Project Report: ESG Elevator Accelerator

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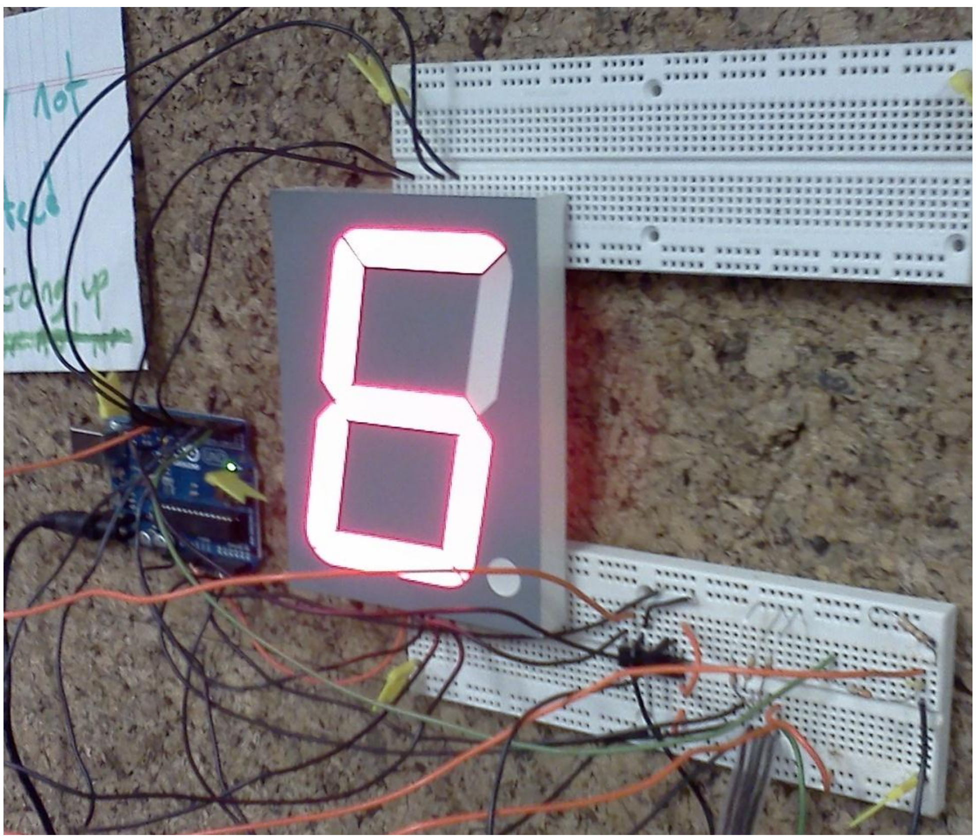


Cover photo: Elevator Accelerator controller and display in the ESG lounge.

Abstract

Many people experience delay entering or existing MIT Experimental Study Group (ESG, located on the sixth floor of Building 24) due to the long waiting times for the only elevator in the building. A survey has shown a strong desire for a faster elevator; therefore, the elevator waiting time needs to be shortened in order to better serve the ESG community. To remedy this problem, this paper documents the design, construction, and testing of the Elevator Accelerator, an elevator control system that displays the elevator's location at ESG lounge and allows the user to call the elevator without physically walking to the elevator. The Elevator Accelerator has two halves: one is located in the ESG lounge to display the elevator position and takes user's inputs, and the other one is next to the elevator to read the elevator's position and push the elevator button. The Elevator Accelerator has been proven to work as expected and in a consistent fashion. Moreover, after the installation of Elevator Accelerator, many people appreciate our design and found it useful according to the post project survey. The Elevator Accelerator does not compromise any elevator safety regulations. The success of this project suggests that the Elevator Accelerator can be expanded to other existing elevators to optimize elevator usage, reduce waiting time and cut redundant elevator trips.

