SYSC 3303 Group Project - Elevator Control System
Group 1

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Iteration 0: Measuring a Real Elevator

For this task, we picked an off campus elevator located in an apartment building where one of our team members lives. We chose this specific elevator due to ease of access and because it would offer an accurate example of an elevator used in the real world.

Building specifications

The building has 16 floors in total. There are 15 steps per floor, with each step measuring 19 cm in height, for a total height of 2.85 m per floor. The building has 2 elevator cars. For this project, we measured both and did not find any statistically significant differences between both elevator cars.

Elevator specifications

While the elevator is traveling, this sequence of events take place:

- The doors start to close slowly until they are fully closed
- Once doors are fully closed, the elevator car begins to accelerate in the direction of the destination floor
- A chime is heard every time the elevator car passes a floor sensor on the way to its destination
- Once the elevator car arrives at the destination floor, a chime is heard again and the car comes to a complete stop gradually
- After the car has completely stopped, the doors begin to open until fully opened
- The doors remain fully opened for a set amount of time to allow for passengers to deboard; this time does not depend on the number of passengers in the car
- After the set amount of time has passed, if the door interrupt has not been activated, the doors begin to close slowly until fully closed

- If the door interrupt is activated, the doors reopen if applicable and remain open for an additional amount of time, after which they begin to close again
- Once the doors are fully closed, the elevator moves to the next requested destination if there is one, or remains at that floor waiting for requests

List of Documents in this Submission:

1. Excel document with raw data: SYSC3303Group1Iteration0Measurements.xlsx
2. https://www.desmos.com/calculator/vu6wwfd2mb this is a link to the graphing software that was used to calculate the estimated values for the rate of acceleration and deceleration of an elevator car, and the maximum speed of the car. Intermediate steps and formulas can be seen there but screenshots are included in this document for convenience.
3. This report outlines the methodology used when taking the measurements, calculating statistics and drawing conclusions.

Raw data - what was collected

Various measurements of the elevator travel time were taken and are included in Tables 1 to 5. An explanation of every category is included below:

1. **Table 1** shows the standard time allotted for loading, in seconds. These measurements were taken while making a trip from the 1st to the 11th floor with all the floor buttons pressed (request to stop at each floor). What each column means:
    a. **Floor number :** the floor at which the measurement was taken.
    b. **Closed door to open door(in seconds):** this is the time from when the elevator has arrived at floor k, with doors closed, until the doors are fully opened.
    c. **Door stays open (time in seconds):** this is the time for which the doors stay open, during which passengers are onboarding or deboarding.
    d. **Door starts to close until it closes completely (time in seconds):** this is the total time it takes for the door to be fully closed.

Floor number	Closed door to open door (time in seconds)	Door stays open (time in seconds)	Door starts to close until it closes completely (time in seconds)
2	3.75	4.82	4.87
3	4.2	4.5	4.61
4	4.03	4.37	4.82
5	4.06	4.83	4.86
6	3.28	4.52	5
7	3.91	4.65	4.98
8	4.05	4.5	5.07
9	3.86	4.5	4.95
10	4.55	4.45	5
11	4.53	4.21	5.03

Table 1: Measure loading time

2. **Table 2** shows the measurement of the elevator while it is traveling between adjacent floors. What each column means:
    a. **Floors traveled (k->j):** the elevator traveled between these two floor numbers, starting from floor k to floor j, where k and j are adjacent floors. E.g. 12 -> 11 means that the elevator was going down from floor 12 to floor 11.
    b. **Delta 1 (time in seconds):** this is the time difference from when the elevator first started to move from floor k, got to floor j and a chime was heard.
    c. **Delta 2 (time in seconds):** this is the time from when the chime was heard in the previous step to the elevator coming to a complete stop and the door beginning to open.

Floors traveled (k -> j)	Delta 1 (time in seconds)	Delta 2 (time in seconds)
12 -> 11	2.05	3.85
11-> 12	2.03	3.58
12->11	2.06	4.05
11->12	2.13	3.81

Table 2: Measure travel time between adjacent floors

3. **Table 3 and Table 4:** these tables show the measurement of the elevator while it is traveling between both adjacent and non adjacent floors. For convenience, we have color-coded the columns.
    a. **Floors (k -> j):** the elevator travels between these two non-adjacent floors, starting from floor k to floor j. E.g. 11 -> 16 means that the elevator was going up from floor 11 to floor 16. Note: G means ground floor
    b. **Delta 1 (time in seconds):** this is the time interval from when the elevator first started to move from floor k until the chime was heard to mark the elevator reaching the following floor k+ or - 1. E.g. in the first row of Table 3, Delta 1 is the time from floor 11 until chime for floor 12 was heard.
    c. **I1, I2, … etc. (time in seconds):** these are the intermediate floors between k and j, including j. We measure the time from the previous chime until the next floor chime is heard. For example, in the first row of Table 3, I1 is from floor 12 chime to floor 13 chime, I2 is from floor 13 chime to floor 14 chime, etc. The last intermediate floor in the series is the destination floor - I4 in the first row corresponds to the floor 16 chime.
    d. **Delta 2 (time in seconds):** this is the time from when the chime for the destination floor is heard until the elevator comes to a complete stop and the door begins to open.

