Badminton Back–Saver

Final Report

SYDE 161
Group Number 5

Ronald Kielstra - 20213399

Spencer Hivert - 20559838

Zachariah Pustowka - 20552841

Clara Saw Wing Lau - 20566366

Woody Lau - 20564316

Jerry Jihao Bai - 20561350

Faculty of Engineering
Department of Systems Design Engineering

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Course Instructor: Doctor Matt Borland

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Abstract

This report presents a new machine designed for use by badminton players, coaches, and other users of a gymnasium to eliminate repetitive stress injuries and reduce time wasted between exercises as a result of picking badminton birdies off the gym floor. Consultation with users and industry research is used to generate a list of customer requirements, which are translated into measureable engineering specifications through a Quality Function Deployment process. These specifications are used to design a series of prototypes, each of which performs the required functions of picking the birdie off of the floor, moving about the gym floor, and moving the birdie to a more accessible collection area. A preferred prototype is selected using Computational Decision Matrix and user is testing carried out, which results in several changes to the final design. The resulting machine presented in this report incorporates elements from two prototypes to accomplish all basic functions, including a rotating brush to lift birdies from the floor, a conveyor belt to move birdies to a catch basket, and several elements that contribute to ease of operation, including a telescopic handle and batteries. A lifecycle analysis for the device is included, which notes that while the use of recycled materials promotes sustainability in production, there are also several areas for improvement relating to the use of batteries for power and the production cycle. Finally, the report concludes by summarizing the development process and offering recommendations for future iterations.

Situation of Concern

For badminton players, coaches as well as gym attendants, the process of gathering large amounts of birdies from a gymnasium floor after repetitive training and during the clean-up is not only time consuming, but it also contributes to several health problems. These problems are due to the amount of time-spent bent over as the action of manually retrieving a birdie forces the arch in one's back to dramatically fluctuate, ultimately putting a serious strain on the lower back [1].

In order to remedy this problem, a device must be designed to be used by badminton players and coaches as well as gym attendants to collect badminton birdies from a gymnasium floor [2] and deposit them in a catch basket in a timely manner and eliminate the need to extensively arch one's back for extended periods of time. This device possesses several engineering requirements: it must operate effectively when pushed between the upper and lower limits of an average person's walking speed which is between 3 and 6 km/h [3]. Next, this device must also damage less than 1% of the birdies it handles and be able to collect a minimum of 35 birdies per minutes. This rate was derived from an average badminton players practice repetition rate as well the rate of the top badminton trainer on the market - The Knight Trainer [4] which shoots badminton birdies at the player at select time intervals.

Customer Requirements & Engineering Specifications

A Quality Function Deployment (QFD) exercise was completed based on primary, secondary and tertiary personas, guided by the requirements and constraints developed in the Situation of Concern chart. In addition to these documents, we relied on the personal experience of one of the authors of this report - Clara Lau, who is a regular badminton player – as well as consultation with a gym attendant at the Columbia Ice Fields gymnasium [5]. The feedback from these two sources was critical to the QFD process, as they were also able to offer insight into two other potential users [6]: recreational badminton players and badminton coaches.

Evaluating our machine's functions and sub-functions with these customers' needs in mind, as well as those of the manufacturer, helped us set criteria for the machine's success. The machine's first primary function, collecting birdies from the gym floor, resulted in customer requirements such as the machine not damaging birdies and the collection speed of the machine. The second primary function, the movement of the machine around the gym by the user, required the machine to be easy to push and steer, easy to adjust to the user, and stable during operation. Finally, the third primary function, depositing the birdies in a collection basket, meant that the machine would be required to provide easy access to the birdies while ensuring that they didn't get stuck or jammed in the machine during operation.

This analysis resulted in a list of customer requirements (CRs); this list was then prioritized according to each CR's relative importance to each potential user, using a fixed sum of 100. For example, to the badminton player, the most important customer requirements were that the collection time and the damage caused to birdies be minimal. However for the gym attendants, the customer requirements deemed most important included that the device be very easy to manoeuvre as well as having a minimal collection time. With these weightings in mind, we did some market research to compare existing options with our users' needs. Our research failed to turn up a competitor device, however, we found several devices that accomplish a similar function: the Newgy Pongpal [7], a tennis ball collector cart [8], and the Range Maxx golf ball collector [9].

From this research, we developed engineering specifications that would allow us to determine whether or not our device met the customer requirements that had been identified. In some cases – when evaluating the movement of the machine, for example – multiple specifications were developed in order to allow several aspects of performance to be quantitatively analyzed. While this function and its sub-functions could generally be described as 'ease of operation', we felt that evaluating this through subjective ranking or through a Likert scale would not result in actionable feedback to the same degree as the use of measurable variables. For this reason, our prototypes were evaluated on the force required to push the machine and the force required to steer it, for example, rather than how difficult or easy a test user perceived them to be.

