SHAPE Kiosk Project Report

Giorgadze A.
Summer High School Academic Program for Engineers, Columbia University, 116th and Broadway, New York, NY 10027, USA

August 2024

1 abstract

2 Introduction

Columbia University has a medium-sized campus, with about 36 acres of land. With this number in mind, it can be quite time consuming

3 calculations

3.1 setting up variables

Because the amount of people in the trolley is very ambiguous, we know that the mass of the overall system changes. Therefore, we will use the power of programming to determine the specific mass; we'll talk more about this later.

For now, assume the trolley is at max capacity, at 25 people, which would mean $m = 3650kg$. let $a = 1.58m/s^2$ and let the trolley accelerate for 3 seconds. This would make our $v_f = 5.56m/s$ first, let's determine how far apart our "accelerator wheels will be:"

3.2 opposing forces

assume the trolley is going with the $v_f = 5.56m/s$, the forces that are opposing the trolley are the drag force F_D and very little frictional force F_f

first let's figure out F_D:

$$F_D = C_D v \tag{1}$$

Here we are assuming that the trolley is rectangular, $C_D \approx 1.05kg/s$ therefore:

$$F_D = (1.05kg/s) \times (5.56m/s) = 5.838N$$

Now, onto the frictional force. It gets very interesting here: figuring out the frictional force of the moving wheel that causes the wheels to stop is extremely complicated and depends on many factors, it requires working with a lot of differential equations. for this reason, we will make some assumptions that will not give us exact results but good approximations. Realistically, the coefficient of friction is extremely small, almost negligible. Therefore, we'll assume that the coefficient of friction, μ, is 0.01. In this case, the determination of frictional force becomes trivial:

$$F_f = \mu F_n \tag{2}$$

since the railway is almost always on a flat surface, $F_n = F_g = mg$, therefore:

$$F_f = (0.01) \times (3650kg) \times (9.81m/s^2) = 358.065N$$

Now, let's add all the opposing forces together:

$$F_{ftot} = F_f + F_D = (358.0.65N) + (5.838N) = \boxed{363.903N}$$

3.3 figuring the distance between the "accelerator wheels"

We can find out the acceleration using the most fundamental equation in all of physics:

$$F = ma \tag{3}$$
$$a = \frac{F}{m}$$

therefore, the deceleration is:

$$a = \frac{363.903N}{3650kg} \approx 0.1m/s^2$$

for the unnoticeable acceleration and deceleration we will fluctuate the between the velocity interval $[5.25m/s, 5.56m/s]$, we know that the acceleration is defined as:

$$a = \frac{v_f - v_i}{t} \tag{4}$$

therefore:

$$-0.1m/s^2 = \frac{5.25m/s - 5.56m/s}{t}$$
$$t = \frac{5.25m/s - 5.56m/s}{-0.1m/s^2}$$
$$t = 3.1s$$

Now we can use another fundamental equation to finally determine the distance between the accelerator wheels:

$$d = vt \tag{5}$$

Now, since we have fluctuating velocity with respect to time, we can determine the average velocity and use it to calculate d.

$$v_{avg} = \frac{v_f + v_i}{2} \tag{6}$$

therefore:

$$v_{avg} = \frac{5.56m/s + 5.25m/s}{2} = 5.405m/s$$

Now that we have the speed:

$$d = (5.405m/s) \times (3.1s) \approx \boxed{16.756m}$$

3.4 Relation to Kinetic Energy

Now, we know each wheel accelerates the trolley to $5.56m/s$ from $5.25m/s$, therefore calculating the work will be easy if we use the equation:

$$W = \Delta KE = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2 \tag{7}$$

therefore:

$$\begin{aligned} W &= \frac{1}{2}(3650kg)(5.56m/s)^2 - \frac{1}{2}(3650kg)(5.25m/s)^2 \\ &= 6115.7575J \approx \boxed{0.0017kWh} \end{aligned}$$