Floors	Delta 1	I1	I2	I3	I4	Delta 2
11->16	1.78	1.6	1.61	1.66	1.75	3.65
16->11	2	1.63	1.61	1.65	1.66	3.96
11->16	2.08	1.66	1.61	1.58	1.51	4.03
16->11	2.11	1.63	1.61	1.53	1.65	4.23

Table 3: Measure travel time between adjacent and nonadjacent floors

Floors	Delta 1	I1	I2	I3	I4	I5	I6	I7	I8	I9	I10	I11	I12	I13	I14	Delta 2
16-G	1.96	1.58	1.65	1.5	1.68	1.71	1.56	1.58	1.71	1.8	1.63	1.56	1.63	1.71	1.78	4.35
G-16	2.18	1.75	1.66	1.7	1.6	1.73	1.6	1.63	1.63	1.68	1.65	1.61	1.63	1.68	1.4	4.45
16-G	2.2	2.05	1.66	1.6	1.5	1.6	1.61	1.6	1.85	1.61	1.76	1.55	1.71	1.7	1.58	4.3
G-16	2.03	1.8	1.65	1.6	1.6	1.6	1.73	1.61	1.61	1.58	1.75	1.46	1.86	1.63	1.55	3.95

Table 4: Measure travel time between adjacent and nonadjacent floors

4. **Table 5:** this table shows the measurement of the door interrupt time. This is the amount of time that the door stayed open if an interrupt was triggered by placing a hand as an obstacle in the path of the door. The measurement was repeated at different times and with different numbers of passengers to ensure it always stays the same.
    a. **Door Interrupt Time (in seconds):** as soon as the door starts to close, the experimenter's hand is placed in its path and then retracted. The times are measured for how long the door will stay completely open again for. This means that the door will fully reopen, stay open for the time measured and then begin to close again.

Door Interrupt Time	1.33	1.40	1.35	1.39	1.46	1.42	1.36	1.44	1.39	1.36

Table 5: Door Interrupt Time

Statistics calculated: mean, standard deviation and confidence interval

The mean, standard deviation and confidence interval were calculated for all the collected measurements as appropriate. All the calculations are available in the Excel document. Confidence Intervals were calculated using https://measuringu.com/calculators/ci-calc/

1. **Table 6: Loading Time Statistics -** this table shows the statistics calculated from the measurements in **Table 1** , with **Table 1 Columns** mapping to the respective columns in Table 1:

Table 1 Columns	**Mean (time in seconds)**	**Standard Deviation (time in seconds)**	**Confidence Interval (time in seconds)**
Closed door to open door	4.02	0.37	$[3.76, 4.29]$, $\alpha = 0.05$
Door stays open	4.54	0.19	$[4.40, 4.67]$, $\alpha = 0.05$
Door starts to close until it closes completely	4.92	0.14	$[4.82, 5.02]$, $\alpha = 0.05$

Table 6: Loading Time Statistics

2. **Table 7 - Movement Statistics -** this table statistics calculated from combining the data from **Tables 2, 3 and 4.** We are calculating the mean, standard deviation and confidence interval for the following:
    a. **Movement at departure (Delta 1)**
    b. **Travel between intermediate floors (I1, I2, … etc.)**
    c. **Movement at arrival (Delta 2)**

Table/Column column maps to the respective table and data that was used. For convenience, we have color-coded these statistics to better pinpoint which data was used in their calculation from the tables.

Table/Column	Mean	Standard Deviation	Confidence Interval
Tables 2, 3, 4 Delta 1	2.05	0.11	$[1.98, 2.12]$, $\alpha = 0.05$
Tables 3, 4 Intermediates I1, I2, etc.	1.64	0.10	$[1.62, 1.67]$, $\alpha = 0.05$
Tables 2, 3, 4 Delta 2	4.02	0.27	$[3.84, 4.19]$, $\alpha = 0.05$

Table 7: Movement Statistics.