Introduction

The Experimental Study Group (ESG) is located on the 6th floor of Building 24 in the Massachusetts Institute of Technology. Building 24 is served by a single elevator that, from measurement, takes about 90 seconds to travel from the ground floor to ESG and back. As elevator wait time can easily exceed two minutes if the elevator makes intermediate stops, many ESG students find this wait time unacceptable, as documented in the initial survey (shown in Appendix A). To improve satisfaction with the ESG elevator, a remote call feature and a floor indicator were added to the 6th floor. This paper documents the design, construction, and testing of these additions.

In improving ESG elevator service, the most important design constraint can be found in Massachusetts law. According to the Board of Elevator Regulations, a permit is required to modify any existing elevator, and re-inspection is required after work is complete [1]. Therefore, changing the elevator machinery proper is illegal; only exterior features may be added. Two plausible ways to increase elevator satisfaction are to make elevator arrivals more predictable, and to allow waiting in the ESG lounge instead of next to the elevator door. Both of these goals can be achieved without modifying existing elevator mechanisms.

To accomplish these two goals, the current position of the elevator must be displayed in the lounge, and passengers must be able to remotely push the elevator call button from the lounge. This requires a sensor array on the elevator floor display panel, a motor to push the elevator call button, a floor indicator in the lounge, and a control system to integrate these features.

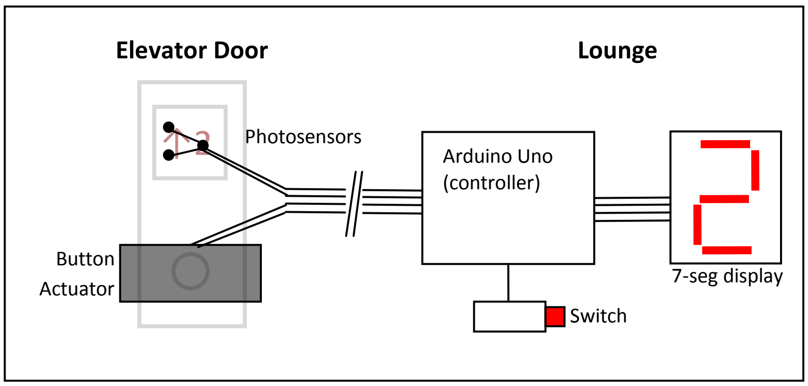
Background

With the advent of computers, some companies have designed control systems to better use existing elevator hardware. One solution, made by Schindler, has a keypad on every floor, on which users enter their destination floors. The control system then efficiently routes elevators based on user input, and points users to the elevator that will reach their destination the fastest. Another method has an ID scanner at every floor, allowing the control system to gauge how many people are waiting at each floor. However, all of these solutions require multiple elevators in a bank, and are typically expensive to install. Furthermore, elevator manufacturers calculate that these solutions are not practical for buildings under 10 stories tall. [2]

On a smaller scale, the Otis Elevator Company holds a patent for a remote control system that detects users as they approach the elevator bank. Users can enter their destination floor on a pocket-sized keypad. This design has not yet been implemented in any building. [3] The scope of this project, however, is even smaller: not on a bank of elevators or even a single elevator, but on one floor of one elevator. Moreover, all of these solutions are designed to be installed in new elevators, not added to existing elevators.

Methods

The Elevator Accelerator consists of two halves, one next to the elevator and one in the ESG lounge. The two halves are connected by a ribbon cable, allowing communication and power transfer. The elevator half includes a motorized device to push the elevator call button and an array of photosensors on the display panel to detect the current elevator position. The lounge half of the system includes the microprocessor (an Arduino Uno), the power supply, a seven-segment display panel to indicate the current elevator location, and an elevator call switch that starts the button actuator. A summary of the Elevator Accelerator's components is shown in Figure 1a.



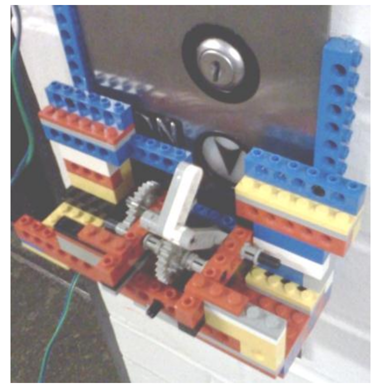


Figure 1 – A: diagram of the Elevator Accelerator's main components. B: button actuator.

