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Final Design Report: The Library Cartel

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1. Executive Summary

The Trinity University library is in need of new and improved library carts. Specifically, the improvements should focus on the level of noise produced by the cart, the cart's book retention capabilities, and the relative ease of use for the library worker. These parameters were chosen based on the needs of the Library as expressed by our sponsor. A budget of $1200 was provided for developing and prototyping a cart that would improve on these aspects. In order to confirm the success of the prototype, the capabilities of the wheels, shelves and chassis were tested and analyzed. These capabilities were tested by measuring noise level, book retention and ease of use for both the existing carts and the prototype. These values were then compared in order to confirm that the prototype improves on the issues present in the current design used by the Library. It was concluded that the prototype was measurably quieter, had greater book retention and was easier to use than the current library cart. Overall, the prototype we produced met all of our project objectives. However, the wheels were not as quiet as we wanted. Although our cart was measurably quieter than the current cart, it was not as significant of a difference as we wanted. We plan to switch the wheels we have on the prototype with slightly larger pneumatic ones. This wheel change will improve the design and lower the measured noise levels as the cart travels through the library.

2. Introduction

According to representatives from the Trinity University library, the library book carts currently in use are noisy, difficult to maneuver, unstable, and replete with ergonomic issues. Specifically, the library staff emphasized that the existing library carts produce too much noise when rolling over non-carpeted surfaces and are difficult to maneuver because the carts are heavy, physically long, and use caster wheels that frequently seize. Furthermore, the library staff explained that they are unable to utilize all of the shelving space in the existing carts because the process of loading and unloading books from the lower cart shelves is too strenuous for library workers. Consequently, the library workers end up only loading books into the upper cart shelves, making the library carts top-heavy and unstable when in motion.

The design constraints provided by the library staff are as follows: The cart must fit within a standard 29-inch-wide aisle. The cart must be safe enough to be operated by and around all library workers. The cart must be easy to use. The cart must be stable when moving and hold books securely. The cart must be able to traverse a small step down or step up, created when the

elevator floor is misaligned with the floor of the library, without falling over or dropping any books. The cart should hold at least 50 pounds of books. The design constraints provided by the engineering science department and senior design administrators are as follows: A single redesigned library cart should cost no more than $1200 to produce. At least one fully-functioning library cart must be delivered to the library staff no later than May 2019. Additionally, the library cart should adhere to applicable consumer product safety standards, as well as relevant ASME and IEEE standards for mechanical design and engineering ethics.

Our objectives are as follows: The project team must deliver at least one redesigned library cart that is quieter, safer, more maneuverable, and more ergonomic than the existing library carts. When in motion, the redesigned cart must produce less noise—measured using a microphone or decibel meter—than the existing carts, when rolling over a given surface at a given speed. When traversing bumpy surfaces or the elevator step up/step down, the redesigned cart must drop fewer books and demonstrate greater stability than the existing carts, wherein stability can be assessed through the use of an accelerometer or tilt meter to measure forward and lateral wobble of either cart. The redesigned cart must have superior maneuverability and ease of use compared to the existing carts, which can be quantified through a combination of factors such as turning radius or pushing force, as well as the evaluation of feedback from library workers. Finally, the redesigned cart must demonstrate superior ergonomic design, compared to the existing carts, which can be assessed by comparing how much of the cart shelving is usable to the average library worker who does not crouch or bend at the waist. The quality of the ergonomic design can also be assessed through the evaluation of feedback from library workers. The prototype we designed and built was tested to determine if it is quieter, safer, more maneuverable and more ergonomic than the existing carts.

3. Overview of the Design as Tested

The major subsystems of our design are the wheels, the shelves and the chassis. We decided to use hard rubber wheels for our design. Our thought process was that solid rubber wheels would require less maintenance than pneumatic wheels. Also the wheels we chose are larger than the wheels on the existing carts. This size difference allowed the cart to traverse a small step down or step up, created when the elevator floor is misaligned with the floor of the library, without falling over or dropping any books. In addition, the shelves are angled in order to

increase book retention and are placed higher in the frame to ensure the library workers would not have to bend to reach a shelf. Unlike the current wooden library carts, the prototype allows for the books to be stored with the spine facing outward. This makes the spine easier to read which in turn, makes book organizing easier. By installing the wheels on the edges of the bottom plate, the prototype has a tighter turning radius and more maneuverability compared to the existing carts. The chassis is comprised of ½ inch thick plywood wood which is thick enough to be structurally sound and capable of holding at least 50 pounds of books, but also thin enough to reduce weight to make it easier to push. Additionally, we installed vertical handlebars to maximize control and increase relative ease of use of the cart.