3. **Table 8 - Door Interrupt Time Statistics:** We calculate the mean, standard deviation and confidence interval for the data in **Table 5: Door interrupt time.**

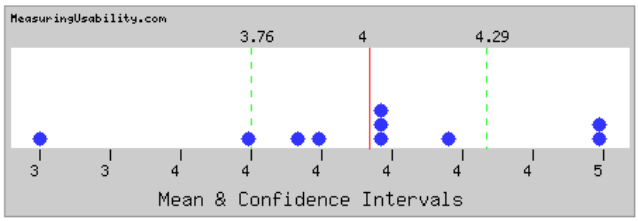
Mean	Standard Deviation	Confidence Interval
1.39	0.04	$[1.36, 1.42]$, $\alpha = 0.05$

Table 8: Door Interrupt Time Statistics

4. **Graphs 1 to 7 - Data Distribution Graphs:** The following figures show graphs of the data distribution, mean and confidence intervals for all the measured statistics.

N	Mean	StDev	SE Mean
10	4.02	0.37	0.117

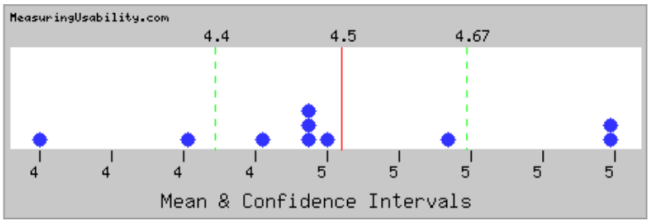
The 95% confidence interval is 3.76 to 4.29



Graph 1: Closed Door to Open Door, mean and CI

N	Mean	StDev	SE Mean
10	4.54	0.19	0.06

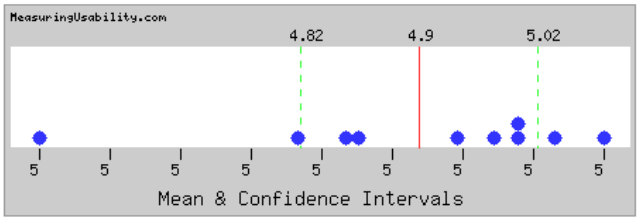
The 95% confidence interval is 4.4 to 4.67



Graph 2: Door Stays Open, mean and CI

N	Mean	StDev	SE Mean
10	4.92	0.14	0.044

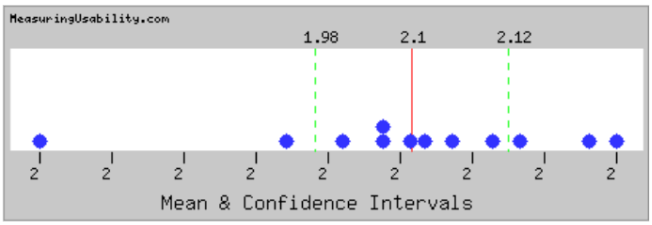
The 95% confidence interval is 4.82 to 5.02



Graph 3: Door Starts To Close Until It Closes Completely

N	Mean	StDev	SE Mean
12	2.05	0.11	0.032

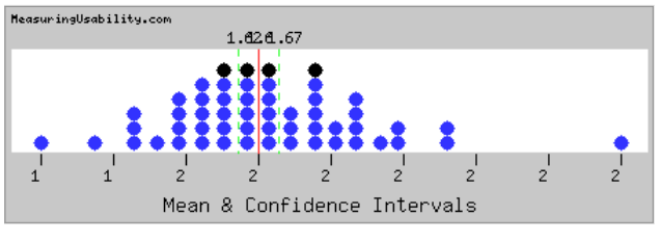
The 95% confidence interval is 1.98 to 2.12



Graph 4: Tables 2, 3, 4 Delta1

N	Mean	StDev	SE Mean
72	1.64	0.1	0.012

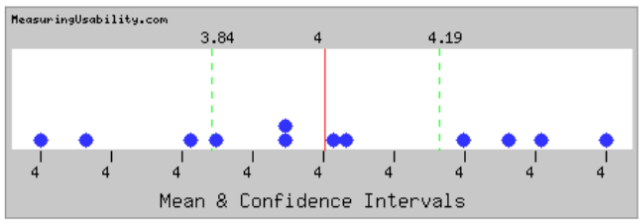
The 95% confidence interval is 1.62 to 1.67



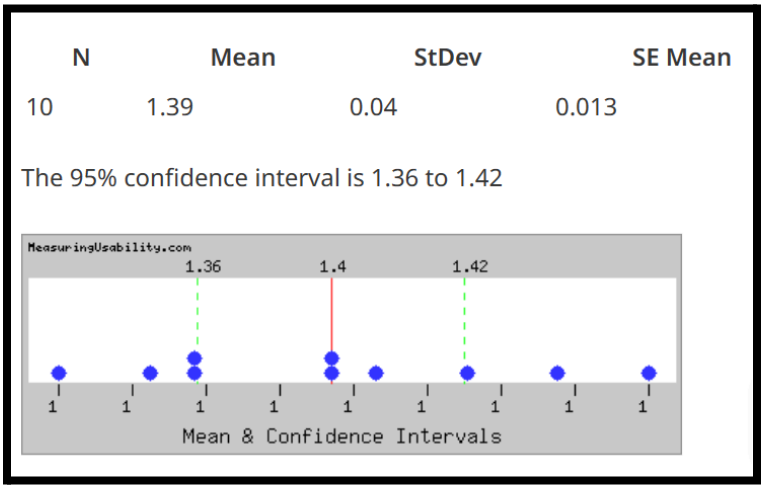
Graph 5: Tables 3, 4 Intermediates I1, I2, … etc