The button actuator is built out of LEGOs and mounted on top of the elevator call button, as shown in Figure 1b. LEGOs were selected over more traditional materials because LEGOs are readily available around ESG and allow rapid prototyping.

To detect the current position of the elevator, photosensors are used. This choice was made because the elevator display consists of bright LEDs, making light sensing the simplest approach to visioning the display. Three photosensors are attached to the existing display panel. Two of the photosensors focus on the arrow display; they detect whether the elevator is moving up, moving down, or staying still. The final photosensor is positioned on a special part of the number display. This special pixel flickers whenever the elevator switches floors: it lights up when the elevator is on the ground, second, fourth, and sixth floors, and remains dark on the other floors. Therefore, the final photosensor detects a change in brightness whenever the elevator moves. Together, the three sensors let the microcontroller detect when the elevator moves and determine its direction of motion, pinpointing the elevator's position at all times. Figure 2 shows the photosensor implementation.

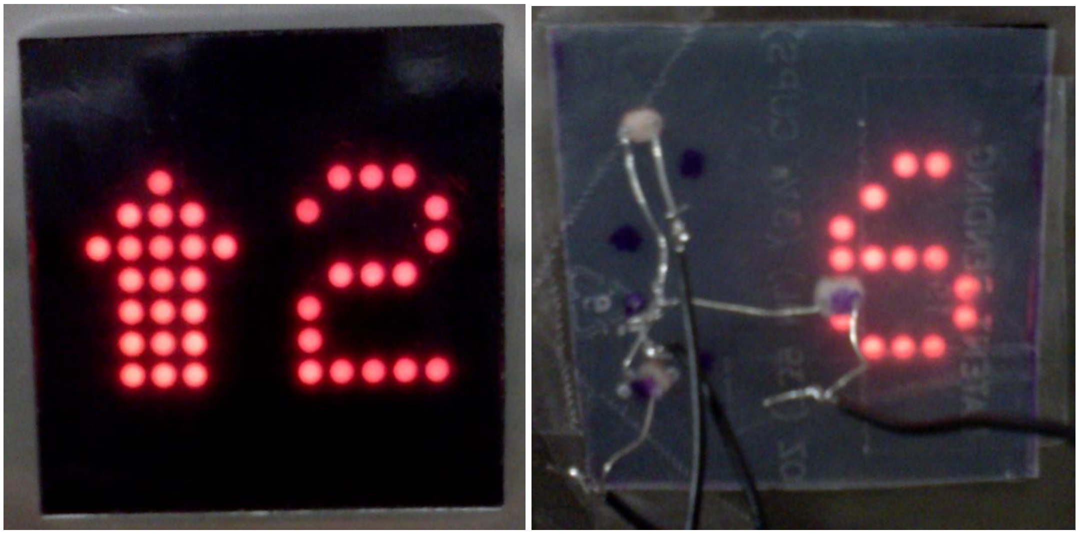


Figure 2 – Photosensor array on the elevator display panel. Left: original display panel. Right: display panel with photosensors, showing the two arrow sensors and the single flicker sensor.

The Arduino microcontroller processes input from the photosensors, outputting a floor number to the seven-segment display. In determining the elevator's current floor, the main roadblock is noisy input. From preliminary observation, there are two sources of noise from the photosensors. The first varies on the scale of milliseconds, caused by shadows passing over the sensors, electromagnetic interference, and other short-term disruptions. The second is caused by the change in ambient light over the course of a day. Short-term noise is largely negated by input averaging: in taking a single sensor reading, the microcontroller takes 10 consecutive inputs from the sensor over a period of 200 ms and averages the middle four values.

