University of Victoria
Faculty of Engineering
Summer 2021 ENGR 446 Report

Design of Game Piece Sorter

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Bryce Dombrowski
V00873928
ENGR 446
Mechanical Engineering
brycetdombrowski@gmail.com

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Letter of Transmittal

April 1, 2021

University of Victoria

Faculty of Engineering

Re: ENGR 446 Report

Dear Susan,

I am a 4th year mechanical engineering student, set to finish graduation requirements by August 2021. I have an interest in mechatronics and automation, so my ENGR 446 report reflects that. In my report, Design of a Game Piece Sorter, I design a device that sorts ship game pieces from train game pieces from the popular game Ticket to Ride: Rails and Sails. The pieces are very similar in size and are often mixed up when cleaning up the game, so having a method to sort them automatically is helpful. The report discusses the various small part sorting methods used in the automation industry while limiting the designs to ones that could be prototyped in the time available for this project, using 3D printing and basic electronics. I hope that reading this report is interesting and that you learn something new about how factory automation runs our world behind the scenes.

Regards,

Bryce Dombrowski,

Year 4B, Mechanical Engineering

ENGR 446, Spring 2021 term

brycetdombrowski@gmail.com

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Executive Summary

The goal of this report was to design a device that would improve the experience of playing the game Ticket to Ride: Rails and Sails by reducing the overhead work of manually sorting similarly shaped, sized, and coloured game pieces each time that the game is played. Three designed were considered and ranked comparatively with a weighted objectives chart. The selected design was a stacked sieve device, which meets all the objectives by having the user agitate the assembly, encouraging the slightly slimmer train pieces to fall through to a bucket at the bottom layer, while retaining the wider ship pieces in the sieve. This mechanical structure of the design was iteratively improved using drop test simulations and verified with a drop test with a 3D printed model. The sorting time was observed to take 40 seconds to sort 33 train pieces from a mixture containing 50 ship pieces without errors, though in rare occasions full sorting was achieved in as low as 20 seconds. It takes more than 40 seconds at top speed for a human to sort this number of pieces, so reducing the mental effort required for the task without sacrificing speed is an exceptional result. The sorting speed data was obtained over 28 trials by manually shaking the box for a set number of seconds, then recording how many unsorted trains remained. The sorting speed data could be improved if more trials were performed with a robotic apparatus that could provide consistent shaking through the tests. This design will be able to be reproduced by any 3D printer so that other Ticket to Ride owners can print out their own copy of the device and use it for sorting pieces in their own games.

Glossary

Defined below is the technical terminology and defined terms used in this report.

ABS	Acronym for Acrylonitrile Butadiene Styrene, a commonly used plastic used in 3D printing. It is known for its heat resistance and strength, but also as being difficult to print with without a heated enclosure around the printer.
DC motor	An electric motor that can by directly driven by a constant voltage without other electronics.
FDM	Acronym for fusion deposition modeling, which is a method of 3D printing. Plastic filament is forced through a hot nozzle that melts the plastic, but the plastic quickly hardens. The hot nozzle is moved in cardinal directions to build up a plastic model over time.
PLA	Acronym for Polylactic acid, a commonly used plastic used in 3D printing. It is known for being exceptionally easy to print with.
Servo	A motor with a built-in position encoder and usually a limited range of motion. This type of motor is often low torque, low weight, and small, and are popular for remote control airplanes.

1. Introduction

This section provides background information on the problem and the ways that industry has approached similar problems. The problem, goal, objectives and potential solutions are then presented. Beyond this section, the potential solutions are compared and one is selected to be further developed. The solution is iteratively improved and its performance is measured against the original objectives.

1.1. Background

Ticket to Ride: Rails and Sails is a board game where players connect cities together with trains and ships. This background will refer to the rules set provided for "The World" side of the board [1]. At the beginning of a game, players sort their train and ship playing pieces into two piles, then count out specific amounts of each piece type depending on their chosen strategy. There is a maximum of 50 ships and 25 trains per player, but only 60 pieces can be selected from those available. Some destinations are more easily connected via ship routes, while others train routes, making the piece selection process a crucial component of the strategy. The ships and trains are a similar size and shape and are often mixed up when the game is put away. If a player accidentally takes a few ships instead of trains at the beginning, they can end up in a strategic disadvantage later in the game. The playing pieces are shown in Figure 1.

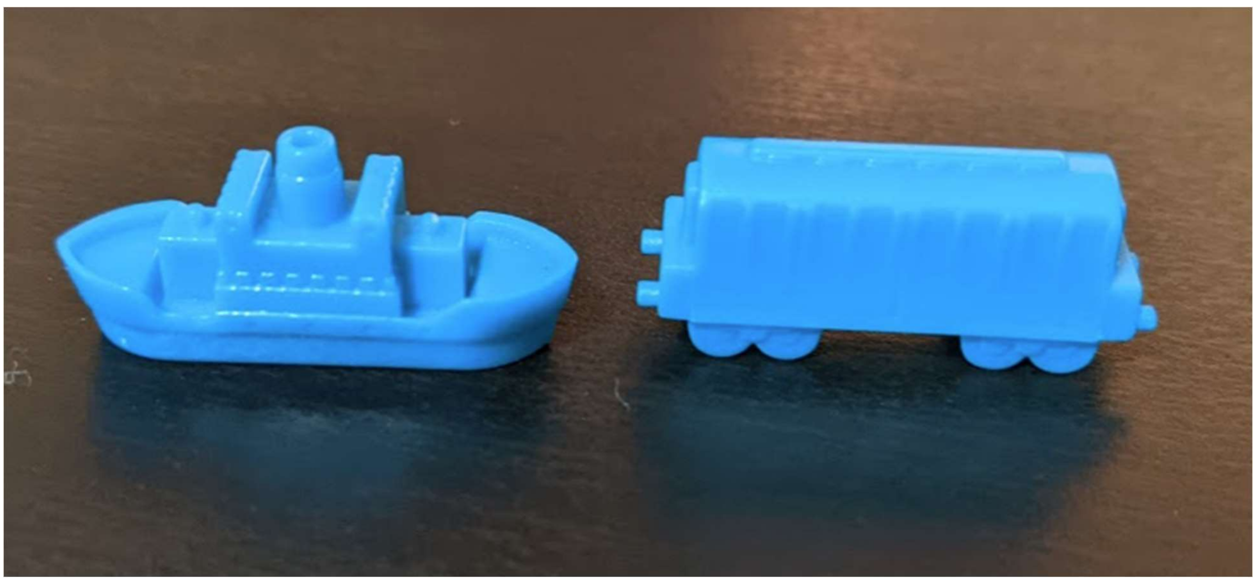

Figure 1. The ship and train game pieces

The rectangular dimensions of the game pieces are listed in Table 1 to emphatically show how close in size and dimensions that the two pieces are. The author's fastest time to sort all 75 pieces by hand was measured to be 41 seconds from 5 trials.