N	Mean	StDev	SE Mean
14	4.02	0.28	0.075

The 95% confidence interval is 3.86 to 4.18



Graph 6: Tables 2, 3, 4 Delta2



Graph7: Door Interrupt Time Statistics

Calculated Rate of Acceleration and Deceleration, Maximum Speed of the Car and Car Loading/Unloading Time

To calculate the rate of acceleration and deceleration, we used the mean values from **Table 7: Movement Statistics** and the measured floor height from **Building Specification.** The calculations and graph shown below can also be accessed at this link: https://www.desmos.com/calculator/vu6wwfd2mb

Figure 1 shows how we calculated the total time traveled, the height traveled and the elevator average acceleration

Figures 2 to 4 below show the formulas that were used in plotting the graph in **Figure 5.**

Figure 5 shows the graph obtained as a result of modeling the acceleration and deceleration of the elevator.

Maximum speed. We calculate the maximum speed of the elevator by assuming that the elevator accelerates until ½ of the trip is complete (using t/2, where t is the total time of the trip), after which it will begin to decelerate. Therefore, the maximum speed will be the elevator's speed at time t/2.

$$S = \frac{d}{dx}\left(a \cdot \left(\frac{t}{2}\right)^2\right)$$

$$S = 2.59829059829$$

The maximum speed of the elevator is 2.6 m/s

Rate of acceleration and deceleration. It is unknown if or under what conditions the elevator reaches and maintains a constant speed (acceleration = 0). Since we are limited in our measuring instruments, we will make the following assumption: **the elevator will accelerate for the duration of the first half of the trip and will decelerate for the duration of the second half of the trip**. The rate of acceleration/deceleration is not constant, but follows a curve as shown in the graph (Figure 6). An average acceleration can be calculated as follows:

$$a = \frac{2h}{t^2} = 0.148050746341$$

The average acceleration is 0.15 m/s^2.