Unlike short-term noise, ambient lighting changes are harder to account for. The solution is integrated throughout the Elevator Accelerator's code. In detecting when the elevator moves, the microcontroller looks at relative brightness over short periods of time. It compares new photosensor readings to a baseline, recording a floor change whenever the difference between new reading and baseline is significant enough. Upon each floor change, the baseline updated to be the change-triggering reading. Assuming no sudden change in brightness, this method should not be affected by ambient lighting conditions.

In determining the direction of elevator motion (the direction in which the arrow on the display is pointing), the microcontroller considers the difference between readings from the two photosensors positioned on the arrow. One photosensor is located near the top of the arrow display area, and the other is located near the bottom. When an upwards arrow is displayed, the difference between readings tends to be higher than when a downwards arrow is displayed. However, light may shine unevenly on the display panel throughout the day, so there is not one simple threshold difference between the directions.

To account for uneven lighting, the Elevator Accelerator uses a learning algorithm. The microcontroller keeps track of the last 12 differences in readings from the arrow sensors – a reading is taken every time the number sensor detects a floor change. Because the elevator only serves 7 floors, at least 3 of these 12 differences are guaranteed to correspond to an upwards arrow, and at least 3 are guaranteed to correspond to a downwards arrow, otherwise the elevator would have to break through the roof or sink below the basement. The microcontroller compares the new reading difference to the average of the three highest and three lowest differences in its memory to determine the direction of travel. This new difference is then stored in memory, and the oldest difference is dropped. After an initial data-collection period, this approach infers the threshold between up and down and therefore the current direction of travel, based on recent data and heuristics.

Testing

To gauge the accuracy of the Elevator Accelerator's current floor display, the elevator will be monitored during a period of normal use. Every half minute, the floor displayed by the Elevator Accelerator will be recorded, alongside the actual position of the elevator. Ideally, these two positions should be the same for the majority of times, and any differences should be of one floor.

To assess whether the Elevator Accelerator meets the larger goal of improving satisfaction with elevator service in ESG a survey prior to the installation of Elevator Accelerator and a survey after the project implementation were sent out to collect peoples' opinions. In order to quantify how well the proposed design has met the functional requirements, each parameter was evaluated carefully before and after the installation of proposed system. The functional requirements are divided further to different criteria and various weights are assigned accordingly. Least important criterion is weighted with a factor of 1 and most important criterion is weighted with a factor of 5. A score between 1 and 5 was assigned for each criterion where 1 represents the least desired respond and 5 represents the most desired respond. The weighted final score was calculated to quantify the degree of successfulness. The final score of the proposed elevator control system was compared to the score of the old elevator system. The project will be considered as successful, if the score is higher than the score of the old system, otherwise the project will be considered as a failure. Moreover, the actual system score was compared to expected system performance. The system will be considered as a huge success if the Elevator Accelerator scores higher than expected. Table 1 list all the criteria, its weight, and method of assigning a score accordingly.

Table 1: List of Criteria

Functional Requirements	Criteria	Weights
Does it work?	Display elevator location at ESG lounge	5
	Display the direction the elevator is going (up or down)	5
	Push the elevator button from ESG lounge	5
	Allow user to push the button next to the elevator	5
Is it safe?	Does it change the original elevator system?	4
	Does it have open parts, wires that might be harmful	5
	Does it pass rolling-eye test?	5
Met all legal restrictions?	Does it meet MIT safety regulations?	5
	Does it meet Massachusetts regulations on elevator?	5
Waiting time reduced?	How do people like about the system?	5
	Did it save people time?	5
MISC	Does it look pretty?	2
	Is it easy to use?	5
	Is it energy efficient?	4
	Do people find it useful?	5
	Does it meet people's expectations?	3

Results

The functionality of the Elevator Accelerator is measured in three general ways: effectiveness of the button-pushing device, accuracy of the floor indicator, and change in satisfaction with the ESG elevator.

By December 13th, 2011, the button-pushing device was fully implemented and functional (as shown in Figure 1b). ESG students used the button on a regular basis without incident.