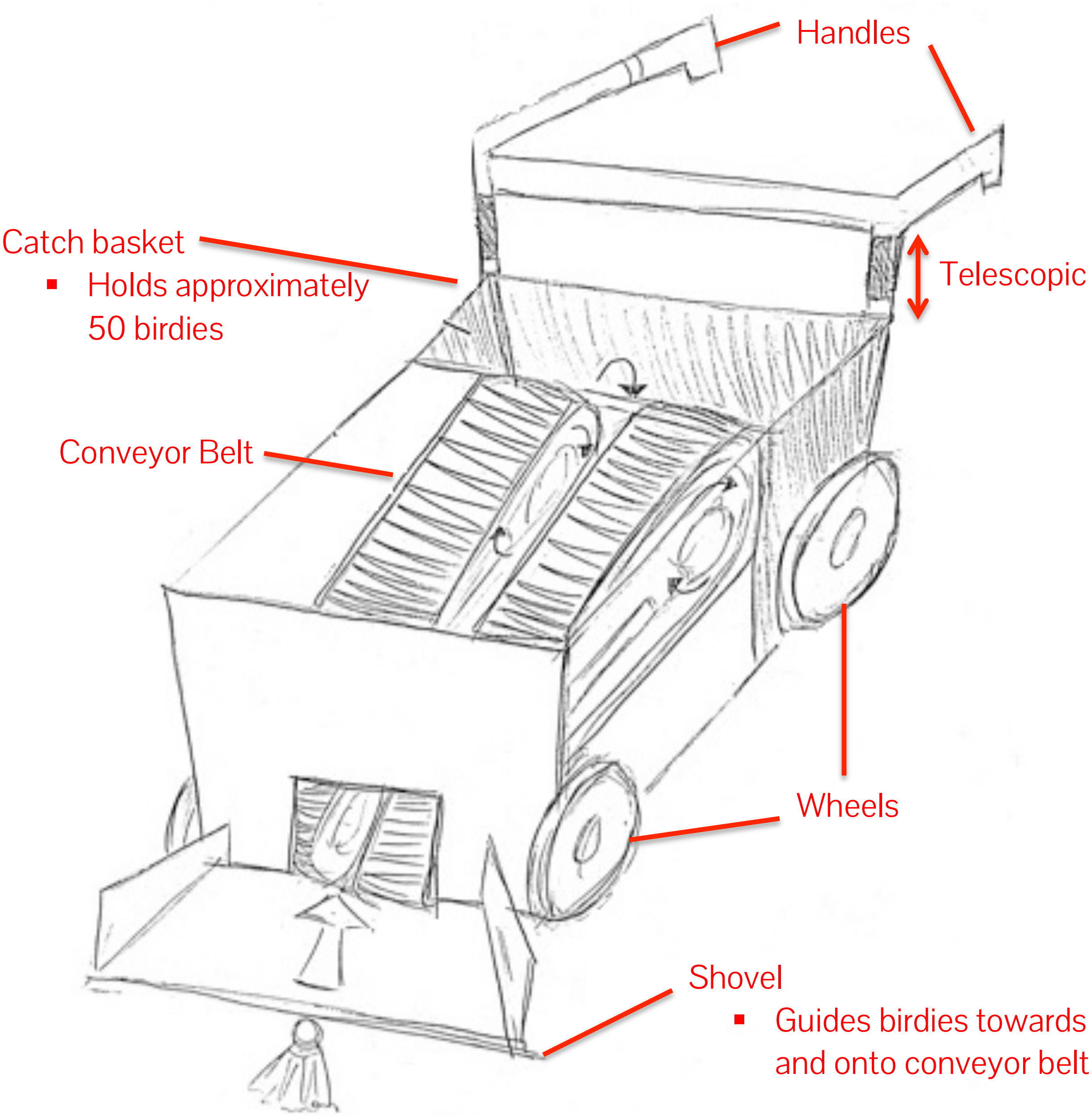
This process left us with a lengthy list of engineering specifications, including ‘pickup fail rate’, ‘speed of internal operation’ [10], ‘force required to push machine’ and many others.

Comparing these measurable specifications with our customers’ requirements helped identify the areas, which were most important to the machine’s design. Steering force, for example, was strongly related to the user’s need to easily propel the machine, and since this was one of the highest priority customer requirements, it meant that steering force became one of the most important specifications when evaluating the success or failure of our machine.

We evaluated the similar devices we had identified relative to our engineering specifications in order to develop target and threshold values, in particular the number of objects that the machine could retrieve per minute. Based on the information available, we knew that their weight or method of operation would force the users to operate the machines at the low end of the average walking speed spectrum. Given the users’ need to clean birdies off the floor at a relatively quick pace, we then set our target value at the midrange of the walking speed determined in the Situation of Concern chart, and our threshold value as equal to the fastest similar device.