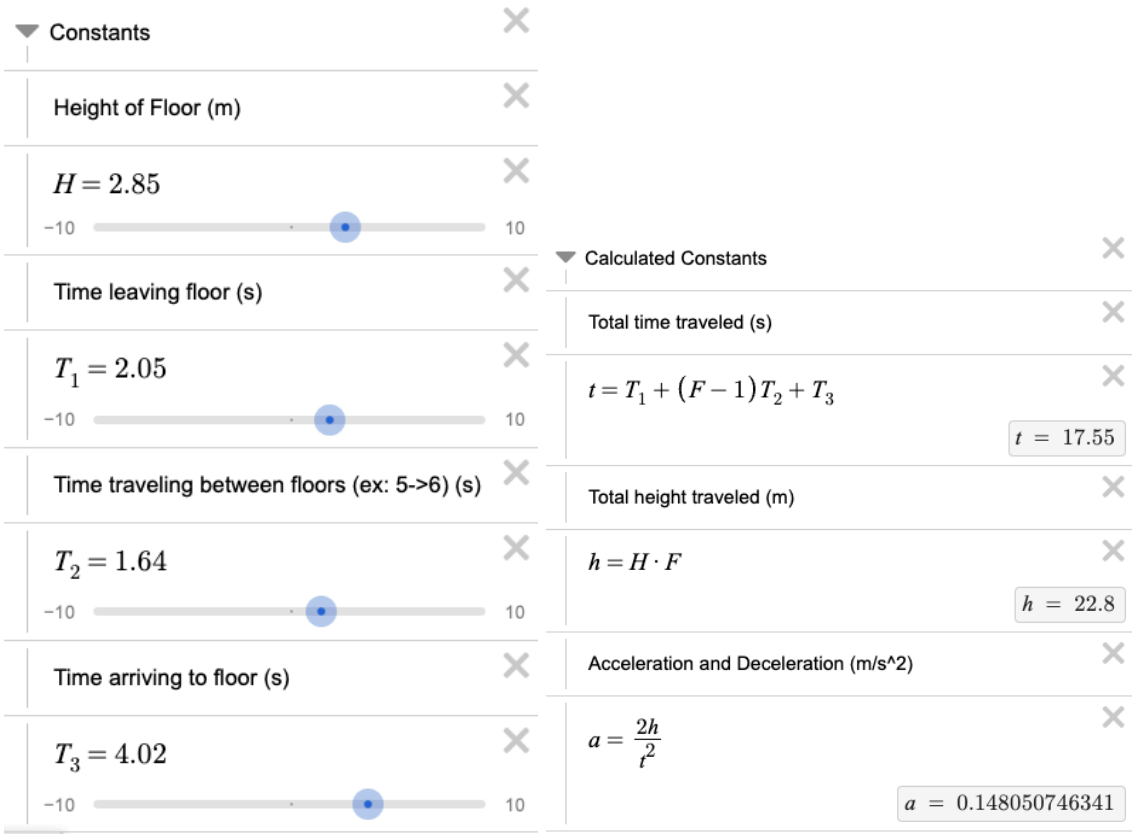


Figure 1. Using mean times to calculate total time traveled, total height traveled and acceleration