4. Prototype Tests

4.1. Noise Level Test

4.1.1. Test Overview and Objectives

The purpose of this test is to measure the noise level of the prototype. Noise level testing involved a noise level meter/microphone, to capture the noise produced by the cart during operation when it is both loaded and unloaded with books. The objective of this tests is to prove that the prototype is measurably quieter than the current carts in the library. The noise reducing capability of the wheels is analyzed in this test.

4.1.2. Test Scope and Test Plan

For this test, the prototype traveled over two different surfaces in the Trinity University Library. The two surfaces consisted of the bumpy brick floor and the smooth carpet. Additionally, the cart will be tested when it is both loaded and unloaded with books. For this test we used an iPhone decibel meter app to measure the noise level of the cart. We set the iPhone up in the middle of a hallway with a carpeted floor and a hallway with a bumpy brick floor. We pushed the cart down the entire length of the hallway twice. Once completely empty and once fully loaded with books. We measured the decibel values from these runs and recorded the maximum values. We followed the same procedure and tested the existing library cart to compare the noise levels produced by both carts.

4.1.3. Acceptance Criteria

The redesigned cart must produce less noise - measured using a decibel meter - than the existing carts, when rolling over a given surface at a given speed. The prototype performed

4.1.4. Test Results and Evaluation

As indicated in tables 1-4, the prototype performed marginally better than the current library cart on the brick flooring, and performed moderately better on carpet. The average percent differences between the prototype and current carts were 3.9% for loaded on brick flooring, 9.5% for loaded on carpet flooring, 3.5% for unloaded on brick flooring, and 12.4% unloaded on carpet flooring. While the prototype indeed improved in regards to noise reduction, we believe using pneumatic wheels will lead to an even larger improvement. We will perform the same tests using pneumatic wheels to ensure that they actually help to further reduce noise levels.

Table 1. Sound data collected from the two fully-loaded carts, current and prototype, when driven over brick flooring and compared.

Test No.	1	2	3	4	5
Current [dB]	81	83	82	81	84
Prototype [dB]	78	78	79	80	80
Difference [%]	3.7	6.0	3.7	1.2	4.8

Table 2. Sound data collected from the two fully-loaded carts, current and prototype, when driven over carpet flooring and compared.

Test No.	1	2	3	4	5
Current [dB]	61	56	54	53	60
Prototype [dB]	51	50	53	52	50
Difference [%]	16.4	10.7	1.9	1.9	16.7

Table 3. Sound data collected from the two unloaded carts, current and prototype, when driven over brick flooring and compared.

Test No.	1	2	3	4	5
Current [dB]	85	87	85	87	87
Prototype [dB]	81	85	80	86	84
Difference [%]	4.7	2.3	5.9	1.1	3.4

Table 4. Sound data collected from the two unloaded carts, current and prototype, when driven over carpet flooring and compared.

Test No.	1	2	3	4	5
Current [dB]	60	55	55	61	56
Prototype [dB]	50	51	49	51	50
Difference [%]	16.7	7.3	10.9	16.4	10.7

4.2. Book Retention Test

4.2.1. Test Overview and Objectives

The purpose of this test is to ensure that the prototype is safe for the workers and the books themselves. The objective of this test is to verify that the prototype can safely hold and transport books, even across small bumps or rough surfaces. The retention capability of the angled shelves is examined in this test.

4.2.2. Test Scope and Test Plan

Book retention testing involved the pushing of the fully loaded cart across small bumps and rough surfaces to determine if books fall out of the cart. In addition the maximum allowable tip was tested and measured. For these tests we used the same amount of books for each run in order to stay consistent. For this test, we pushed the cart over the bumpy brick floor of the library and over the small gap between the floor and the elevator shaft. We tested the book retention of the cart in each scenario ten times. After each run we counted the number of books, if any, that fell out. In addition, we used a protractor to measure the the maximum angle of the cart before a book falls out. We followed the same procedure and tested the maximum angle of the existing library cart to compare the book retention capabilities of both carts.

4.2.3. Acceptance Criteria

When traversing bumpy surfaces or the elevator step up/step down, the redesigned cart must drop fewer books and demonstrate greater book retention than the existing carts, wherein book retention can be assessed through the use of a protractor to measure the maximum allowable tilt.