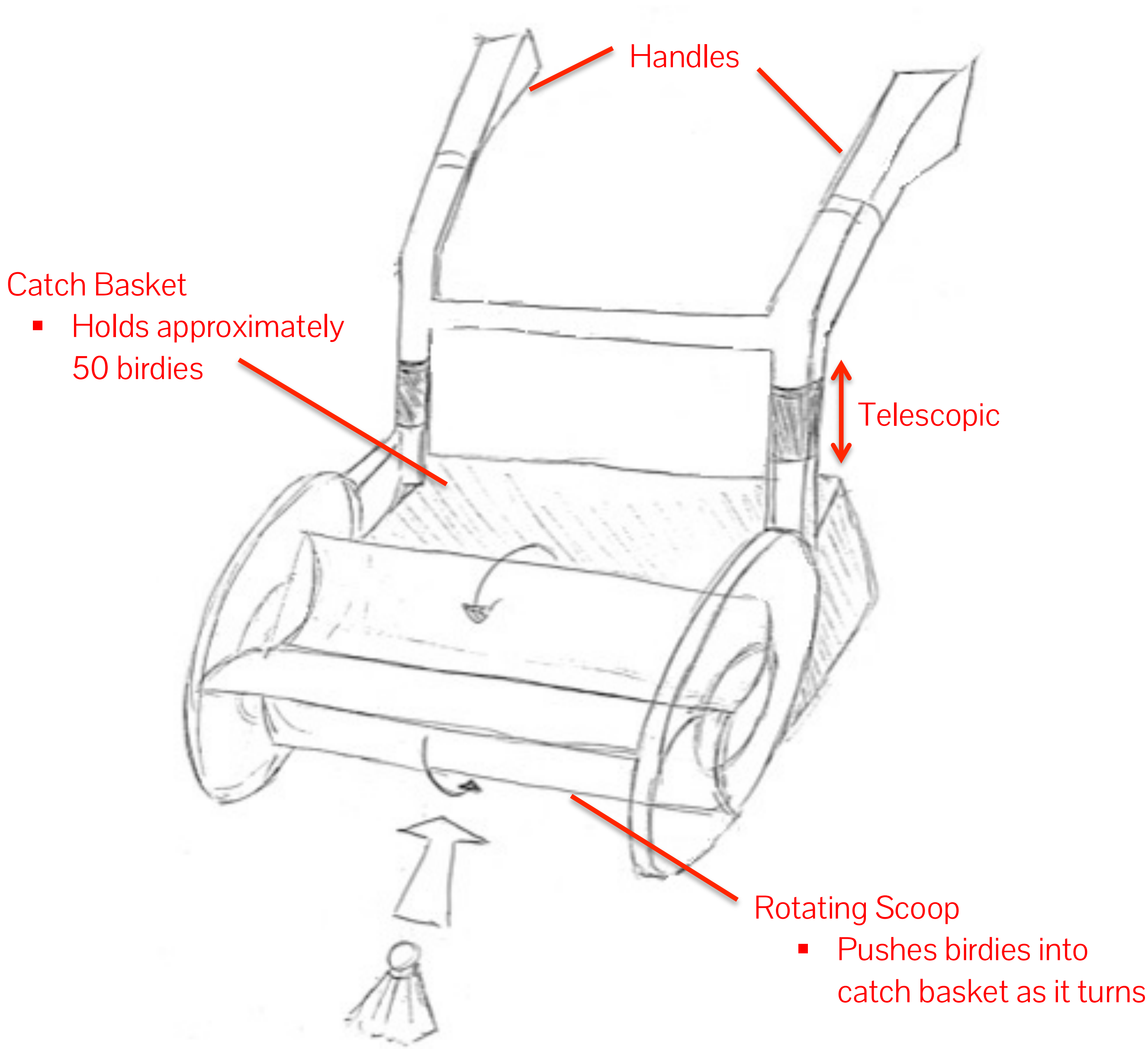
The tennis ball collector cart also helped us establish our benchmarks for the number of birdies picked up per second. We observed a demonstration of the product being used and performed our own calculations to determine its pick-up rate. We used this value - 0.5 birdies per second - as our base value. While evaluating a design sketch involving conveyor belts, we were also able to determine that exceeding 1.5 birdies per second makes the machine too quick and puts the birdies at risk of damage.

LFP Design Option A – Conveyor Belt



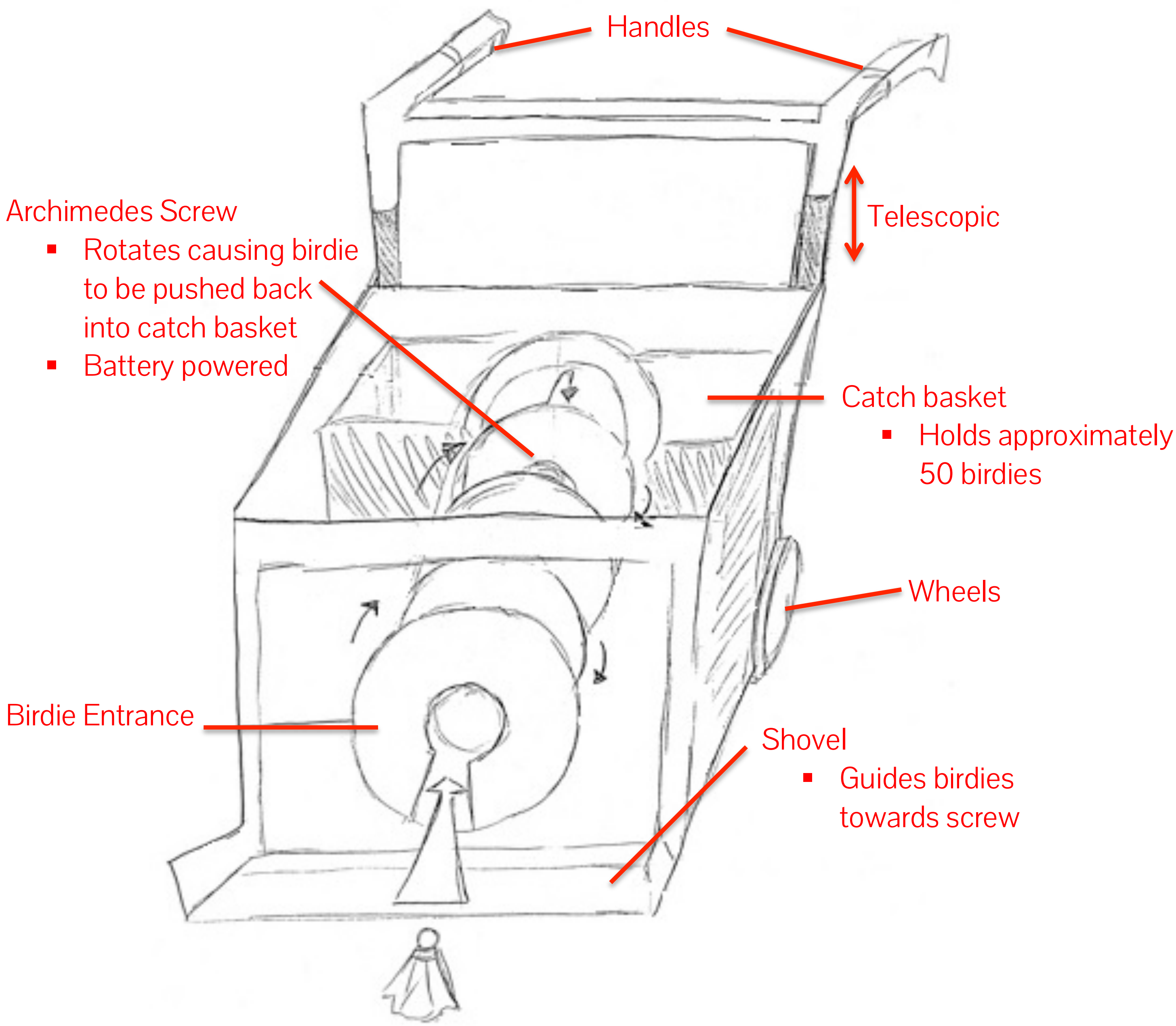
Our first prototype, the conveyor belt method, incorporates a motorized rotating brush to push birdies from ground up a ramp to the conveyor belt. The conveyor belt is motorized and brings the birdies up into a catch basket. The pros of this prototype are that it would be easy to use, would feature a removable catch basket and would be able to pick up birdies at odd angles as long as they reached the brush. The con's of this prototype are that it is larger, birdies could jam and has multiple moving parts would could lead to more mechanical failures.