Table 1. Game piece dimensions

	Length [mm]	Width [mm]	Height [mm]
Ship	24.9	7.8	11.3
Train	25.0	7.0	10.6

Sorting small parts is a task that the manufacturing industry has been solved in many ways, through use of a combination of vibrating tables, conveyors, electrical sensors, sieves, and clever mechanisms. The workflow of a sorting system can be broken up into 4 steps: separation, orientation, sorting, and capture. Separation is where the items are moved apart so they do not interfere with each other as they go through the rest of the system. This step is often performed by feeder mechanisms, such as an elevator / step feeder [2], a vibratory bowl feeder [3], or a centrifugal feeder [4]. These devices are pictured in Figure 2.

Figure 2. A) Elevator feeder [2], B) Vibratory bowl feeder [3], C) Centrifugal feeder [4]

The next step, orientation, is often part of the mechanism that performs the separation. The orientation check is performed by cleverly designed geometries along the track that the part is traveling along and diverting any parts that are mis-oriented back into the feeder. Alternatively, some systems use electronic sensors with actuators to actively divert misaligned parts out of the feed path [5]. The sorting step is often like the orientation check, as it uses the differences in the part geometry to sort them mechanically, or uses a combination of sensors and actuators to actively sort the parts. After this, the part may be transformed in some way, such as being painted, bended, or assembled to be part of a larger whole, but this is not applicable to the desired system. Finally, the capture step is where the sorted parts are collected. This may include counting a certain amount of parts into containers, such as boxes of nails to be sold retail. These steps make up the lifecycle of a part's transition from unsorted to sorted in a factory setting.

1.2. Objectives

This section will lay out the objectives of the final product.

1.2.1 Problem

Players of the board game Ticket to Ride: Rails and Sails must sort ship and train game pieces by hand between each game. The ships and trains are easily mixed due to their similar size, shape, and colour. It is tedious and slow to sort them by hand and can cause strategic disadvantage if the improperly sorted pieces are not noticed until later in the game.

1.2.2 Purpose

A device should be designed to sort the train and ship game pieces from each other quickly.

1.2.3 Aims

The report will recommend a solution to the problem by providing thorough analysis. The following listed items are what the device should accomplish:

- Minimize time to sort 75 game pieces, taking a maximum of one minute.
- Minimize required interaction from the user.
- Minimize the number of parts to reduce design complexity.
- Be durable. It should able to withstand a 1 metre fall onto wooden floor without functional damage.
- Be portable. It may have a maximum volume of a rectangular 100,000 cm^3 (or 3.5 ft^3).
- Minimize the cost of materials needed to replicate the device. It may cost a maximum of $100.

1.2.4 Limitations

The base project materials available are wood and 3D-printed PLA. Electronics such as motors and microcontrollers are also available. Metal or other materials cannot be a required material in the potential solutions because the author does not have access to metalworking tools, and aims to create a prototype to test the selected solution with available tools.

1.3. Potential Solutions

The potential solutions are described in detail in the following sections.

1.3.1 Stacking Sieve Shaker

The stacking sieve shaker is made of 3D-printed interlocking trays that stack together vertically. The game pieces are placed in a sieve tray on top of a bucket tray, then the lid is placed on top. The user shakes the assembly which allows the slightly smaller train pieces fall through the sieve layer to the bottom tray. The trays can then be separated from the stack to result in a container for each type of piece. The device is the shape of a cube when assembled and will measure 20 cm on each side (8,000 cm^3). A sketch is shown in Figure 3.

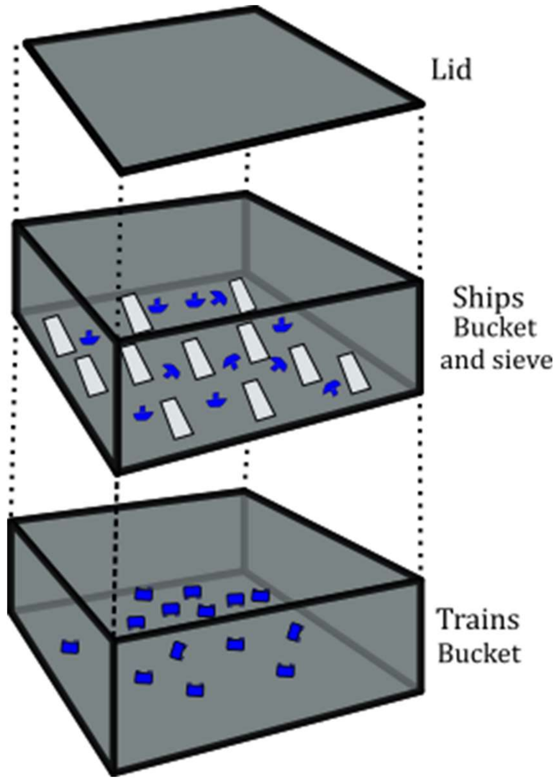

Figure 3. Stacking trays shaker design

1.3.2 Mechanical Vibrating Table

The parts would enter this system on a slanted surface that is vibrated by an imbalanced DC motor, which excites the game pieces down the slope. They are then oriented onto their sides from a slanted roof that does not let upright pieces pass. The pieces are then separated by forcing them against a perpendicularly slanted wall with a slot in the bottom, allowing the slightly thinner train pieces to fit through while diverting the wider ship pieces to the side and into a separate container. This system would be fed by a hopper that would limit the flow of parts by the size of its nozzle. The estimated dimensions would be 1 m x 30 cm x 30 cm (90,000 cm^3). The vibrating table is pictured in Figure 4.

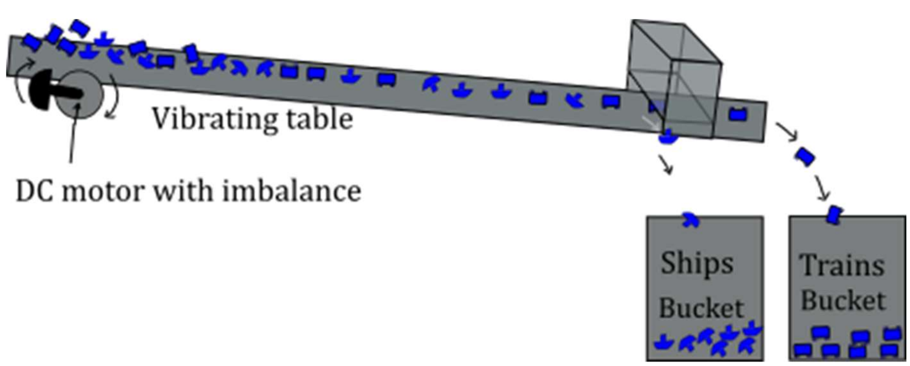

Figure 4. Mechanical vibrating table design. The slanted roof portion to push the pieces onto their side is not pictured to avoid cluttering the sketch.

1.3.3 Conveyor System

This electromechanical system composes of a microcontroller (MCU), a conveyor belt, a DC motor, a servo motor, and sensors. This system would be fed by a hopper that would control the flow of parts by the size of the nozzle. The MCU actively monitors the sensors to characterize the part to be sorted, then it would actuate a servo motor to move an arm to direct the part into its container. The DC motor would move the conveyor belt. This system may be difficult to tune due to the precision required for differentiating between the very similarly sized parts. The estimated dimensions would be the same as the mechanical vibrating table; 1 m x 30 cm x 30 cm (90,000 cm^3). This design is drawn in Figure 5.