Figure 3 shows the results from the floor indicator accuracy test. The floor indicated by the Elevator Accelerator was measured alongside the actual floor, and the frequency of the difference is plotted. In all, 49 measurements were taken over the course of 30 minutes. There is a two-minute gap in the data, as the camera used to monitor the elevator's actual position froze midway through the experiment.

The floor indicator does not display the correct floor through the majority of the test, although the modal error is 0. This test shows that the indicator is indeed more accurate than random guessing, but it is still not accurate enough for everyday use.

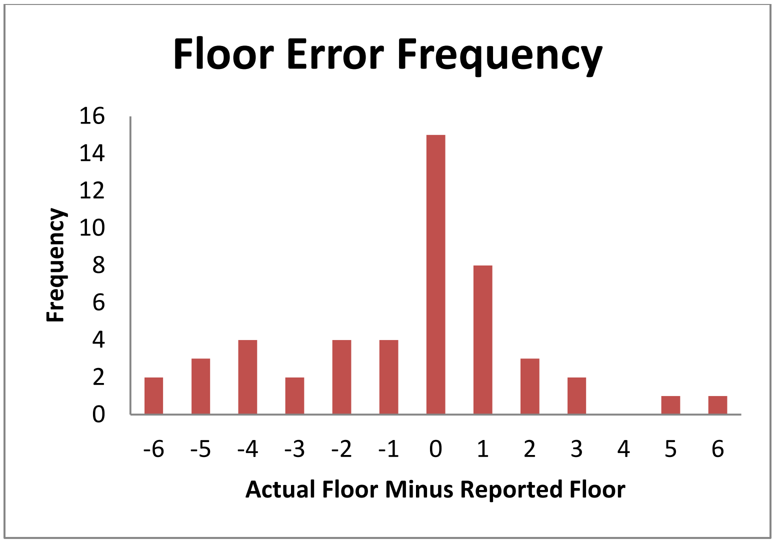


Figure 3 – Results of floor indicator error test ($n = 49$, $\bar{x} = -0.61$, $SD = 2.62$). Though there is a mode of no error, the floor indicator did not display the correct floor the majority of the time.

Using the evaluation method stated earlier, and the survey result (Appendix B) the implemented system received the following score shown in Table 2.

Table 2: Criteria list and scores for Case I: before the Elevator Accelerator is implemented; Case II: expected result after the installation of Elevator Accelerator; Case III: after Elevator Accelerator been implemented

Criteria	**Case I**	**Case II**	**Case III**
Display elevator location at ESG lounge	0	5	4
Display the direction the elevator is going (up or down)	0	5	5
Push the elevator button from ESG lounge	0	5	5
Allow user to push the button next to the elevator	5	5	5
Does it change the original elevator system?	5	5	5
Does it have open parts, wires that might be harmful	5	5	5
Does it pass rolling-eye test?	5	5	5
Does it meet MIT safety regulations?	5	5	5
Does it meet Massachusetts regulations on elevator?	5	5	5
How do people like about the system?	1.5	5	4

Did it save people time?	1	5	3
Does it look pretty?	0	5	5
Is it easy to use?	5	5	5
Is it energy efficient?	5	5	5
Do people find it useful?	2	5	3
Does it meet people's expectations?	1	5	4
Weighted Final Score	**215.5**	**365**	**332**

As shown, Elevator Accelerator scored much higher than the original ESG elevator system and slightly below the expected performance. Overall, the project was successful and a lot of ESG people liked the design and found it useful to them (survey results shown in Appendix B).

Analysis

There are a few ways to improve the Elevator Accelerator as it exists in ESG. The most obvious is to improve the floor indicator, the current weak link in the system. More sensors may be added to the face of the elevator display, allowing the Elevator Accelerator to detect errors through redundant measurement. During testing, it was found that the photosensor array was most prone to error when the elevator area was bathed in bright sunlight, so adding blinds to the window near the elevator area may improve accuracy. On the lounge side, inaccurate readings may still be useful if presented in the right way: if the exact location of the elevator cannot be accurately determined, a light indicating whether the elevator is currently moving up, moving down, or staying on a floor may still help ESG.