LFP Design Option B – Rotating Scoop



Our second prototype features a rotating scoop design; it would act similarly to a manual push lawn mower [11] and would scoop the birdies from the gym floor and up into the catch basket. The pros of this prototype are that it would be a lightweight prototype and would rotate based on the user's force applied to the machine and would not require a motor. The cons of this prototype are that it would not turn easily in a gym, the pickup fail rate would be very high and there is a greater chance of damaging the birdies.

LFP Design Option C – Archimedes Screw



Our third prototype, the Archimedes Screw method, works like the Archimedes screw [12] to pick up water, once the birdie enters the turning cylinder, the grip of the treads would slowly bring it up the line and dropped into the catch basket. The pros of this prototype are that it has only one moving part; it would not jam and would minimize birdie damage. The cons of this prototype are that it would struggle to pick birdies off the gym floor, the catch basket did not have a good spot to attach, and tight-corner movement would be a problem.

Concept Selection

We evaluated our three prototypes using a Computational Decision Matrix (CDM), which identified high-level badminton players and gym attendants as the two most important users. The five categories chosen in the CDM chart were pulled directly from the QFD chart as they were evaluated to be the most important: number of birdies picked up per second, pickup fail rate, ease of operation (combing 'steering force' and 'force to push to machine' - this simpler category generalizes the two and is more appropriate for the CDM), speed of operation, and damage to birdies. Using the average value for each engineering specification between the two users, we came up with a relative weighting and chose the three specifications, which possessed an above average weighting to consider when selecting the prototype to be used in future iterations. This resulted in analysis of each prototype based on:

1. Ease of Operation
   The steering mechanism for all three prototypes was designed to be quite similar. The only factor affecting the ease of use for the prototypes would be the individual weight of each object. The greater the weight, the harder it becomes to push the machine and consequently the ease of operation diminishes. In this aspect, prototype C scored the best.
2. Speed of Operation
   All three prototypes were designed to be used at the same walking speed, between 3 and 6 km/h. Prototypes A and C can be used effectively even when approaching the upper limit for the machine defined as 8 km/h however prototype B will begin to malfunction as this upper limit is approached, making it less effective.
3. Damage to birdies
   All prototypes have the ability to cause damage, however the rotating screw in prototype C has the largest potential to cause damage. Prototype C was thus assigned an arbitrary 5. Prototype A's conveyor belt can be designed to move at a slow rotational speed, resulting in very the lowest potential damage to the birdies, and it was thus assigned a 3. Prototype B had a large propensity for damage as the scoop can crush the birdies in the act of picking them up or transferring them to the collection basket and was this assigned a value of 4.

Based on our CDM evaluation, the best choice was Prototype A, the conveyor belt design. Prototype B was promising as well, however concerns about the potential for damage to birdies meant that the design could not be selected. We did, however, modify and incorporate elements of this design into our final prototype; Prototype A's biggest weakness was in getting the birdies to the conveyor belt, but attaching a rotating brush to the front of the machine allowed us to overcome this limitation.