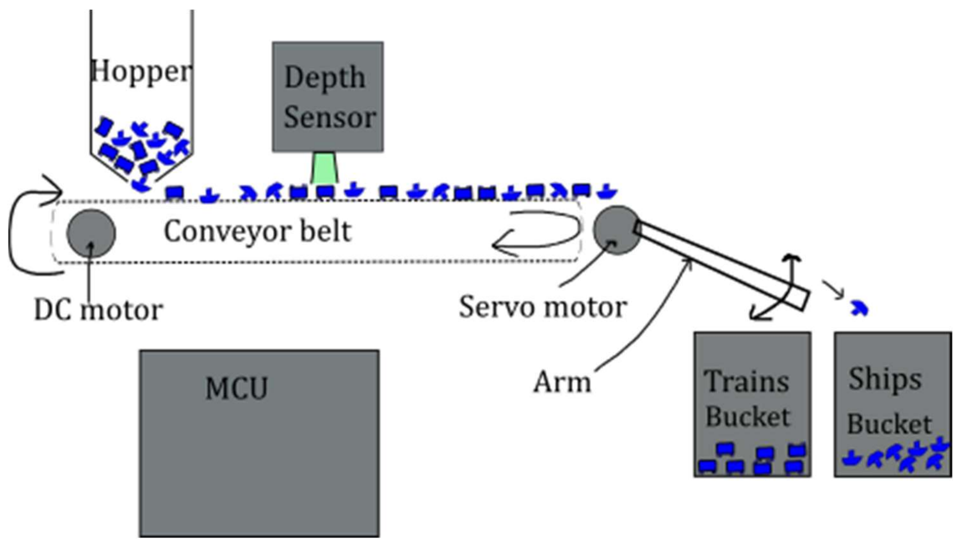

Figure 5. Conveyor system design

2. Discussion

This section first shows the selection process of the chosen design. Then, analysis and improvements are performed in an iterative process. The limitations of the analytical results are discussed. Finally, the chosen design is compared again to the original objectives to quantify how well it meets them.

2.1. Design Selection

Each design shown in Section 1.3 was evaluated on how well they are estimated to meet the objectives, using the scoring charts provided in Appendix A. The scores were then weighted according to the importance of each objective and the results tabulated in Table 2. The reasoning for each the scoring is explained in Section 2.1.1. The stacking sieve design was selected as the best option and was further developed into a prototype later in the report. This option was selected for performing high in the durability, portability, cost, and minimal complexity objectives. In contrast, the other two options scored higher in user effort required, but were not as portable, cost more, and were less durable. The vibrating table is an acceptable alternative, were the stacking sieve not an option. However, the conveyor system is estimated to cost more than the constraints allow for, so is disqualified regardless of performance in other categories.

Table 2. Weighted objectives matrix

		Stacking Sieve		**Mechanical Vibrating Table**		**Conveyor System**	
Criteria	**Weight** *(%)*	Score *(/5)*	Weighted Score	Score *(/5)*	Weighted Score	Score *(/5)*	Weighted Score
Sorting Speed	30	3	0.9	3	0.9	3	0.9
User Effort Required	20	2	0.4	5	1.0	5	1.0
Minimal Complexity	20	5	1.0	4	0.8	1	0.2
Durability	10	4	0.4	2	0.2	1	0.1
Portability	10	5	0.5	2	0.2	2	0.2
Cost	10	5	0.5	3	0.3	1	0.1
Total (/5)			**3.7**		**3.4**		**2.5**

2.1.1 Objective Scoring

In this section, the rationale for scoring the designs on each objective is addressed.

The most important objective, sorting speed, is somewhat nebulous to rank without having built the device and measuring the performance directly. To avoid ranking one design higher than another arbitrarily, all three designs were assigned a score of 3, meaning that they should be able to sort the 75 game pieces without errors within 40 seconds.

For the user effort required objective, the conveyor system and vibrating table both score the maximum of 5, since they only would require a button press input from the user. In contrast, the stacking sieve needs the user to aggressively shake it to force the sorting to occur, so it scores a 2 as indicated in the table.

Minimal complexity is straightforward to score. The conveyor system would require a motor and a microcontroller, so scores a 1. The vibrating table needs a motor and around 5 parts, so it scores a 4, and the stacking sieve is composed of less than 5 parts with no electronics required, so scores a 5.

Durability of each design is estimated from the shape of the device and the sensitivity of the parts therein. The sieve shaker is a very simple device made of mechanical parts that are unlikely to break from a fall if designed well, so scores a 5. However, the other two designs have heavy motors that change the centre of mass, as well as electronics. The conveyor system would be very sensitive to falls since the sensors need to be precisely aligned so scores a 1. The vibrating table is less sensitive to falls without any sensors, but could still be damaged, so it scores a 2.

The second last objective is portability. The sorting sieve is estimated to be less than 10,000 cm^3 and scores a 5. The other two designs are much larger, likely near 90,000 cm^3 and therefore earning a score of 2.

Finally, the cost objective. Cost is ranked by tabulating the parts required to make a prototype and estimating their costs by looking at prices on Digikey.ca and Amazon.ca. The price does not include the cost of shop materials, such as wires, solder, resistors, etc. These bills of materials are tabulated in Table 3, Table 4, and Table 5. The sieve sorter costs under $20, so merits a score of 5. The vibrating table design costs near $80, so scores a 2. Last, the conveyor system is quite expensive and goes over the budget of $100 by a significant margin, and scores a 1 in this category.

Table 3. Bill of materials for the sieve sorter design – estimated prices

Item	**Price ($ CAD)**
3D printer filament (1/3 kg)	$10
Total	**$10**

Table 4. Bill of materials for the vibrating table design – estimated prices

Item	**Price ($ CAD)**
12 V DC motor, 15 RPM, high torque	$20
12 V DC power supply	$20
Toggle switch	$5
3D printer filament (1/2 kg)	$15
Wood board	$20

Item	Price ($ CAD)
Total	**$80**

Table 5. Bill of materials for the conveyor system design – estimated prices

Item	Price ($ CAD)
12V DC motor, 15 RPM, high torque	$20
12 V DC power supply	$20
DC motor controller	$20
Servo motor	$5
Conveyor belt material	$20 to $150
Microcontroller	$5
12V to 5V buck converter	$5
3D printer filament (1 kg)	$30
Wood board	$20
Sensor for distinguishing between ship and train pieces (unknown type, to be specified later)	$5 to $100
Total	**$150 to $375**

2.2. Initial Prototype

One of the 3D printed prototypes of the stacking sieve sorter is shown in Figure 6 as a full assembly, and is disassembled in Figure 7 to show the separated ships from trains.

Figure 6. Printed prototype of stacked shaker design, assembled

Figure 7. Printed prototype of stacked shaker design, disassembled

2.3. Engineering Analysis

The following sections look at the design's sifting capability, the sifting speed, the ability to survive a 1 metre drop, the size, and the cost to reproduce.

