skill to master for a design team because team members seem to have opposite schedules. It was also complex to solve problems, because there were many hidden flaws in the design that were initially overlooked, and it took a lot of innovation and creativity to fix those weaknesses later on in the road. The difficulties of dealing with constraints such as a very limited $100 budget could not be underestimated but could be solved by using free waste material in the lab. Overall, we learned a lot of technical and project-oriented skills this semester. Next, we want our customers to test our prototypes and get feedback, continue to improve our design, and possibly turn the concept into a small business.

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APPENDICES

APPENDIX I: Customer needs survey

Customer needs survey

In order to design a more suitable snow plow for you, we invite you to complete this survey. It might take you several minutes, thanks for your patience.

Part I Performance

The survey include 5 ranks, for each question, you can choose one of them:

1- Poor 2- not that poor 3- not bad 4- good 5- excellent

1. The weight of the snow plow (3)
2. Easy to assemble (2)
3. The ability to clean snow as expect (3)
4. Easy to store (4)
5. Safety (4)
6. Lifetime (4)

Part II Expected value

In this part, please rank the above 6 performances according to how important you think they are.

Answer: (5,2,3,6,4,1)

Part III Special for you

Do you have any special requirements and hopes for snow plow?

Hope my son will be able to use this plow to help our community and thereby feel he is a contributing member of society.