4.2.4. Test Results and Evaluation

After testing both carts, we measured that the maximum allowable tilt of the current library cart was 12° while the allowable tilt of the prototype was 25°. This measurement signifies the maximum tilt of the cart before a book falls out. Additionally, we found that no books fell out of the cart after repeatedly traveling across small bumps and rough surfaces commonly found when traversing elevator gaps. The results of these tests prove that our prototype has greater book retention than the current carts in the library.

4.3. Ease of Use Test

4.3.1. Test Overview and Objectives

The purpose of this test is to assess the ease of use of the prototype through qualitative testing. The objective of this test to prove that the prototype is overall easier to use compared to the existing library carts. The capability of the wheels, wheel spacing and handlebars are examined in this test.

4.3.2. Test Scope and Test Plan

Library workers were surveyed to compare the prototype with the current library carts. The comfort and ergonomic capabilities of the new cart were assessed. The cart was used in various parts of the library in order to see how well it maneuvered on different surfaces. Surveyed users were given five criteria by which to assess how ergonomic the prototype is: Comfort, steering, starting and stopping, and loading and unloading. The carts were tested for both loaded and unloaded states. They were instructed to rate both the current library carts and the prototype on a scale of 1 to 5 for each category. The scores assigned to the new cart were compared to those for the current ones.

4.3.3. Acceptance Criteria

The redesigned cart must demonstrate superior ergonomic design, compared to the existing carts, which can be assessed by comparing how much of the cart shelving is usable to the average library worker who does not crouch or bend at the waist. The quality of the ergonomic design can also be assessed through the evaluation of feedback from surveyed users.

4.3.4. Test Results and Evaluation

Table 5 displays the feedback from the qualitative surveys conducted after the user operated the current cart in the library. The scores are on a scale of 1-5, where 5 is the best, and it can be seen that the ratings were low across the board. The highest rating being 3 in relation to starting and stopping. The average ratings for comfort, steering, starting and stopping, and loading and unloading were 1.7, 1.4, 2.5 and 1.8, respectively. Table 6 displays the feedback from the qualitative surveys conducted after the user operated the prototype. It is clear that the ratings were much higher when compared to the existing cart ratings. The average ratings for comfort, steering, starting and stopping, and loading and unloading were 4, 3.9, 4.9 and 4.7, respectively. On average, the prototype was rated higher in every category compared to the

current library carts. These results confirmed that the prototype is overall easier to use and more ergonomic than the current library carts.

Table 5. Current library cart feedback

	User 1	User 2	User 3	User 4	User 5	User 6	User 7	User 8	User 9	User 10
Comfort	2	2	1	2	1	2	2	1	2	2
Steering	1	1	1	2	1	1	2	2	2	1
Starting and Stopping	3	2	3	3	2	2	2	3	2	3
Loading and Unloading	2	2	1	3	1	3	2	1	1	2

Table 6. Prototype feedback

	User 1	User 2	User 3	User 4	User 5	User 6	User 7	User 8	User 9	User 10
Comfort	4	4	4	4	5	4	4	4	4	3
Steering	4	4	4	3	4	4	5	3	4	4
Starting and Stopping	5	5	5	5	5	5	5	5	4	5
Loading and Unloading	4	4	5	5	5	5	5	5	5	4

5. Conclusions

Throughout the testing of the prototype capabilities, we determined that the current design drastically improved upon ergonomics and book retention and slightly improved the noise levels produced. This slight improvement was not as significant of a difference as we wanted. Consequently we will replace our current wheels with pneumatic wheels expecting that they further reduce noise levels. The same noise tests will be performed once the wheels are replaced.

Appendix A

Setup, Operating and Safety Instructions

The cart is fully assembled and ready to use. The cart can be operated by pushing the end with the handles. The cart can be loaded on either side. It was designed to handle 200 pounds of books, AKA about 100 books. The cart should not be loaded with more than 100 books. Additionally, the bottom plate of the cart can be used for extra storage. During operation, the cart should remain upright and have all four wheels on the ground. The cart should not be tipped more than 25 degrees. If the cart is tilted 25 degrees, books will fall out. We recommend for the safety of the user and public that the operator of the cart not run while pushing the cart. This would make it very dangerous and hard to stop. Finally, we recommend that the prototype not roll over a bump, ledge or gap larger than 2 inches. Moving across a bump, ledge or gap larger than this may result in books falling out or possibly the cart tipping.