2.3.1 Sifting Effectiveness

Design of the sieve's sorting holes to allow the slightly thinner train pieces through the sieve while obstructing the ship pieces is challenging. The ship pieces are very similar in size and shape, pictured in Figure 8. Due to inaccuracies introduced by the 3D printing process on a consumer-level printer, dimensions of the product will be slightly different than in the computer 3D model. This usually can be accounted for with a tolerance in the design dimensions, allowing the printed part to be slightly smaller or slightly larger than the base dimensions. However, due to the high accuracy required to sift the ship that is less than 1 mm wider than the train, test prints necessary to quantify exactly what dimension to put in the model to result in the desired printed product. Some of these test prints are pictured in Figure 9.

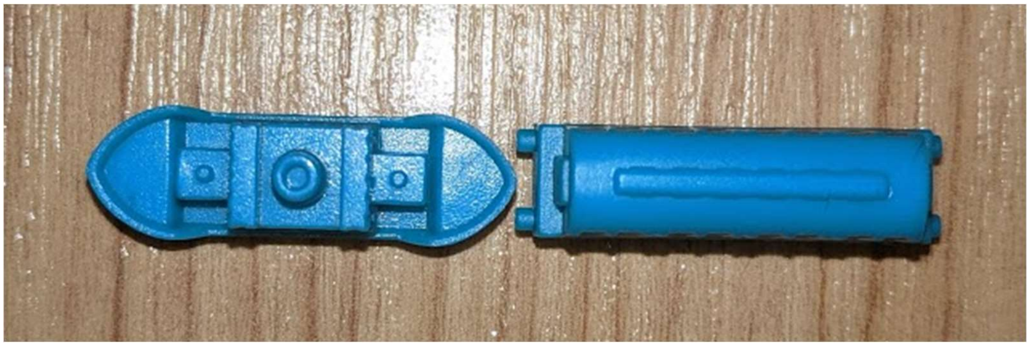

Figure 8. Top-down view of ship game piece

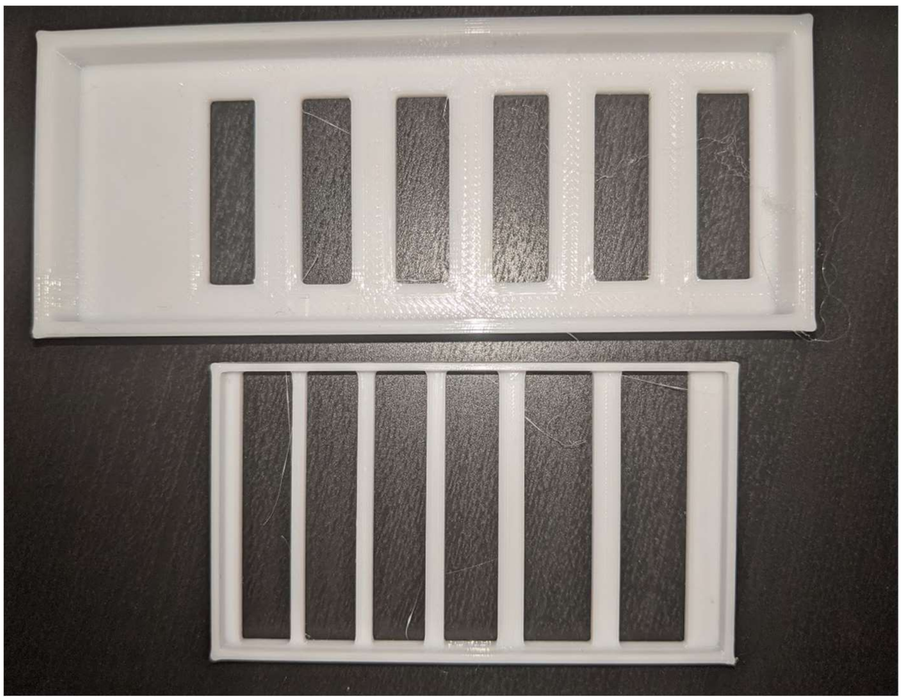

Figure 9. Test prints to check sizing

Minimizing the amount of material used in 3D printed parts is important, since this directly increases the cost of replication as well as the time required for each print. After determining that chamfering the edges of the sieve sorting holes greatly increased the likelihood that a train would be aligned to fall through, a full-size print was made, while trying to minimize the thickness of the sieve. The rectangular holes are the correct size, but ships were still getting through the holes. On closer examination, the sieve failure was due to the interesting geometry of the ship pieces. The ship pieces were able to hook their bow through the hole, twist 90 degrees to slide the main hull through, then twist 90 degrees again to allow their stern to hook through. This process is shown in Figure 10.

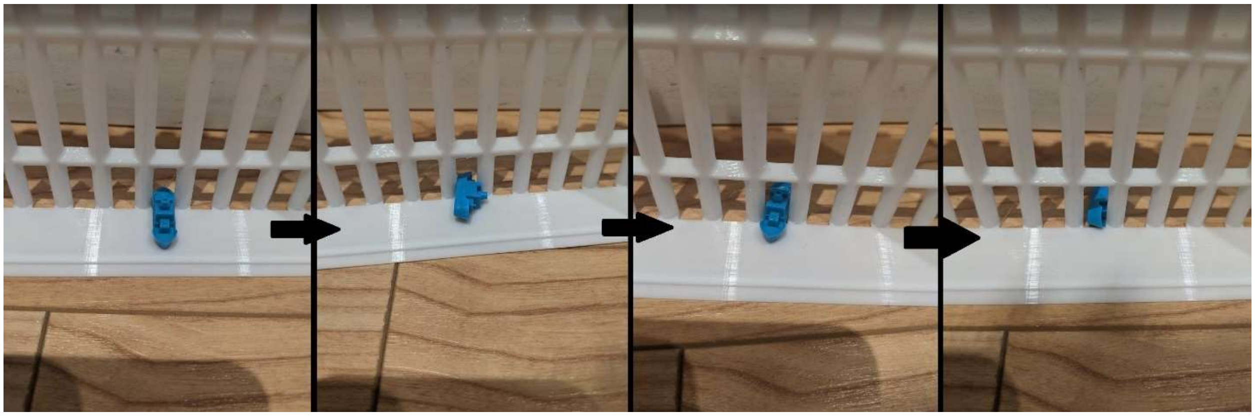

Figure 10. Ship game piece wiggles through sieve prototype

Increasing the thickness of the sieve bottom is the solution. The bow is no longer able to be hooked through and this ensures that only game pieces that fit the rectangular width will fit through the holes. This unfortunately significantly increases the amount of plastic material used but it was required for effective sorting. The new design is pictured on the right of Figure 11, and the old design is on the left for comparison of the bottom thicknesses.

Figure 11. Thickness increase from old (left) to new version (right)

2.3.2 Sifting Speed

After making the changes from Section 2.3.1, the assembly was shaken for varying amounts of time between 5 and 60 seconds, then the box was opened and the amount of unsorted train pieces were counted. After the box was opened, shaking was not continued and the test was restarted. The number of train pieces in the shaker was 33, and the number of ship pieces is 50, for a total of 83 game pieces. This number is higher than the pieces used for "The World" side of the game board, but that is how many pieces come in game box, so it is likely that the user would sort all 83 pieces at the same time. Data from these trials is summarized in a boxplot in Figure 12.