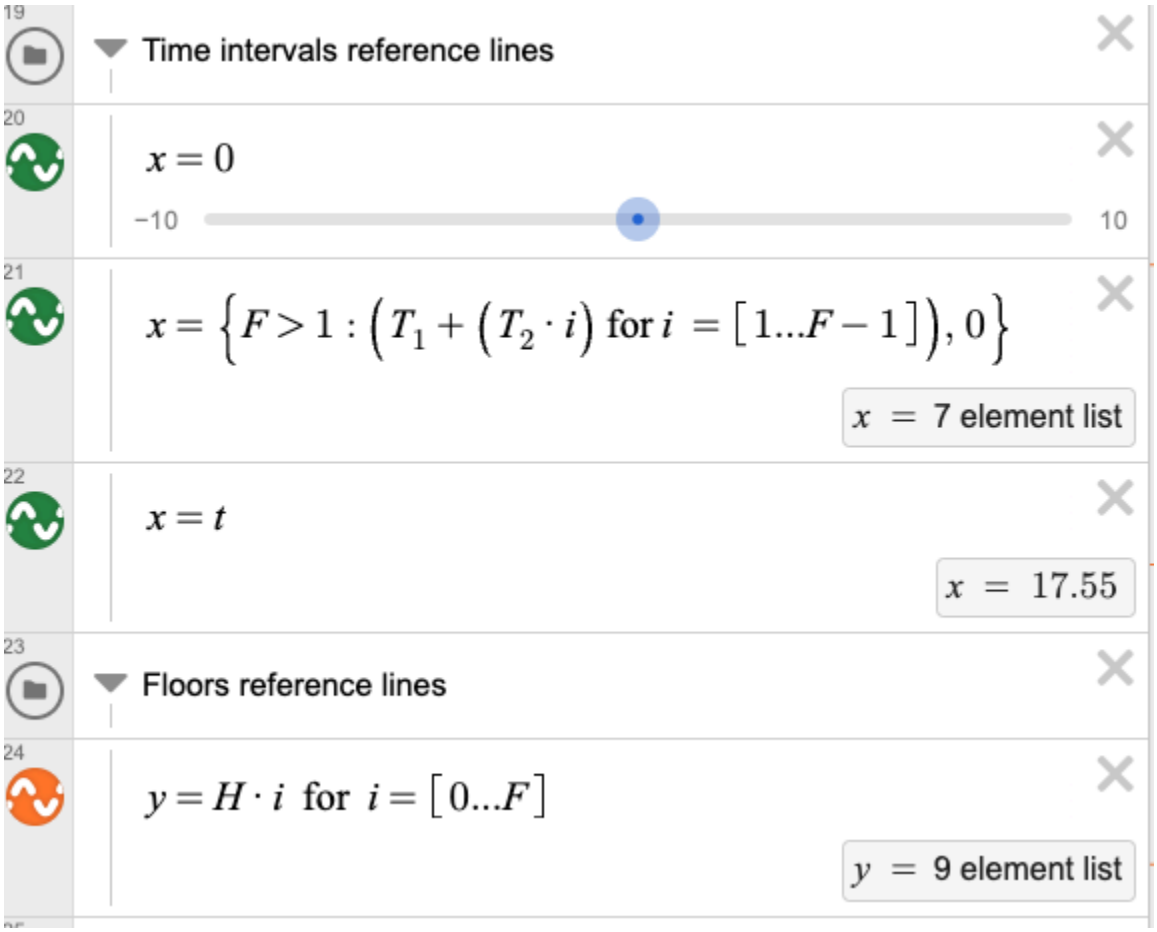


Figure 2. Time Intervals and Floors Reference Lines

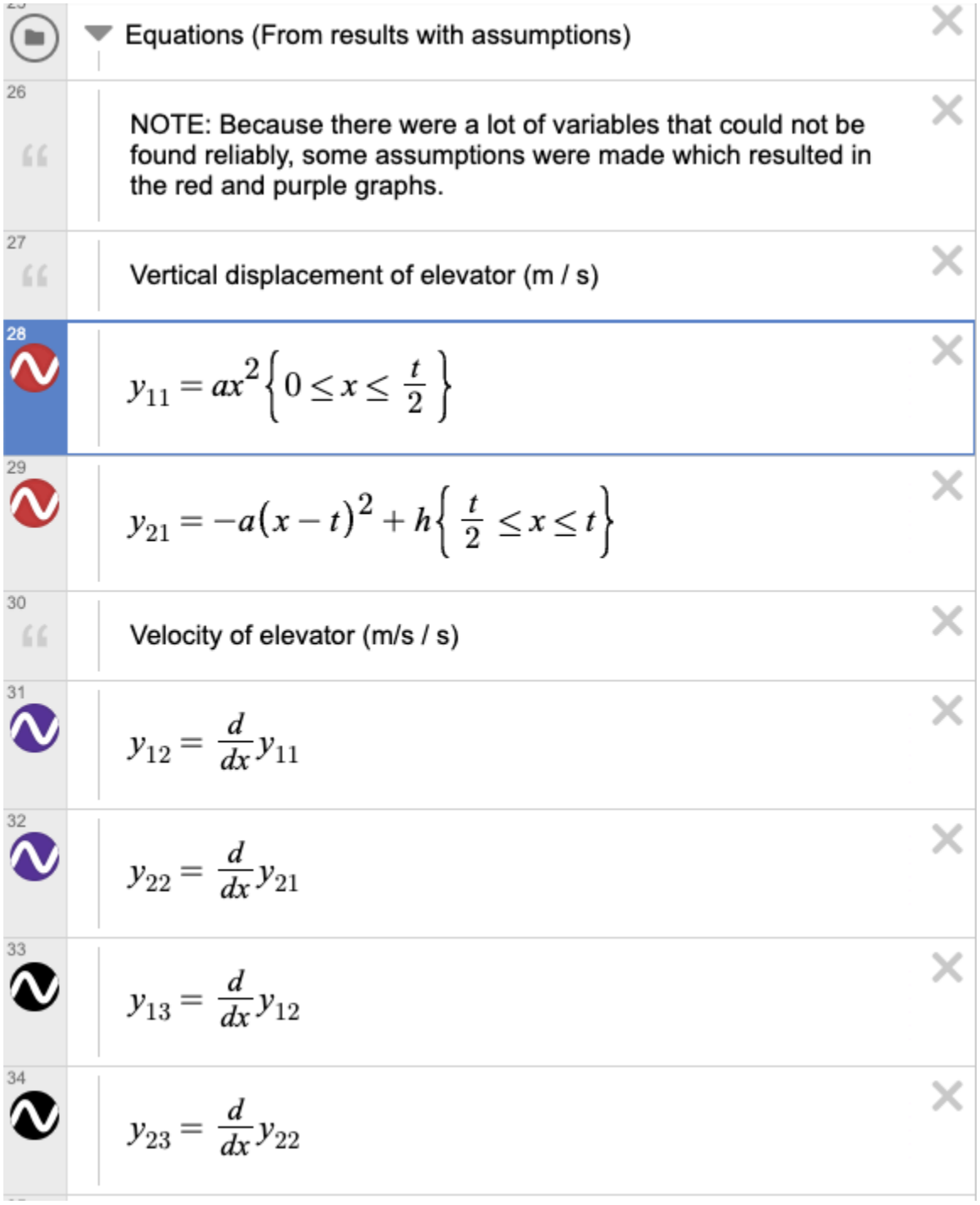


Figure 3. Equations (from results with assumptions)