We already assumed that the width of the campus is $200m$ and the length is $400m$
Knowing these dimensions, we can scale this measurements to our track. After some approximations, we figure that the track is about $940m$ long. We already know the distance between wheels so we can figure the total amount of wheels:

$$940m/16.368m = 57.42913...$$

We can't have decimal amount of wheels, so we will have $\boxed{58}$ wheels instead.
Now, we can calculate the energy it takes for 1 whole rotation:

$$0.0017kWh \times 58 = 0.0986kWh$$

We know that the trolley will stop at the stops for about $45s$, there are 8 stops in total. Therefore, $8 \times 45s = 360s = 6min$, keep this number in mind.
Now, we can calculate the total time it takes the trolley to do the rotation without the stops. For this, we can use our average velocity and the distance:

$$t = \frac{d}{v} \tag{8}$$

$$t = \frac{940m}{5.405m/s} \approx 173.913s \approx 2.9min$$

Moreover:

$$t_{tot} = \sum_{k=1}^{n} t_k \tag{9}$$

In here, $n = 2$

$$\begin{aligned} t_{tot} &= \sum_{k=1}^{2} t_k \\ &= t_1 + t_2 = 2.9min + 6min \\ &= \boxed{8.9min} \end{aligned}$$

we know that the trolley will run for $14h$ or $840min$ therefore the ammount of total rotations we will have in 1 day, n_{rot} is:

$$n_{rot} = \frac{840min}{8.9min} = 94.382...$$

Now, we have to round it up, since we can't have decimal rotations:

$$\lceil 94.382 \rceil = 95$$

Now we have enough information to calculate total energy use for 1 day for trolley only:

$$E_{trolley} = 0.0986kWh \times 95 = \boxed{9.367kWh}$$

3.5 Digital map displays' consumption of energy

As we mentioned, we will have also digital map displays which will act similar to google maps: it will tell you where you currently are; what the next stops are; and your surroundings. We will have 1 monitor per trolley. The average monitor uses $50watts$ of power. As mentioned before, it will be run for $14h$, therefore, we will have energy used per digital map, E_{map}:

$$E = Pt \tag{10}$$
$$E_{map} = \frac{50w \times 14h}{1000} = 0.7kWh$$

Now, the value we have is the value for 1 map, we will have 2 trolleys, which means 2 maps, therefore:

$$\begin{aligned} E_{map} &= E_{map1} \times 2 \\ &= (0.7kWh) \times 2 \\ &= \boxed{1.4kWh} \end{aligned}$$

3.6 Total energy consumption

Now, we calculate the total energy consumption, which is pretty elementary:

$$E_{tot} = \sum_{k=1}^{n} E_k \tag{11}$$

therefore:

$$\begin{aligned} E_{tot} &= E_{trolley} + E_{map} \\ &= (9.367kWh) + (1.4kWh) \\ &= \boxed{10.767kWh} \end{aligned}$$

3.7 Solar panels

Lastly, we are to calculate the total area solar panels need to cover. The equation for the energy that solar panel gives is the following:

$$E_{solar} = I \times A \times \eta \times t \tag{12}$$

In here, I is the solar irradiance, in W/m^2, of the sun, which – on a sunny day – is considered to be about $1000W/m^2$. η is the efficiency of the solar panel. We will assume that our solar panels have average efficiency, around 0.2. t is time, and we know that it is $14h$. Lastly, A is the area of solar panels; that is what we are solving for. Combining everything together:

$$A = \frac{E_{solar}}{I \times \eta \times t} \tag{13}$$

$$A = \frac{E_{solar}}{(1000W/m^2) \times (0.2) \times (14h)}$$

Now, we do know that $E_{tot} \leq E_{solar}$ must be true in order to generate enough power. We have determined that $E_tot = 10.767kWh$. So just for safety measures, let $E_solar = 12kWh = 12000Wh$ So:

$$A = \frac{12000Wh}{(1000W/m^2) \times (0.2) \times (14h)}$$

$$\boxed{A \approx 4.2857m^2}$$