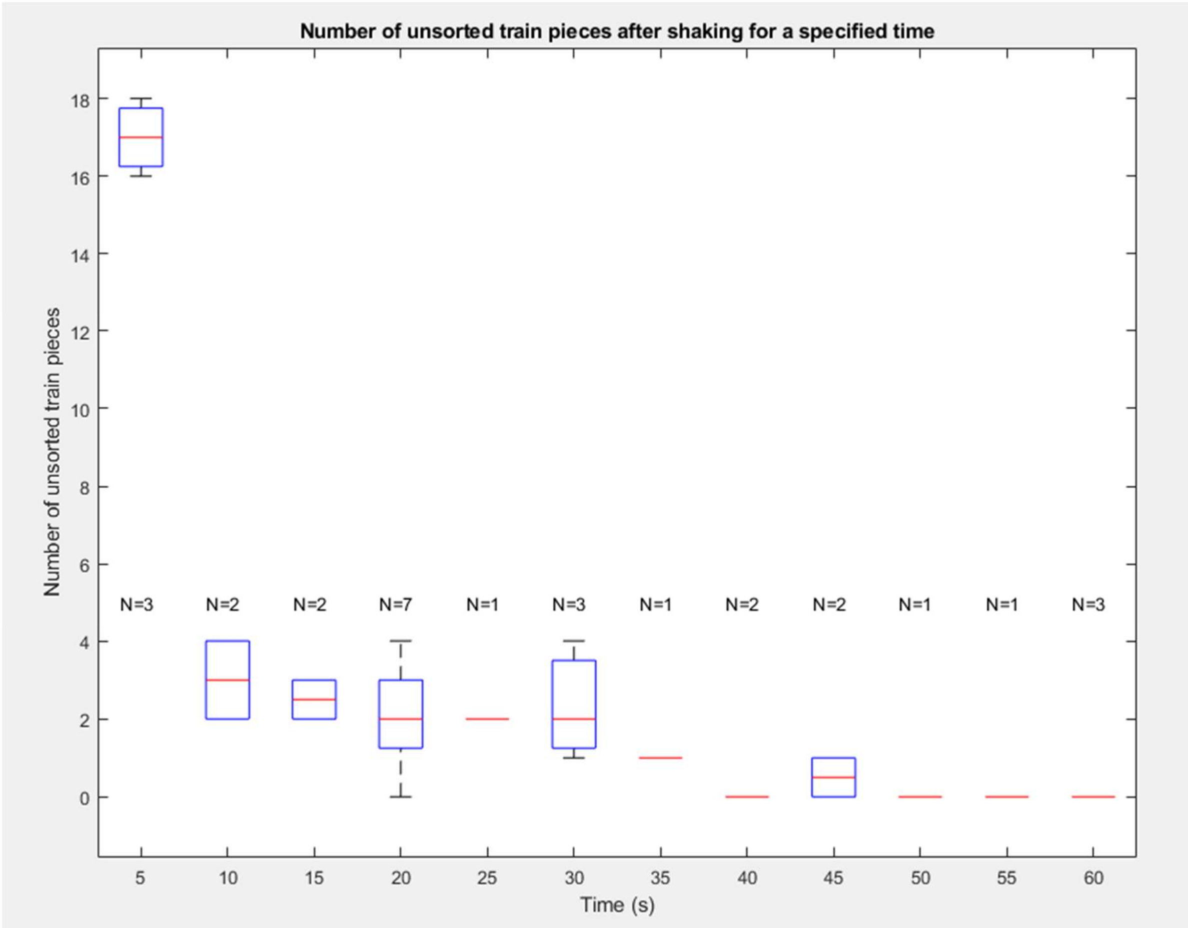

Figure 12. Number of unsorted train pieces after shaking for a specified time. "N" is the number of trials at each time step.

Clearly, the data shows that the number of unsorted trains goes to zero as the shaking time increases, after an initial high spike of entropy at T < 10 seconds. It is also important to note that there were 0 ships that fell through the sieve in any of the 28 shaking tests, confirming that the modifications made in Section 2.3.1 were effective. It is expected that if more tests were performed, more spread would be observed throughout the data. A logarithmic fit line to the data at T >= 10 seconds gives the equation $y = -1.92*\ln(x) + 7.79$, shown in Figure 13. The associated R^2 value of 0.85 shows that the equation provides a good fit to the data, and its shape matches what the expected effectiveness of the sorter over time. With more data, it's expected that the curve would asymptote to zero faster, near the T = 40 seconds mark.

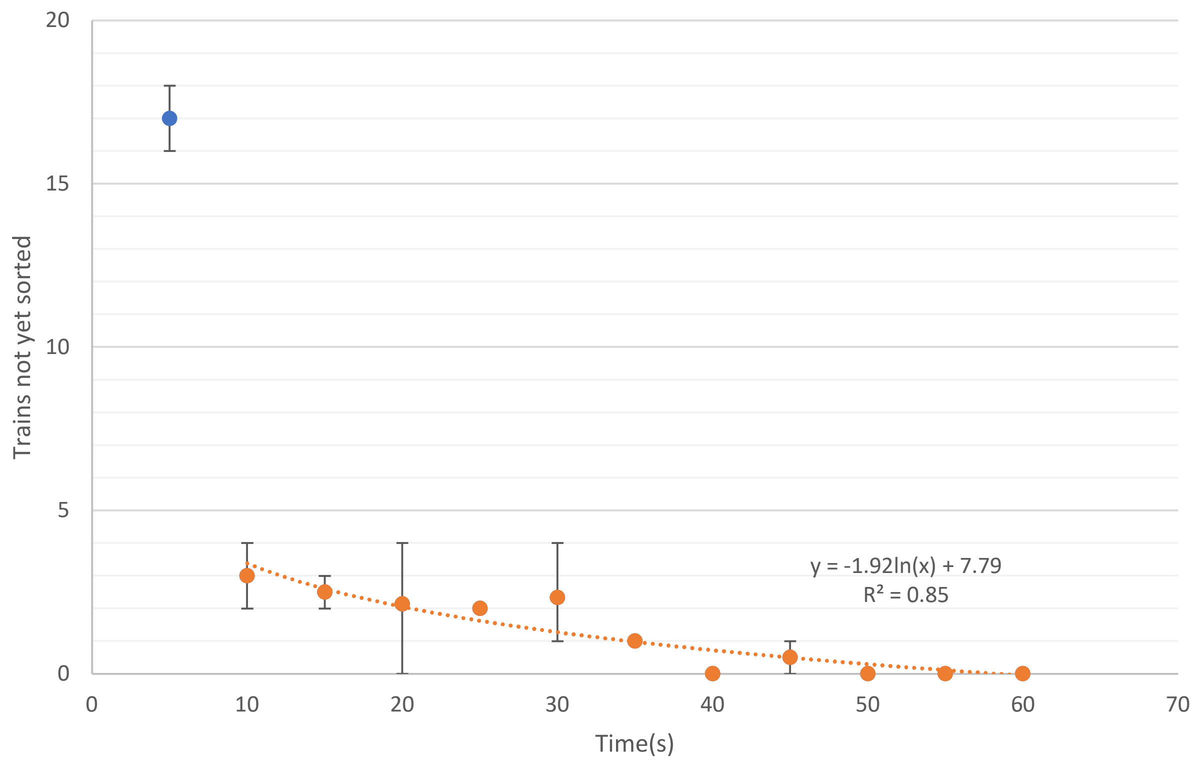

Figure 13. Logarithmic fit to sieve sorting of train pieces over time (For t >= 10 seconds)

A video of the sorting process and showing off the prototype is available on the video-hosting website YouTube [6].