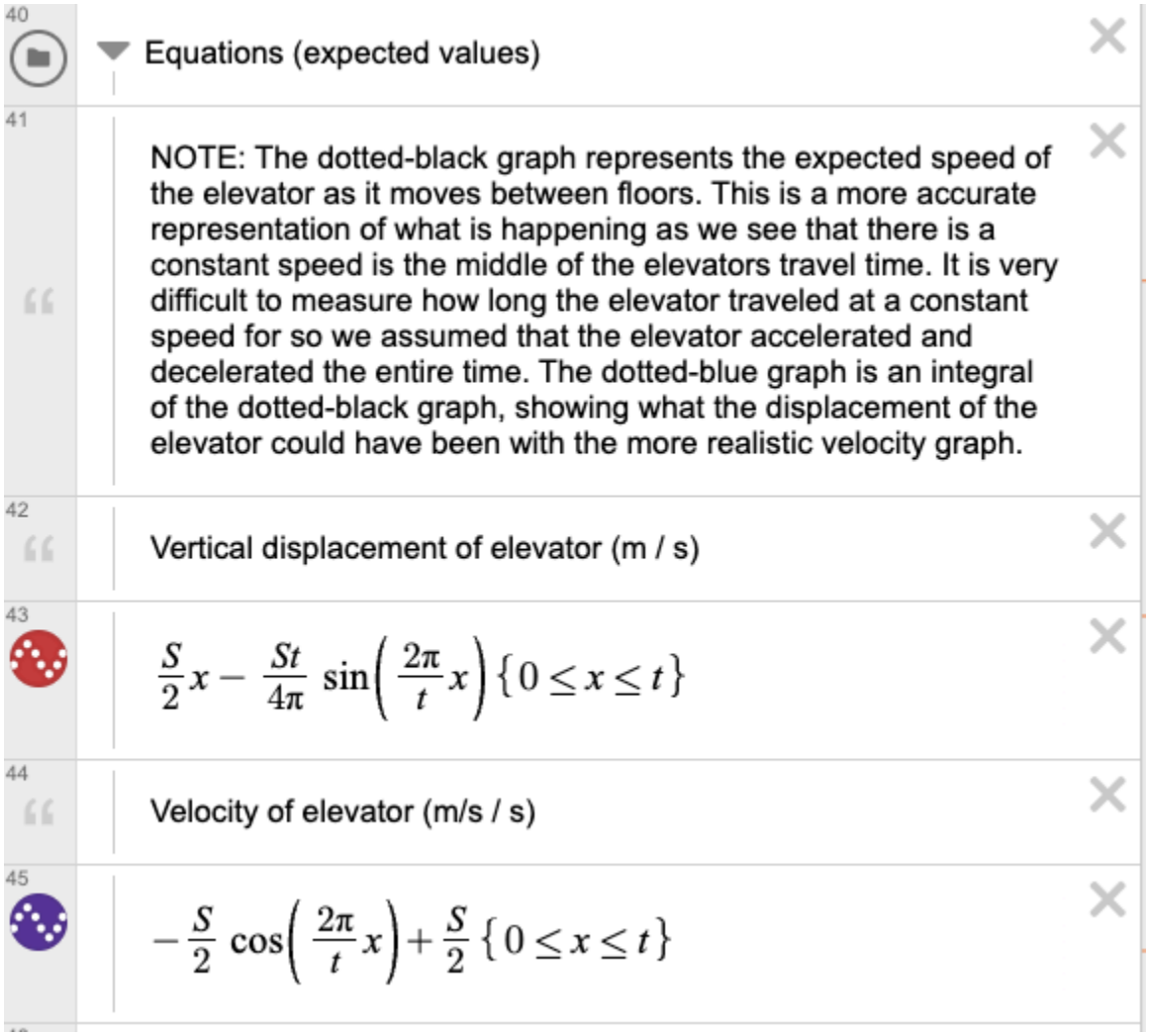


Figure 4. Equations - Expected Values

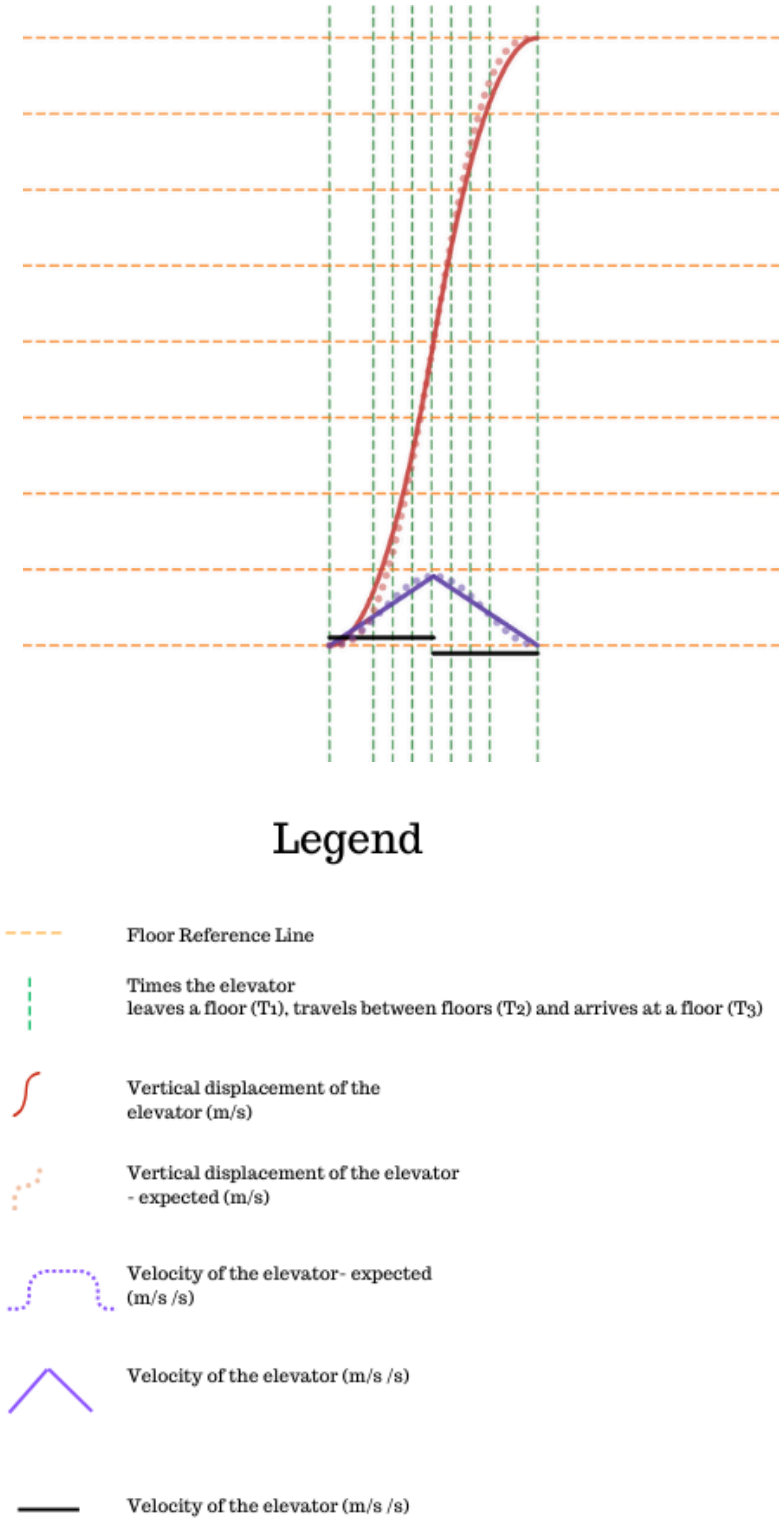


Figure 5. Graph

Estimated time to load/unload a car

We use the mean times calculated in **Table 6** to estimate the total time it takes to load/unload.

Time(total) = Time(closed door to open door) + Time(Door stays open) + Time(door starts to close until it closes completely)

Time(total) = $4.02 + 4.54 + 4.92 = 13.48$

The estimated time it takes to load/unload a car is 13.48 seconds.

Note: this does not include the door interrupt time. Interrupting the door would add an average of 1.39 seconds each time it is activated.

Discussion

- Interpretation of data: for each statistic, state definition, our value obtained and why it is sufficient data
- General implications for each type of data -> e.g. we can safely use the mean value for door open time

We calculated the mean, standard deviation and confidence interval for three sample categories, all with different sample sizes:

1. The elevator loading time, sample size is 10
2. The time that the elevator takes to travel between adjacent and non-adjacent floors:
    a. Initial time delta at the starting floor, sample size is 12
    b. Intermediate time between floors, sample size is 72
    c. Arrival time delta at the destination floor, sample size is 12
3. The door interrupt time, sample size is 10

We were not able to directly observe how a different number of passengers affects the loading and unloading time, however we did calculate the door interrupt time. The standard time of 4.54 seconds that the door stays open will allow onboarding/deboarding in most situations and any additional time would be in increments of 1.39 seconds (door interrupt time).