More drastic changes are also possible for the floor indicator. While testing the floor indicator, a webcam was mounted near the elevator and pointed at the floor display. The webcam allowed debugging by broadcasting the actual elevator position to the lounge, where group members could tweak the microcontroller. It was suggested that the webcam may function well as a permanent solution. The webcam would allow ESG students to watch live video feed of the elevator display, eliminating sensor error. However, this solution requires a dedicated computer in the lounge to display the video feed, and may exceed the project budget.

During construction of the Elevator Accelerator, several ESG students expressed interest in having a similar button-pushing installation on the first floor of Building 24, the other bottleneck in travelling to and from ESG. Also discussed was the possibility of creating a web-based application out of the Elevator Accelerator, on which users can view the position of the elevator and call it remotely. While this idea is feasible with the Arduino and related off-the-shelf technologies, a much greater effort is required for implementation. There is also real potential for abuse (floor prank-calling).

While the Elevator Accelerator stands alone as a working project, it can also be seen as a proof of concept for expanding this design to other existing elevators. The Elevator Accelerator costs under $200 per floor as implemented here, far below the cost of any new elevator system: even a basic two-floor hydraulic elevator costs over $70,000 to install [4]. Therefore, the Elevator Accelerator would be a great option for building owners seeking to optimize the usage of their existing elevators. The open-source nature of the Arduino allows customization for different clients. For example, an apartment tower manager may want to install a call button in every unit, letting residents call the elevator before exiting their doors. In all, there are many possible next steps for the Elevator Accelerator that will result in better functionality and wider applicability.

Conclusions

Although the Elevator Accelerator did not operate with no errors, it is a great success overall. The Elevator Accelerator met all elevator safety restrictions, easy to operate and energy efficient; it has also addressed some of the issue with long waiting time for ESG elevator. Many ESG people did find it useful and have shown a great favor towards the installed design. As shown by this project, Elevator Accelerator can be expanded to many other buildings on MIT campus and introduced to many other facilities. The implemented elevator control system is capable of optimizing the usage of existing elevators, shorten average customer waiting time and avoid redundant elevator trips.

Bibliography

[1] The Massachusetts Office of Public Safety and Security. "Elevators." 2011, http://www.mass.gov/eopss/consumer-prot-and-bus-lic/license-type/elevators/elevators.html.

[2] J. Zarroli. "Smart Elevators: A Faster Way Up and Down." 2007, http://www.npr.org/templates/story/story.php?storyId=6799860

[3] Sirag et. al. "Remote Elevator Call Placement with Provisional Call Verification." U.S. Patent 6 109 396. Aug. 29. 2000.

[4] D. Dalvit. "How Much Does a Hydraulic 2-Stop Elevator Cost?" 2010, http://evstudio.info/how-much-does-a-hydraulic-2-stop-elevator-cost/.

All photographs, diagrams, and figures were produced by the group, unless otherwise noted.