2.3.3 Drop Testing

Due to the miniscule weight of the hollow plastic game pieces, the only strength requirements for the sorting assembly are derived from the need to survive a one-metre fall. 1 metre is at or above waist height for most people, so a fall from this height is the most likely during regular use of the product. When considering the best and worst impact orientations for the part, it is clear that hitting a bottom edge would be the most functionally damaging, as it could cause deformation to the sieve's sorting holes. If the bucket layer or the lid were damaged, the device would still remain functional since either could be easily substituted for a Tupperware container for the bucket or a book for the lid. Drop test simulations were performed on the sieve layer in SolidWorks, using the orientation shown in Figure 14.

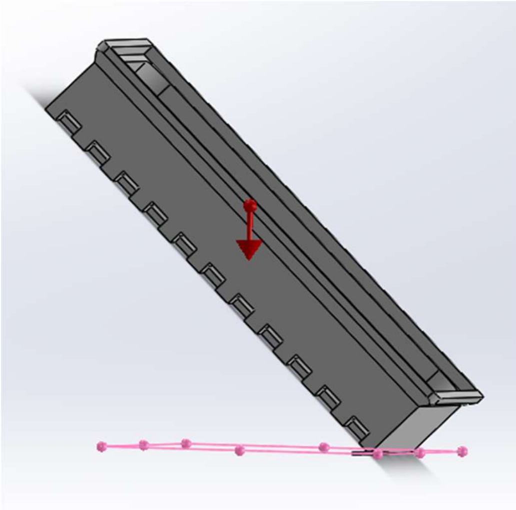

Figure 14. Drop test simulation orientation

The material for the drop test simulation must be specified. A custom material was created for PLA plastic, based on the ABS plastic pre-set. The values in Table 6 were used to manually override the custom PLA material pre-set to more closely represent the behaviour of PLA [7].

Table 6. PLA properties [7]

Property	**Value**
Density	1.24 g/cm^3
Poisson's Ratio	0.33
Yield Strength	26 MPa
Elastic Modulus	3145 MPa

The first simulation results showed that the peak von Mises stress is 96.8 MPa on the inside of the corner when the sieve first strikes the floor. According to tests performed by MakerBot, the peak stress that a solid-printed PLA part can endure is 93.8 MPa in compression or 65.7 MPa in tensile [8]. This simulation indicates that the part would fail, since the experienced stress is larger than the maximum empirical stress. This failure near the sieve hole is not acceptable as it could allow a ship game piece to pass through an enlarged hole, rendering the product ineffective at its intended purpose. Figure 15 is a screenshot of the simulation's high stress point.

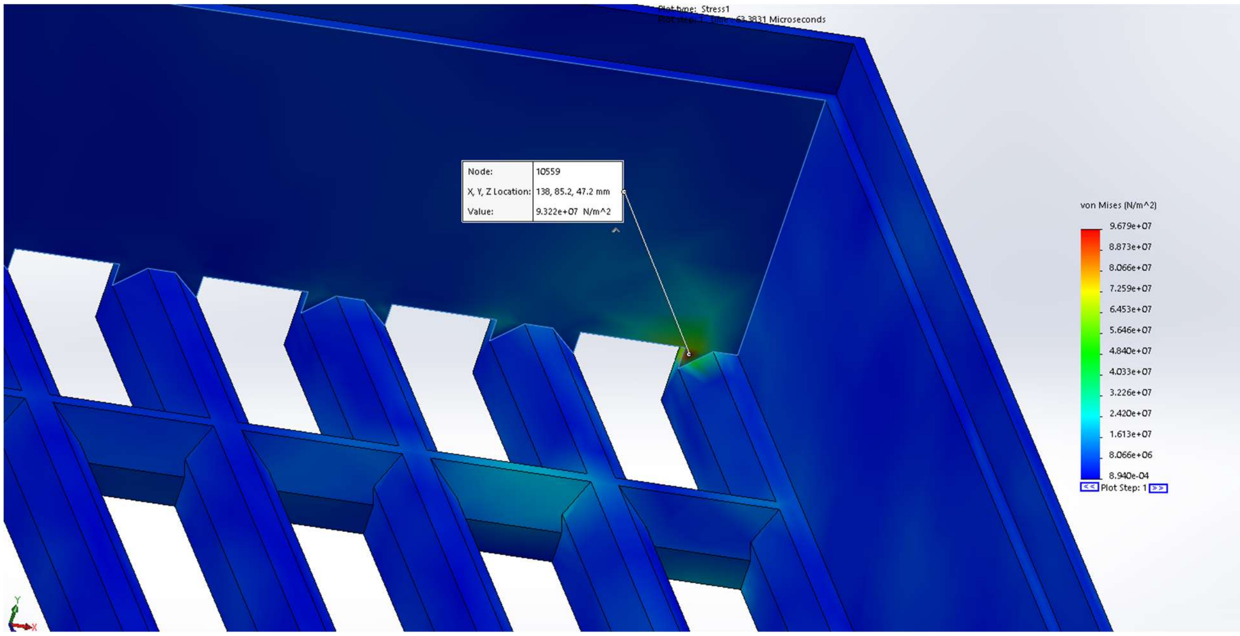

Figure 15. First drop test simulation

To verify the simulation results, the model was 3D printed in PLA at 100% infill (by increasing the number of walls) and dropped from a similar angle and from the same height as the simulation. A crack was observed originating from the point of high stress predicted by the simulation. The top edge also broke, but this only serves to easily the lid in place while the sieve is being shaken, so is not critical for operation of the device. These observed cracks are circled in red in Figure 16.