User Testing

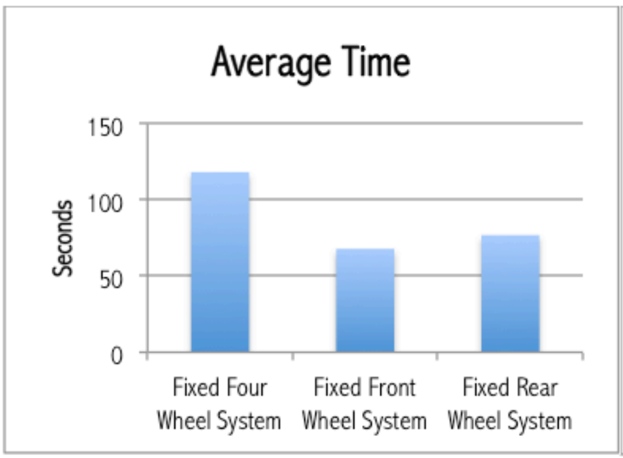
Through our low and medium fidelity prototypes we conducted small-scale surveys with an unbiased group of people (non-systems engineering students) to get a feel for necessary improvements as we moved into high fidelity. People told us to change the wheel system, to lower the angle at which the handle was mounted and to increase the catch basket volume. We also received feedback about the overall size of the machine. As we began our first tests with our medium-fidelity prototype we swiftly realized some enhancements and refining to our design would be needed to get a fully functional prototype. We began by user testing within our group to determine which aspects needed enhancements. The most glaring sections were: the wheels, the handle and the conveyor belt. The wheels needed to have a way to swivel so that you could move the device in a non-linear way around the gym. The direct result of our user testing was to use two swivel wheels on the back of the device. The handle, after accommodating to a better angle, we realized would not fit to a multitude of people and their respective heights [13], to fix this we used a telescopic handle. Finally came the issues with the conveyor belt, the first issue was that the slope was too great. To resolve this we mounted the upper axle to a support rather than the frame. The second issue we ran into was material, our original idea that looked a lot like a conveyor belt was too heavy and would not spin on such a small axle, to resolve this we substituted our original material for lightweight cloth.

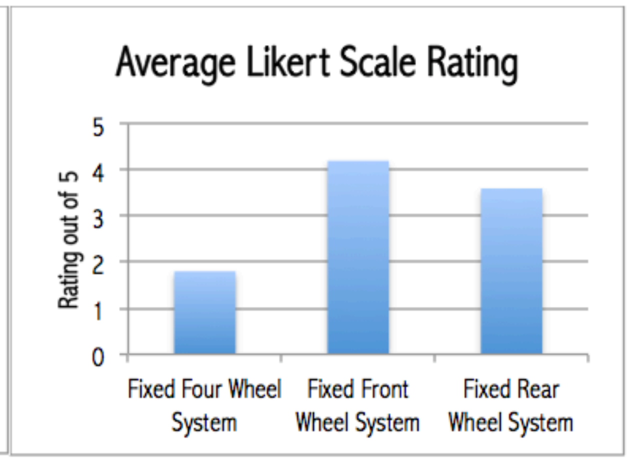
After we had a semi-functioning prototype we began the next phase of user testing: functionality. Two obvious areas for improvement were; the device needed side guards and it also needed guards on the ramp. To resolve the first without hindering the conveyor movement, we mounted the side guards on the frame so that hover just above the belt. To fix the gears on the ramp we wanted to build a large guiding system, however with the implementation of the mechanized brush this became impossible, we instead but a small guard directly in front of the gear to prevent birdie damage. As our prototype approached full functionality, we did a final round of user testing from an unbiased group of people including badminton players. We had people like, our resident badminton expert Clara and her friends, test everything, from ease of use to functionality. Through this user testing we noticed some key elements, which helped us prepare for the design fair and future iterations. Firstly, because of the size/power of the motor [14] the brush requires an extra push before you begin collecting birdies. In later iterations we would like to increase the power of the motor. Another thing we found was that the swivel wheels worked quite well except for tight turns, this meant that when actually operating the device, the user needs to take wider turns. Another function we changed though this iteration was the catch basket, we realized that putting it on the outside made the user run into it. We utilized the space under the conveyor belt to build a catch basket that would be completely removable, and would decrease the necessary size of the conveyor belt. We made other minor adjustments like adding extra support to the front wheels to compensate for the weight.

An example of one of our test would be the ease of operation test. The users were asked to push the device through a single obstacle course, which involved a variety of different types of turns as well as several stretches of straightaways – this course was designed to emulate the type of conditions it will face. Three design solutions were evaluated: (1) fixed four wheel system (2) fixed front wheel system (3) fixed rear wheel system. Each solution was evaluated in two categories: the average time required to complete the obstacle course and the average rating of ease of operation given by each test user. Listed below are the results.

Question asked: How difficult was it to navigate the obstacle course?

