

# SHAPE Kiosk Project Report

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## 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 to go from one part of the campus to another, especially if they are directly opposite to each other.

To fix the problem, we propose the idea of a solar-powered trolley. As the name foreshows, The solar-powered trolley would be run on Solar panels. It would have a length of  $3.5m$ , width of  $1.5m$ , and height of  $2.2m$ . The maximum capacity of the trolley is approximately 25 people. The trolley itself would weigh about  $1900kg$ , and  $3650kg$  if it's at max capacity of people.

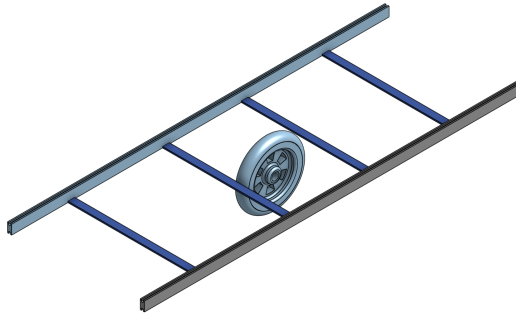


Figure 1: fig 1.1

The mechanism of the trolley was inspired by the "El Toro" ride from Six Flags. The mechanism itself is presented in Figure 1 and Figure 2. These wheels will be on the ground and moving will start moving when the trolley and the wheel make contact which will result in the acceleration of the trolley.

The pathway of the wheel is presented in Figure 3. Moreover, this trolley will have a digital map inside, similar to Google Maps which will be elaborated later on in this report.

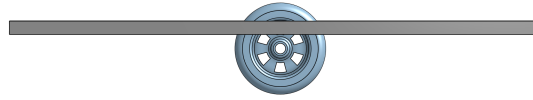


Figure 2: Enter Caption

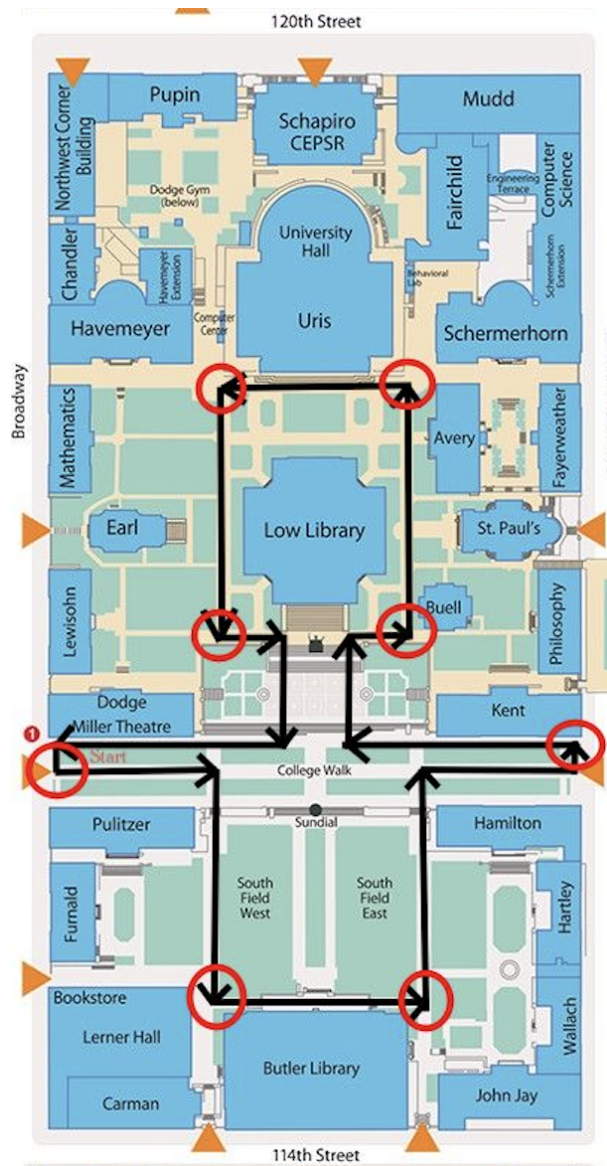


Figure 3: Caption

### 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  $F_D$ :

$$F_D = C_D v \quad (1)$$

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,  $\mu$ , is 0.01. In this case, the determination of frictional force becomes trivial:

$$F_f = \mu F_n \quad (2)$$

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:

$$F_{ftot} = F_f + F_D = (358.065N) + (5.838N) = \boxed{363.903N}$$

#### 3.3 figuring the distance between the "accelerator wheels"

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

$$F = ma \quad (3)$$

$$a = \frac{F}{m}$$

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:

$$a = \frac{v_f - v_i}{t} \quad (4)$$

therefore:

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

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

$$d = vt \quad (5)$$

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

$$v_{avg} = \frac{v_f + v_i}{2} \quad (6)$$

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:

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

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:

$$t = \frac{d}{v} \quad (8)$$

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

Moreover:

$$t_{tot} = \sum_{k=1}^n t_k \quad (9)$$

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,  $E_{map}$ :

$$\begin{aligned} E &= Pt \\ E_{map} &= \frac{50w \times 14h}{1000} = 0.7kWh \end{aligned} \quad (10)$$

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:

$$E_{tot} = \sum_{k=1}^n E_k \quad (11)$$

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:

$$E_{solar} = I \times A \times \eta \times t \quad (12)$$

In here,  $I$  is the solar irradiance, in  $W/m^2$ , of the sun, which – on a sunny day – is considered to be about  $1000W/m^2$ .  $\eta$  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:

$$\begin{aligned}
A &= \frac{E_{solar}}{I \times \eta \times t} \\
A &= \frac{E_{solar}}{(1000W/m^2) \times (0.2) \times (14h)}
\end{aligned} \quad (13)$$

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:

$$\begin{aligned}
A &= \frac{12000Wh}{(1000W/m^2) \times (0.2) \times (14h)} \\
&= \boxed{A \approx 4.2857m^2}
\end{aligned}$$



Figure 4: Caption

## 4 Conclusion

In conclusion the final result we got which is  $A \approx 4.2857m^2$  represents the area of solar panel needed for one trolley. We can add more trolleys if needed, which will result in more area, depending on how many trolleys we add.

Now, you might ask yourself: where will all these solar panels be? Well, if you look at Figure 4, you will see the solar panels on top of some of the buildings of Columbia University. These solar panels will be more than enough for our trolley, furthermore, we can have panels on top of the trolley itself.

Our goal was to offer a fast and efficient mode of transport to move around campus and make it eco-friendly. Taking inspiration from the famous amusement park ride El Toro to construct the wheel mechanism that moves the carts to create an interior based on NYC transit systems. This trolley could also be used as a transportation for people with disabilities, which could greatly benefit Columbia University. Our result led us to create a sustainable form of transportation for members of the community.