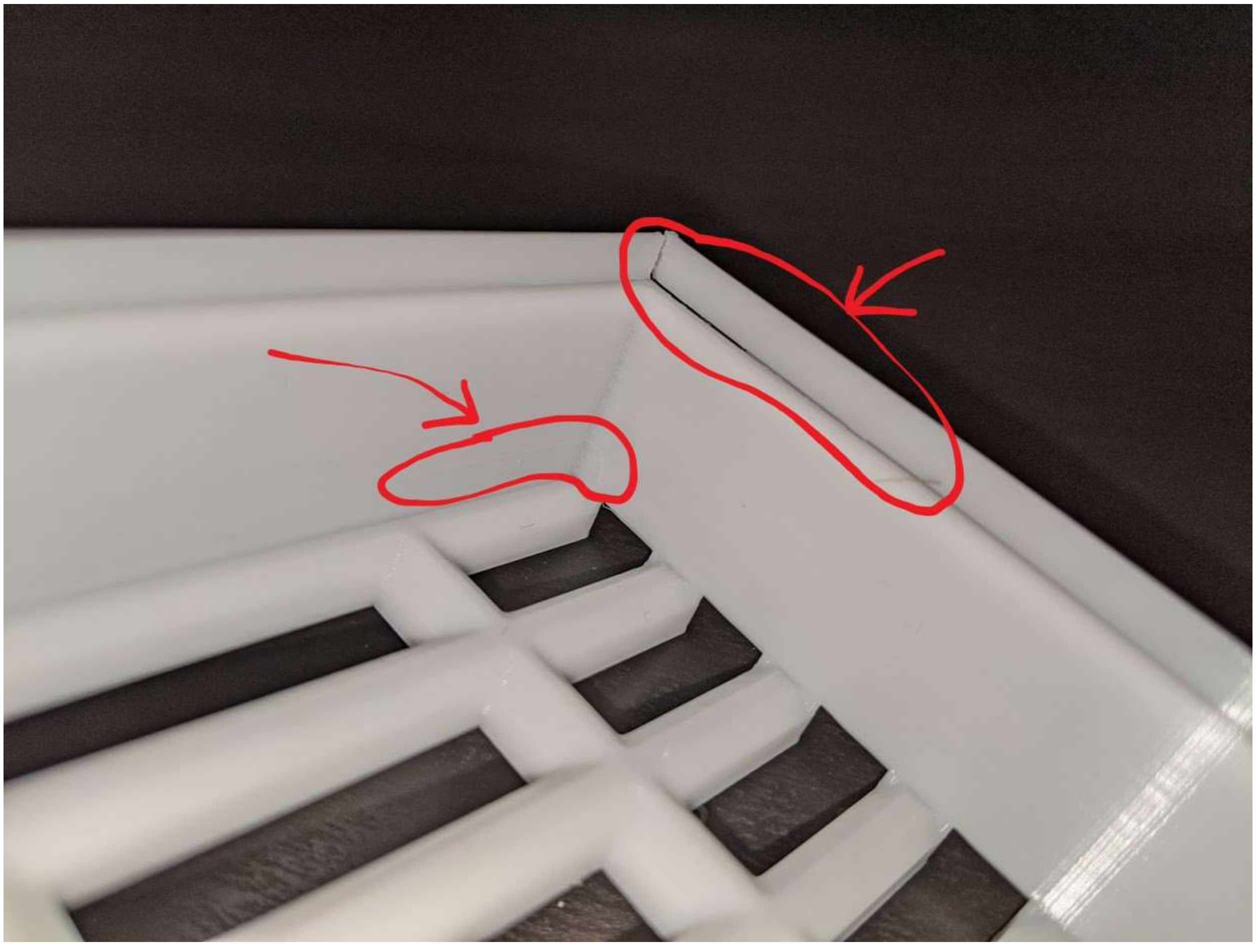

Figure 16. Printed sieve drop test examination

To improve the impact strength of the shaker, the wall thickness was increased from 1 mm to 3 mm, and various interior corners were filleted to reduce strength concentrations. After these changes to the model, Figure 17 shows that the maximum stress was decreased dramatically to 48.8 MPa, and the point of highest stress was moved to the outside corners. Were these corners to break, there would be no loss of functionality of the device and only minor aesthetic damage. This results in a safety factor of 1.3 when comparing the corner's maximum stress to MakerBot's measured maximum tensile strength.

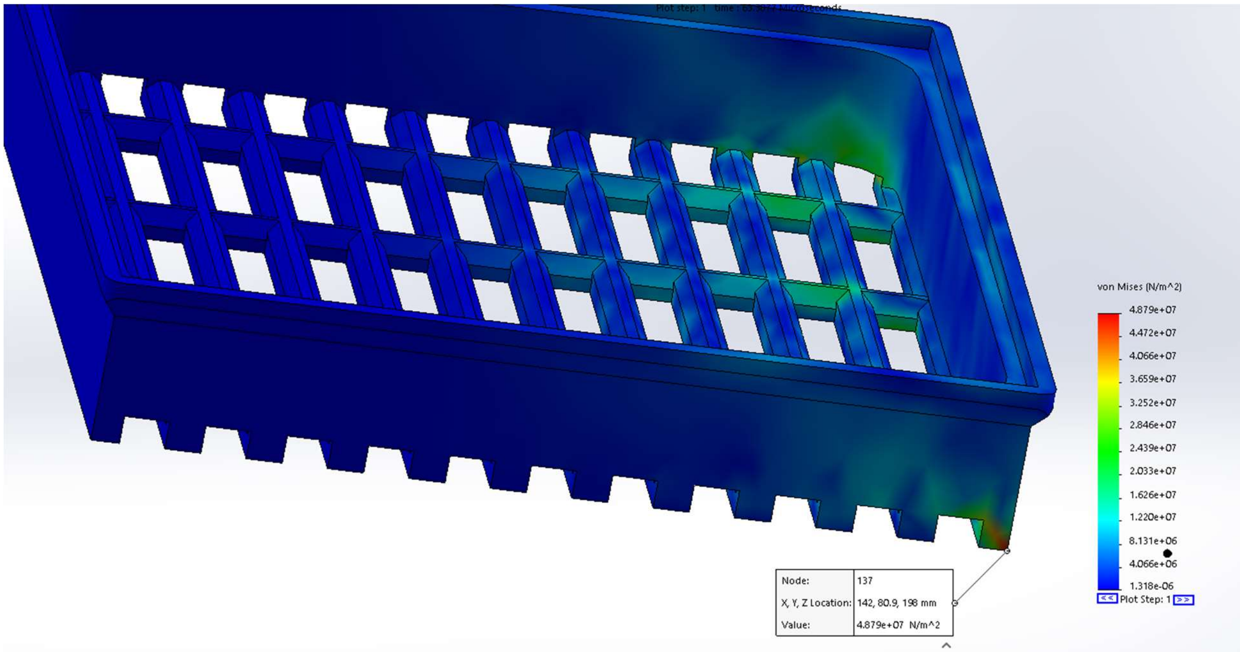

Figure 17. Second drop test simulation

To remove the chance of any aesthetic damage from falls, using a less brittle material than PLA is recommended, or potentially re-designing the shaker's structure to further reduces stress concentrations could be effective. However, for this product that is meant to be used occasionally and is unlikely to be dropped often, this design is sufficient.

2.3.4 Cost

The cost of the revised assembly, using the changes from Section 2.3.3, is less than $10. For just the sieve layer, the estimated cost of filament is $4.26 from the 3D printer slicer program Cura. The bucket for catching the sorted trains uses less filament than the sieve layer, and the lid uses hardly any, so the total assembly will cost less than $10. The whole assembly can be printed in under 30 hours if using a 0.4 mm nozzle and a 0.32 mm layer height. If a larger print bed or multiple printers are available, the total print time could be less than 12 hours.

2.3.5 Size

The dimensions of the shaker assembly are 15.5 cm x 15.5 cm x 6.2 cm, occupying a volume of 1,500 cm^3.