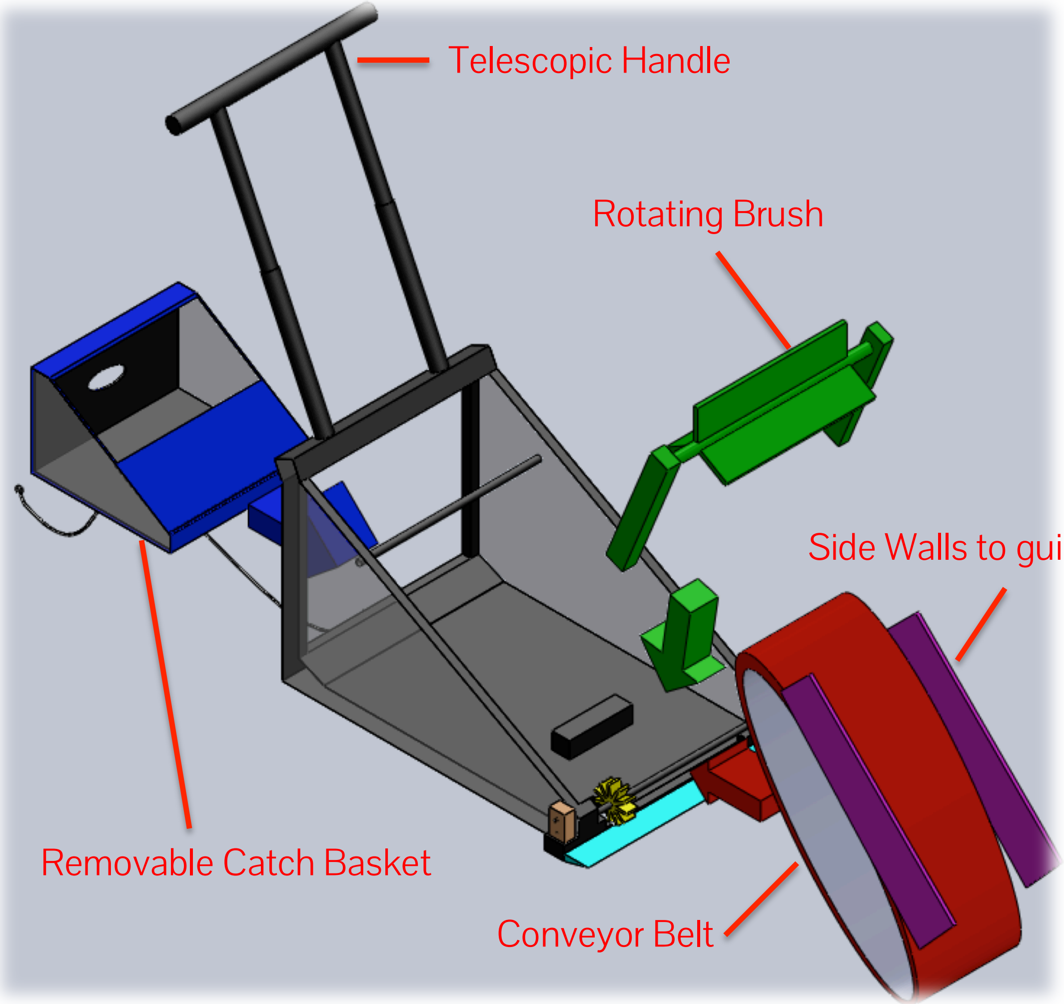
1 - Challenging | 2- Strenuous | 3 - Mildly Strenuous | 4 - Moderate | 5 - Easy

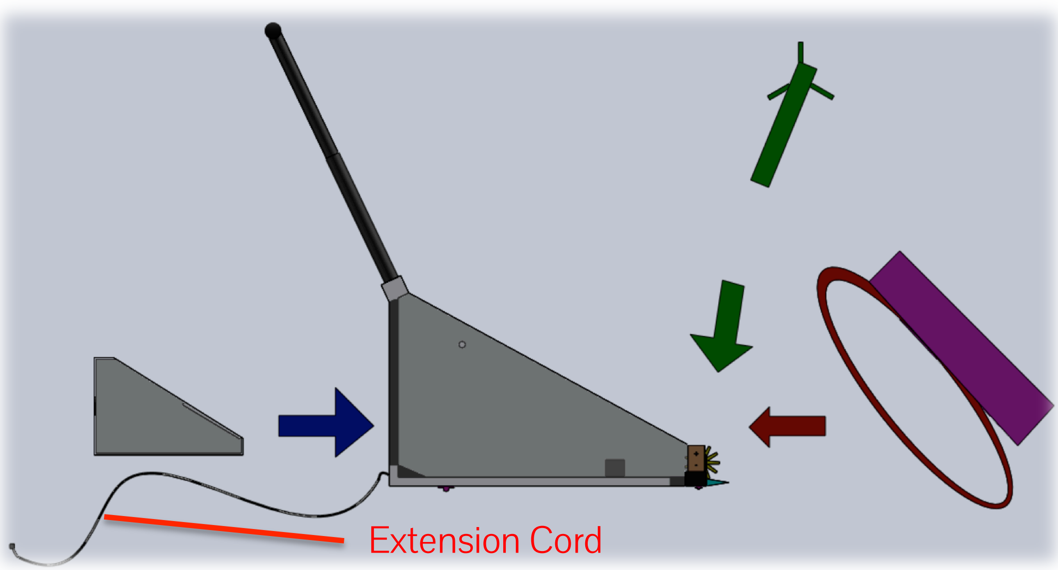




Overall we had many iterations and subsequent levels of user testing, we found these to be incredibly helpful to our overall final design. Each time we conducted user testing we were able to work out the kinks and flaws in our design, going deeper and deeper and eventually reaching a fully functional prototype. Our different levels of user testing included survey type response questions, inner-group testing and finally testing from an unbiased group of people. The biggest feedback we heard from the badminton players, which didn't concern the operation of the device was that while they very much enjoyed the device and would be interested in future iterations however they felt it functioned a little too slowly and the catch basket capacity should be increased. Our high fidelity prototype is the culmination of the design iterations and user testing, it takes into account our engineering specifications and customer requirements and matches them to usable features. It takes all of the information we have gathered, all the advice and learning and combines it into a functioning birdie picker-upper.

Final Design





Our high fidelity prototype was a functional device, however there are some changes we would like to make moving forward. The final design of our Badminton Back-Saver, like our high fidelity, has three main components. First is the brush in front, which brings birdies up the ramp. The second part is the conveyor belt, which brings the birdies up to, and deposits them into, the catch basket (third main component). The machine's outer frame is constructed from metal or plastic frame to prevent damage to the components and increase the durability of the machine.