By far, the size of sample 2.b was the largest and we observe from the data distribution graphs that its confidence interval is very narrow. The distribution of the data appears to follow a bell-shaped normal distribution where the mean is located in the center of the curve and there are very few outliers. This, along with the obvious bell shaped distribution, strongly suggests we have collected a sufficient number of samples.

The sample sizes for 2.a and 2.c were significantly smaller and the distribution appears to be flatter, with less of a curve and the confidence intervals appear to be wider. This suggests that the averages calculated here may not be as accurate as the average time for each intermediate floor. However, we used all three averages to calculate the average speed of the elevator and, in this context, the weight of the two averages with smaller sample sizes is significantly lower than

the weight of the average of intermediate floor times. In addition, the rate of acceleration was calculated based on all measurements. While the door interrupt time graph shows a widened confidence interval and a flat curve, the absolute value of the time measurements shows very little change, in the order of 1/10th of a second. Since we took all these measurements manually, a small difference could very well be due to measurement error.

These findings suggest that, overall, our sample size was sufficient to give an accurate estimate of the elevator's speed, rate of acceleration and other specifications.

Contributions

Group member name	**Contribution**
Tristan Demers	Took all elevator data measurements and transcribed them into a spreadsheet.
Toman Aleksiev	Calculated physics and generated visual graphics for acceleration
Kenji Isak Laguan	Calculated statistics (Standard Deviation and Confidence intervals), helped model some graphs, organized data in excel.
Steven Johnson	Contributed ideas to the initial discussion on how to measure the elevator, calculated statistics, helped model some graphs.
Irina Ionescu	Initial team software setup (Jira, Git, Discord, team documents), team management, writing this report