Appendix-A: Initial Survey Result

38 people have responded to the initial survey

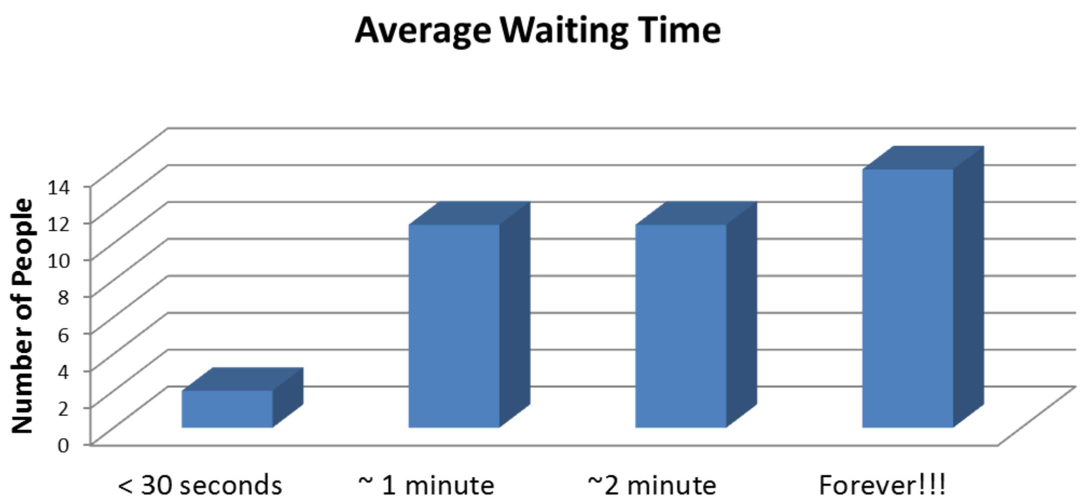


Chart 1: Survey result for the average waiting time of ESG elevator.

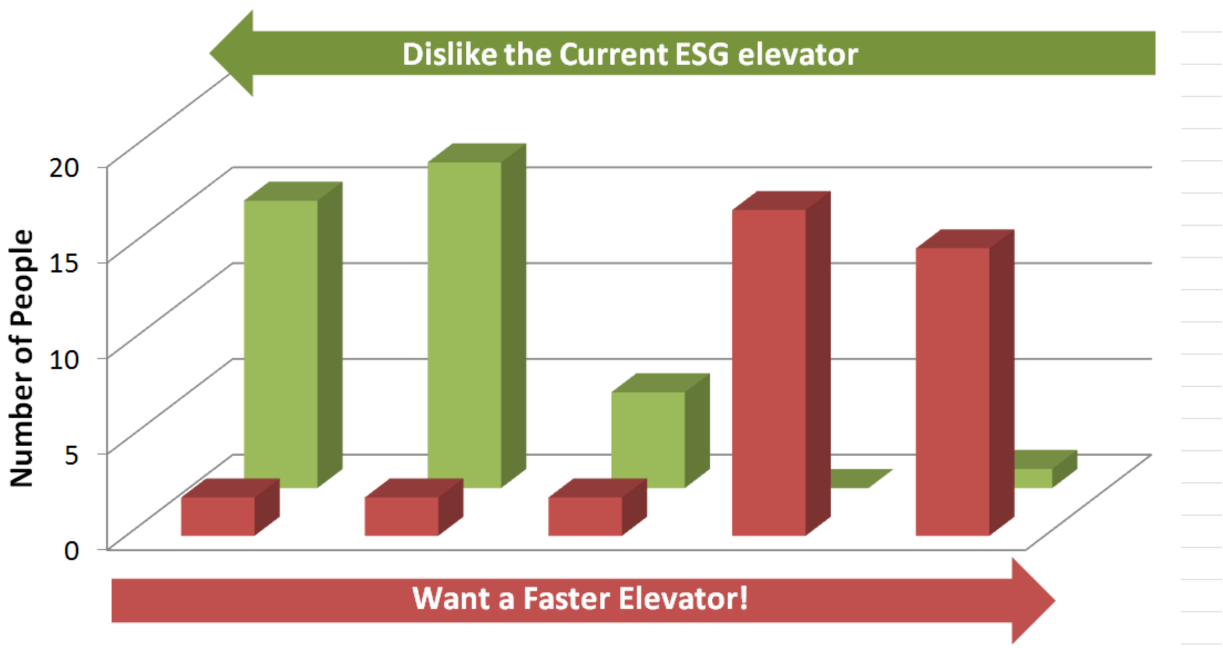


Chart 2: As shown, there is a strong desire for a faster ESG elevator (Red). [Most left: "Nope I am fine with the current Elevator"; Most right: "I want a faster elevator! ASAP, just as I am craving for Thanksgiving break after 10 midterms and 20 Psets!"]