The brush will be made with lightweight, flexible bristles, which will not damage the birdies or the floor, without adding to the overall weight of the machine. A rechargeable battery will power a motor strong capable on handling a large quantity of birdies without jamming. This motor will rotate a gear, which is connected to the axle that will rotate causing the entire conveyor belt to rotate. The brush is positioned such that the birdies are on the conveyor belt before they lose contact with the brush. There are guards preventing the birdies from falling off the conveyor belt. The rotational speed of the conveyor belt is fast enough to keep up with a large number of birdies at the regular walking speed of a person while not damaging any the birdies. The catch basket is designed to be durable and remain in place during operation, but also be easily removable and can comfortably hold more than 50 birdies.

Other included features are: a telescopic handle, a cord to recharge the battery and a downward slant of the machine. The telescopic handle allows users to adjust the height of the handle to suit their needs making it adaptable to every height. When not being used to charge the battery, the cord is neatly tucked away inside the machine. Finally, the front of the machine sits lower to the ground than the back, which reduces the amount of work to be done by the brush as birdies do not need to be raised as much in the beginning. To achieve this, the front wheels are placed on the side of the frame higher than the rear wheels. The ramp is set wider than the entry point to the conveyor belt in order to protect the birdies from being run over by the wheels as well as increasing the overall intake of birdies. A fixed front wheel and swivel rear wheel system will be used so that users cannot accidentally move the front laterally and damage the birdies but may still easily manoeuvre and turn the machine. The wheels are made out of a soft rubber, which does not damage gym floors. All design features are constructed with the safety of the birdies and the court in mind as well the usability for all users.

These features combined to provide a quality user experience by decreasing the amount of time spent collecting birdies and reducing the risk of repetitive stress injuries in the process. The final machine also represents an increase in efficiency and ease of use over prior prototypes.

Lifecycle Analysis

Life Cycle Stage	Inputs	Outputs	Analysis of Impact	Level of Impact	Possible Improvement
Material Acquisition	- Wood - Imported pre-built electric motor (composed of metal) - Oil for rubber - Rechargeable batteries - Fibres (in brushes) - Recyclable metals - Recyclable plastics Transportation (for importing materials): - Diesel oil - Coal	- CO_2 emissions [15] - Greenhouse gases from machinery in factories - Depleted land [16] - Polluted water - Air pollutants -Recyclables [17]	- Deforestation to acquire wood contributes to greenhouse gases while reducing foliage. - Mining and drilling for oil [18] destroys the land, reduces ecological diversity, produces wastewater and greenhouse gasses. -The transportation to ship materials from other countries contributes to CO_2 emissions -The usage of recyclable metals and plastics decreases the amount of raw materials that need to be extracted and refined	Deforestation: Very Negative (- -) CO_2 & Greenhouse gas emissions: Very Negative (- -) Mining and Oil Drilling: Very Negative (- -) Recyclables: Very Positive (++)	-Replace the wood and rubber components of the Badminton Back Saver with parts made from recyclable plastics and metals -Source materials locally
Production	Non-renewable resources [19] -Coal - Oil - Energy [20]	- CO_2 emissions [15]	- The CO_2 emissions are harmful to the environment, as they contribute to global warming	CO_2 emissions: Very Negative (- -)	- Outsource energy to a clean source such as Bullfrog power [21]
Transportation	Transportation [22]: - Diesel oil - Coal (train) Shipping Materials: - Wooden pallets - Styrofoam - Metal (nails) - Plastic - Cardboard boxes	- CO_2 emissions - Recyclables Scrap: - Styrofoam - Plastic - Wooden pallets - Cardboard boxes	- The CO_2 emissions are harmful to the environment, as they contribute to global warming. - The recyclables would be considered positive as they are being reused from other products. This eliminates the need to acquire new raw materials which may require processes with a negative environmental impact	CO_2 emissions: Very Negative (- -) Recyclables: Very Positive (++)	- Change the design to be collapsible; this would allow more units to be loaded per truck and ultimately reduce the CO^2 emissions
Product Use	- Rechargeable batteries [23] [24] -Electricity (to charge batteries)	-Hazardous waste (dead batteries) -Metals & heavy metals - CO^2 from burning coal - Nuclear waste from nuclear energy	- Batteries contain heavy metals and toxic materials - However, the usage of rechargeable batteries prolongs time period before batteries need to be replaced	Hazardous waste: Very Negative (- -) CO_2 emissions: Very Negative (- -) Rechargeable Batteries: Positive (+)	- Change design to not require batteries, and rather function based off of the rotation of the wheels when the user pushes the device
End of Life	-Fuel to power machines which transport disposed non-reusable materials [25] - Battery disposal [26]	- CO_2 emissions - Hazardous waste - Plastic, scrap metal, wood	- Contributes to global warming - Hazardous waste needs to be disposed in complicated ways. This poses a threat to the environment if disposal procedures are followed incorrectly	CO_2 emissions: Very Negative (- -) Hazardous waste: Very Negative (- -)	-Select materials that are reusable or materials that can be disposed of easily by users without requiring additional transportation to specific disposal centres

Lifecycle Analysis

This Life Cycle Impact Assessment assists in identifying the areas of success and improvement of the Badminton Back Saver in promoting sustainability. The current design successfully promotes sustainability through its usage of recyclable metals and plastics in the materials acquisition stage and by using plastic and cardboard recyclables as packaging materials for transportation. By recycling materials, the raw material acquisition is no longer required; this allows the negative externalities of raw material refining processes such as excess waste and CO_2 emissions to be avoided [29]. To continue, the choice of rechargeable batteries in the final design has a positive impact in terms of performance and sustainability as it reduces the amount of hazardous waste generated over an extended period of time.

