Wheeled Vehicle Design For Science Olympiad
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The Wheeled Vehicle competition requires that the vehicle travel a specific distance set by the judge at the time of the contest. So the problem can be broken down into two distinct problems: I) How to make the vehicle travel at least the maximum possible distance; and, II) How to make the vehicle stop at the specified distance.

I. Driving Distance

For this vehicle, a design was chosen that uses a rubber band to pull and unwind a string tied to a drive axle. The string is fastened to the axle in such a manner as to cause the axle to rotate as the string unwinds. To the axle are fastened a pair of drive wheels that propel the vehicle along the travel lane.

The design approach for the drive wheels, drive axle, string length and car length is to have the string long enough to rotate the axle and thus the drive wheels a sufficient number of times such that the drive wheels will at least travel the maximum required distance.
The parameters of this problem are:

\[ D = \text{diameter of drive wheel} \]
\[ d = \text{diameter of drive axle} \]
\[ L = \text{Length Driven} \]
\[ l = \text{length of drive string} \]
\[ n = \text{number of rotations of wheel and wheel axle} \]
\[ C = \text{circumference of drive wheel} = \pi D \]
\[ c = \text{circumference of drive axle} = \pi d \]

The formulas for the solution are:

\[ L = C \cdot n \]
\[ l = c \cdot n \]
\[ \frac{L}{l} = \frac{C}{c} = \frac{D}{d} \]

Now, choose a convenient size for the axle. Considerations include: the axle must not be too fragile (small diameter); must yield a reasonable size for the drive wheel and must yield a reasonable length for the whole vehicle. For this design, we’ve chosen an axle diameter, \(d\), of \(\frac{1}{4}\) inch. Next we draw a chart of drive wheel diameter, \(D\), versus string length, \(l\):

![Wheel Diameter (D) vs String Length (l) for d=0.25, L = 394 inches (10M)](image)

From this chart can be chosen a practical drive wheel diameter, \(D\), and a reasonable string length, \(l\), which determines, along with the relaxed rubber band length, the minimum length of the vehicle.
Considerations in choosing the Rubber Band.

A. Rubber Band Stretch Ratio – The difference in the rubber band length between stretched and relaxed must be equal to string length. In other words, the rubber band must stretch at least the length of the string.
B. The length of the string plus the relaxed length of the rubber band is the minimum length of the vehicle.
C. It’s preferable for the rubber band to still be in a stretched condition when string is totally unwound because the less a rubber band is stretched, the lower it’s elastic force. Of course, the force goes to zero in the relaxed condition.

II. Stopping Distance

To stop at the required distance, we need a variable braking mechanism that we can set accurately for each run.

A. Mechanism

The front wheels are different from the rear drive wheels in that they are mounted on ¼” threaded rod and have threaded nuts in the center of the wheel. As they rotate, the wheels also travel along the threaded rod on the threaded nuts until they push against “stops” that stop the wheel rotation and thus the forward motion of the vehicle. Since the threaded parts have right-handed threads, the stop for the right wheel is the nut holding the threaded rod to the vehicle on the right side. Similarly, the stop for the left wheel is two nuts locked together on the left end of the rod.
B. Calculations

- Rod has $P$ threads per inch pitch (tpi) or rotations per inch (1 thread = 1 rotation)
- Wheel moves $C$ (circumference) distance per rotation
- To travel distance $L$, wheel rotates $n$ times and moves $n$ threads or $l$ distance along the threaded rod.

\[ L = C \cdot n \]

\[ n = \frac{L}{C} \text{ rotations} \]

\[ l = n \cdot \frac{1}{P} = \frac{L}{C} \cdot \frac{1}{P} \text{ inches} \]

Once again, we can draw a chart to help us choose our parts. We need to choose a wheel diameter that gives a reasonable number of threads per forward distance traveled. For example, 4 threads per meter traveled is enough resolution so that we can set the brake in 0.25 meter increments. And the accuracy will generally be less than the resolution so we can expect to realistically be able to set the travel distance to increments of 0.5m which is ideal for the initial competition.

![Wheel Movement along Rod as function of Wheel Diameter and Distance Traveled](chart.png)

From the chart we see that an approximately 3 inch diameter wheel will give us 40 threads over 10 meters which is our desired resolution. Note that we can also use this value to calculate the total length of our threaded rod.
Other Considerations

A. Both braking wheels need to be set to brake at the exact same distance in addition to accurately braking at the specified distance. This is harder than it seems.
B. It may be easier to set the brakes based on their distance from their respective stops rather than counting threads. This distance can be calculated from the thread pitch and number of threads.
C. Due to vehicle momentum, the braking wheels (and thus the vehicle) will tend to slide for some distance after the brakes are applied. This is a function of 1) the friction between the braking wheels and the travel surface, 2) vehicle mass and 3) vehicle speed. This must be taken into account...somehow.
D. Due to the “sliding after brakes applied” and other factors, it is expected that many “calibration” runs will need to be performed prior to the competition. From these runs, a chart can be created showing brake settings versus travel distance.
E. Rubber band selection may be important. Provision can be made to employ multiple rubber bands if more energy is needed to start up the vehicle. But this will also increase the sliding distance.

Comments, suggestions, corrections or questions welcome.

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