2.4. Limitations

The sorting speed data from Section 2.3.2 is qualitative, but the data would be more robust with more trials run at every time category to better show the variance and mean values for each amount of shaking time. For the best results, all tests would be done with a mechanical apparatus that could perform the same shaking motion each trial, so that the variability introduced by a human performing the shaking would be removed. Even though it would be better, setting up this type of testing rig is beyond the scope and budget of the project.

2.5. Comparison of Final Design to Objectives

When comparing the final design to the original estimated scoring

The data currently suggests that 40 seconds of shaking is required to consistently sort all 33 trains from the total 83 game pieces through the sieve. This would meet the original constraint of sorting 25 trains from 75 game pieces in under a minute. However, it only would score a 3 out of 5 on the original objective.

Durability scores high at a 4 out of 5, as it could have cosmetic damage at the corners if it takes a fall from a specific orientation. The simulation was verified with a single real-world test, creating a high confidence in the data. Even though the design doesn't blow expectations away in this category, it does in others. The 3D printer filament cost of $10 scores a 5 out of 5 on the original objective since it is under $20 to replicate. It should be noted that a consumer-level FDM 3D printer costs $300 [9] to $750 [10] depending on what model is selected, so there is a large capital cost that is not part of the cost analysis of this report. The design also scores a 5 out of 5 on rectangular volume used, since it is smaller than 10,000 cm^3. The last objective that this design meets is minimizing complexity, as it contains no electronics and requires only one mechanical part to analyze, resulting in a score of 5 out of 5.

Lastly, the user effort required objective is scored relatively low at 2 out of 5, since the user needs to continuously shake the product to have the sorting action occur. Since board games are often played with children, it is the author's opinion that this semi-tedious task can be handed off to the children, who will shake the device gleefully and add a meta-game to games night.

3. Conclusions

The stacked sieve sorter design is a successful improvement from having to sort the train and ship game pieces from each other manually for the game Ticket to Ride: Rails and Sails. It takes 40 seconds to sort all 83 game pieces with the device, while it the fastest that the pieces were sorted manually was recorded to be 41 seconds for 75 pieces. The user can sort the pieces using the device while using much less mental effort, and have no speed loss introduced. The sorting speed data was obtained by manually shaking the box for a set number of seconds, then recording how many unsorted trains remained. This manual component introduces error because the shaking is not consistent each test, but an automatic shaker apparatus was outside the scope of the report. The shaking data would also be more robust if many trials were performed at each of the 5-second increments from 5 seconds to 1 minute, but only 28 trials were recorded. For the mechanical structure development, drop test simulations were performed and verified by experiment, which helped shape the next iteration of the prototype. The design meets all other objectives, and is able to be reproduced by anyone with a 3D printer.

4. Recommendations

The design could be improved beyond the objectives by improving how the device's aesthetic. Currently, the design is quite functional, but is not very pretty. Some suggestions are to turn the device into a cylinder or a sphere, and perhaps modifying the design to use multiple colours of filament instead of a single colour. A quality-of-life improvement would be to add snap-fit connectors so that the layers do not have to be held tightly together during operation.

5. References

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Appendix A. Scoring Metrics

This appendix contains the scoring charts used to rate the designs on each objective. The objectives were selected with the end user in mind. At the end of this project, the hope is that this project can be re-produced to give to friends and family that own Ticket to Ride: Rails and Sails so that the tabletop experience can be that much better. Each objective has a description of what merits each level of grade, using integer values one to five to score. A five is considered the optimal user experience, while a one is a terrible user experience that may stop the player from using the device in the future.

Sorting speed can be quantified by the time it takes to sort 75 game pieces (25 trains and 50 ships) without errors. The author's fastest sort time was measured to be 40.8 seconds, but the average sort time when attempting for a fast time was 47 seconds. When the players are playing the game normally and not attempting for a new personal best sorting time, it would likely take a bit over 60 seconds to sort. From this, it can be concluded that if the device takes less than 60 seconds, it will be faster than the current method. The scoring scale is tabulated as Table 7.

Table 7. Sorting speed scoring scale

Score	Sorting Time (seconds)
1	More than 60
2	60
3	40
4	30
5	20

User effort required is an objective that, if achieved, will take away tedium and stress from the player. Ideally, the sorting device will require minimal interaction from the user, such as pushing a button. Table 8 gives the subjective scores assigned to different levels of intervention required from the player.

Table 8. User effort required scoring scale

Score	User effort required
1	The player must sort the pieces (with help from the device).
2	Stirring or shaking is required.
3	A hand crank must be turned to operate the device.
4	The player must moderate how many pieces are put into the system at one time so that the system does not become clogged.

Score	User effort required
5	Only simple and short interaction required, such as a button press.

The complexity objective was implemented so that the projects are scored with some consideration given to the amount of effort required to design and build prototypes. If the project is not sufficiently completed by the end of the semester due to too large of a scope, then the end user will not be able to enjoy using the device, so the grading should reflect that. Also, reducing the number of parts and general complexity will likely decrease the amount of maintenance required to keep the device working in the future. The scale used to score the devices is Table 9.

Table 9. Minimize complexity score scale

Score	Minimize Complexity
1	Requires microcontroller and more than one motor.
2	Requires microcontroller, one motor, and less than 5 mechanical parts to perform analysis on.
3	Includes DC motor and drivers and/or less than 10 mechanical parts to perform analysis on.
4	Includes DC motor and drivers and/or less than 5 mechanical parts to perform analysis on.
5	No electronics, less than 5 mechanical parts to perform analysis on.

Durability is necessary when dealing with board games because accidents happen; things sometimes get knocked off the table or kicked when a player gets up to get a snack. This score chart, Table 10, is subjective and tuned to show spread between the 3 options. Wood flooring was selected as the falling surface, since most homes are likely to have wood or carpet flooring in the dining room, where board games often are played.

Table 10. Durability score scale

Score	Durability (from 1 metre fall onto wood flooring)
1	Device is destroyed.
2	Functional damage that can be repaired.
3	Functional damage if it falls in a certain orientation.
4	Cosmetic damage.
5	Does not show any visible damage.

Portability is an objective due to how players will use the device. To be an effective device, it needs to be easily transportable between houses for games nights (if the pandemic ever ends), and easy to bring in and out of closet storage. This objective will be measured by the rectangular volume that it requires. The maximum volume is selected to be 100,000 cm^3, or approximately 1' x 1' x 3.5'. 100,000 cm^3 is the rectangular size of a stand-up vacuum cleaner.

Table 11. Portability scoring scale

Score	**Rectangular Volume (cm^3)**
1	More than 100,000
2	100,000
3	70,000
4	40,000
5	10,000

Minimizing cost is always included as an objective in projects because we live in a society that ascribes value to pieces of paper (or plastic as they are now in Canada!). The users of this device have already spent $110 on the board game [11], so they are unlikely to want to pay more than the cost of the game, just to sort the game pieces faster and easier. The highest price in Table 12 is set as $100. If it takes more than this in materials to reproduce the device, it clearly is not worth making (other than as a passion project). This price is still high, and buyers would likely expect the price to be closer to that of a card shuffler, which costs $26 on Amazon.ca [12].

Table 12. Cost scoring scale

Score	**Cost**
1	$100
2	$80
3	$60
4	$40
5	$20