However, this life cycle impact assessment also brings to light several negative impacts on the environment. To begin, in the material acquisitions, production and transportation stages, a majority of the raw materials such as metal, oil and coal can only be acquired through processes such as oil drilling and mining. These processes generate pollutants and waste and also significantly erode the land [24]. The burning of fossil fuels to provide energy to import and transport materials also contribute negatively to the environment. Life cycle assessments of power generation have shown that life cycle stages including fossil fuel combustion and mining have been proven to have the highest potential impact on human health [28]. Additionally, trees must be cut down to acquire the wood for the handles and packaging. This contributes to deforestation. Trees have a positive role in the carbon cycle as they absorb CO_2 and release oxygen. Deforestation results in a reduced number of trees leading to an imbalance in this cycle and therefore negatively influences the environment.

Moreover, the choice of batteries, though rechargeable, unfortunately still contributes to hazardous waste as they contain heavy metals, which are highly toxic [26]. The necessity to dispose of dead batteries after usage is left to the user. If not disposed of properly, there exists a risk of leaking hazardous substances, which would have detrimental consequences [26].

There are many possible improvements that can be done to reduce or eliminate the negative environmental impacts. Starting with materials, recyclables can easily replace the wood and rubber being used. This would decrease the reliance on non-renewable resources. In terms of production, energy could be outsourced to clean sources like Bullfrog power [27] instead of burning coal, which generates a significant amount of CO_2. Additionally, changing the design of the device to be collapsible would make both storage and transportation more efficient. This would successfully reduce the transportation and reduce greenhouse gas emissions. Finally, in terms of the power, a solution could integrate a design that runs solely on the mechanical pushing force by the user, which would eliminate the hazardous waste.

Conclusion

The Badminton Back-Saver began as a simple Situation Impact Statement, with the purpose of alleviating the lower back stress of badminton athletes. This problem space was then brainstormed, and the ideas produced were put onto a Situation of Concern Chart. Through this the stakeholders, processes, artefacts, environments and resources of the project were defined, as well as the critical requirements and constraints under each category. This allowed for a general product solution to form, and the design concept became a portable, hand-pushed device capable of collecting birdies of all materials on all types of gym floors. With this concept in mind, the user requirements and engineering specifications of said concept were merged together using a Quality Function Deployment Chart. Through this chart it was learned that the four most heavily weighed engineering specifications were 'pickup fail rate', 'ease of operation', 'speed of operation' and 'damage to birdies'. By optimizing these specifications, the final product's competitive edge and level of user enjoyment could be maximized. Three prototype concepts were then created with these specifications in mind and low fidelity prototypes were built for each. A Computational Decision Making chart was then created using data obtained from these prototypes to determine the best design based on our target users needs. Prototype A (conveyor belt design), having the lowest score, was chosen and a medium fidelity prototype was constructed.

After more user testing with the medium fidelity prototype, we discovered that common feedback involved dissatisfaction with the handle placement, and the machine's steering capabilities. We took this into consideration while designing our high fidelity prototype, and building telescopic handles as well as revolving back wheels solved the issues. We also came across many issues while building our high fidelity, including faulty conveyor belt material, as well as insufficient motor power. These problems were eventually all tackled, leading to a better understanding of the potential future iterations of our device. After getting the high fidelity prototype to a considerable degree of functionality, a Lifecycle Analysis of our product was conducted by brainstorming the inputs, outputs, and impacts of our device along each step of its lifespan. This, along with lessons learned through designing and testing our high fidelity prototype, generates an excellent idea of the future improvements for the Badminton Back Saver.

Recommendations

[#1] Replace the current batteries with longer lasting, rechargeable batteries

Rationale: The batteries used in the high fidelity prototype are extremely harmful to the environment; since they would need to be disposed of frequently and new ones would be constantly manufactured. The lifetime on the current batteries, when used for an average of 2.5 hours per day, lasts 1.5 weeks. By using rechargeable batteries, the waste produced during product use could be diminished. This benefits both the environment and the user.

Costs and Benefits: The resources saved through eliminating the need to purchase new batteries allow the user to save money, and decreases the environmental footprint of our product. However, the one complication of having a rechargeable design is that it would mean attaching a charging cable to the machine. This increases the number of components and the complexity of use for the design, and also complicates the manufacturing process. Although these drawbacks exist, the financial and environmental benefits of this change outweigh the costs. Rechargeable batteries are a good recommendation for future iterations of this product.

[#2] Creating the frame out of recycled metal or plastic instead of wood

Rationale: From the Life Cycle Analysis of this design, it was determined that the current wooden frame is not sustainable or cost effective for future manufacturing. Recycled metal or plastic [27] allows for a greater range of design possibilities, for example a collapsible metal frame for easy storage. It also optimizes the engineering specifications of portability and manoeuvrability. Furthermore, the current wooden frame is not sturdy enough to support the weight of the internal components, or withstand the force by the user, changing our material will improve the design and increase the lifetime of our product.

Costs and Benefits: The materials acquisition section of our Lifecycle Analysis scored a "very negative" on impact, since obtaining wood also leads to deforestation. A recycled metal or plastic frame would not only reduce this impact, but would also allow the machine to be lighter. Reduced weight results in better portability and manoeuvrability, which were both user requirements on our Quality Function Deployment Chart. By improving the sturdiness of our machine, we increase its lifespan, which helps in reducing the cost. It also makes the device easier to operate, as the user will not have to make repairs. Finally, the ability to change the design for different markets, i.e. different available sizes for the machine and a collapsible frame for easy storage. Makes the device marketable to more people allowing us to decrease the cost of each machine.

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