Moreover, there is a great portion of people who dislike the current elevator (Green). [Most left: "It sucks!"; Most right: "I love it!"]

Appendix-B: Final Survey Result

15 people have responded to the final survey

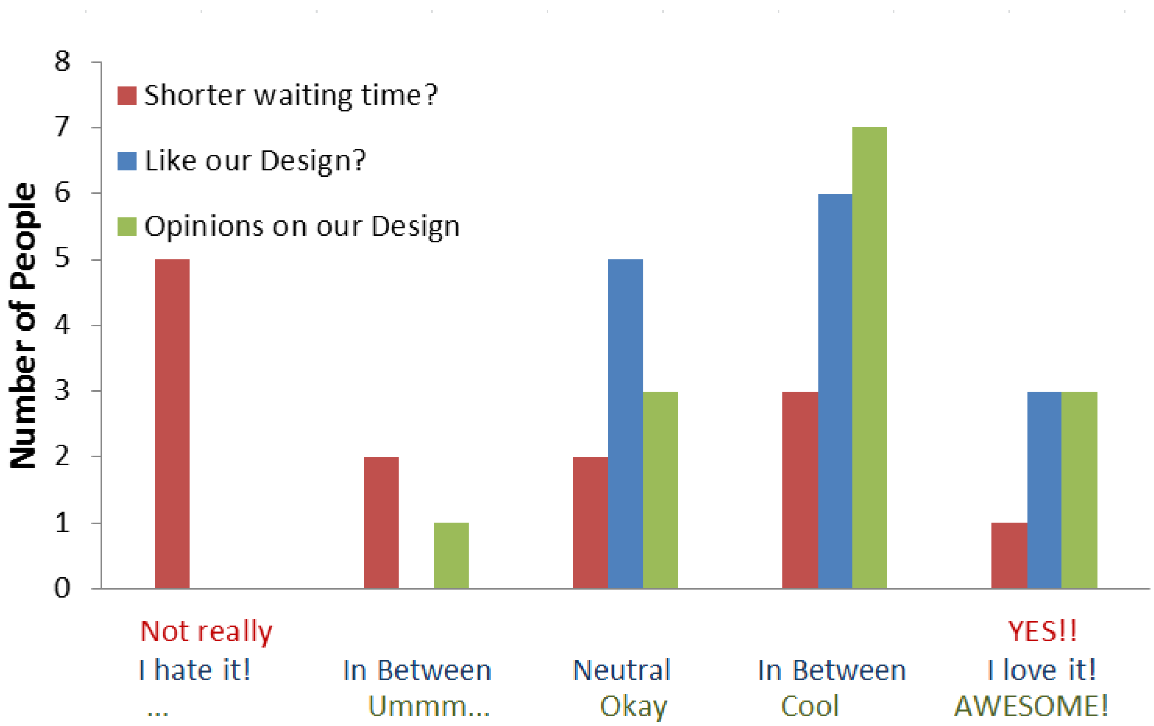


Chart 3: Red bars shows the impact Elevator Accelerator had on the average waiting of ESG elevator, many people did find it useful on shortening the waiting time.

Blue bars shows how people liked the Elevator Accelerator, many people liked the design while others are neutral.

Green bars shows people's opinions on the Elevator Accelerator, many people from the ESG community found it "Cool" and "AWESOME".

Appendix-C: Budget

Item	Original Budget	Actual Cost	Comments
Arduino Uno Board	30.00	24.20	Amazon discount
Breadboard x 2	10.00	0.00	Scavenged for free
Photosensors x 5	3.19	6.38	Lost one set of photosensors
Push Buttons x 2	6.00	6.00	
30 AWG Wire - 500 ft	23.87	42.00	Purchased ribbon cable instead – easier to organize
LED 7-Segment Display	23.88	23.88	
Power supply	-	5.99	Forgot to include in original budget
Total	**96.94**	**108.45**	

Though there were a few cost overruns, the project budget remained well under $250, the maximum allowed.