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Junior Solar Sprint

So...
You Want To Build
A Model Solar Car

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Building a solar powered model car is similar to building a real car. Young engineers must consider the effects of the following forces when they design their vehicles and select the materials to use for the chassis and wheels.

Friction	Inertia	Speed
Momentum	Gravity	Drag

Engineers must consider aerodynamics - the motion of air and the forces that act on a body in motion - when they design the vehicles.

In addition, the builders of solar cars must know how a solar cell works and how to transfer the sun's energy to the wheels of the vehicles. This packet includes information and activities that will demonstrate solar cells and gears.

SOLAR ENERGY

Teacher Background

Why do we experiment with and research alternative energy sources such as solar energy? Solar vehicles convert the sun's energy directly into electricity. Electric vehicles have their energy stored in a battery. Since electric and solar vehicles do not directly burn fuel, there are few harmful emissions produced. Replacing gasoline fueled vehicles with electric and solar cars would reduce CO^2 emissions by 43% to 54% per vehicle.

The basic building block of a solar-electric system is the Photovoltaic Cell. The amount of electrical power delivered by the cell depends on its size and efficiency. These cells are thin silicon wafers with a positively charged impurity, such as Boron deposited on the surface. The parent silicon wafer is negatively charged. This "sandwich" forms a "p-n" junction where the "p" layer accepts electrons and the "n" layer gives them up to create a flow of current.

When exposed to light, a Photovoltaic panel experiences a flow of electrons from one layer to another; these electrons are driven by photons in the light striking them. By attaching conducting wires to the "p" and "n" layers, a source of power is formed that will power a radio, drive a motor, or charge a storage battery.

The electrical output of a photovoltaic panel or cell may be measured directly by using a voltmeter or millimeter. Voltage represents the potential or pressure of electricity being produced while Amperes are a rate of flow for the electrical current.

Power or wattage can be determined from a combination of volts and Amps. A small multi meter works best for these experiments and can be connected directly to the positive and negative terminals of the solar cell.

The activities that follow give students an opportunity to explore the power generated by solar cells or panels. By trial and error, students can determine conditions that provide for optimal performance of a model using this system.

Activity One

Topic: During what part of the day is the most power produced by the sun?

Materials Needed:
Solar cell
Motor with propeller or spinner
Sunshine

Procedure:
1. Connect the solar cell to the motor.
2. Take the cell and motor outside. Notice how fast it runs.
3. Count how many times per minute the fan turns.
4. Do this at different times of the day - 9 a.m., 12 noon, and 3 p.m.
5. Note the weather conditions at each trial.
6. Repeat above steps for several days.

RECORD THE NUMBER OF TURNS OBSERVED AT DIFFERENT TIMES OF DAY:

DATE	**9 a.m.**	**12 noon**	**3 p.m.**	**WEATHER CONDITIONS**
AVERAGE				

Conclusions:

At what time of the day is more power produced?

What weather conditions are most advantageous to the production of power?

What weather conditions are the least advantageous?

Expansion:

Why are storage batteries used in the system?

Activity Two

Topic: At what angle of inclination does the sun produce the most power?

Materials Needed:
Average Turns Data from Activity One
Straw
Protractor
Sunshine

Procedure:
1. Hold a straw so that it is parallel to the sun's rays and casts no shadow. (Other than a ring)
2. Measure the angle using a protractor.
3. Do this at the times of day used in Activity One.

RECORD THE ANGLE OF THE SUN AT DIFFERENT TIME OF DAY

	9 a.m.	**12 noon**	**3 p.m.**
ANGLE OF THE SUN			
AVERAGE # TURNS			

Conclusion:

What effect could the altitude of the sun have for the use of solar power?

What modifications must be made in the solar panel's placement in order to maximize the power at any time during the day?

Expansion:

Graph the angle of inclination and the number of turns observed in Activity One.

Activity Three

Topic: Which delivers more power, 2 solar cells in a series or parallel?

Materials Needed:
2 photocells about 5V
1 small motor (1.5V)
1 millimeter
1 voltammeter
Soldering iron
Black and red wire

Procedure:
1. Prepare the cells (if not already) by soldering the red wire to the backside or positive poles. Solder the black wire to the front or negative pole.
2. Wire the solar cell into a series. (See the diagram)
3. Place in full sun and measure the milliamps and volts.
4. Wire the solar cells into a parallel circuit. (See the diagram)
5. Place in full sun and measure the milliamps and volts.
6. Compute the Power in watts that was generated.

$$\textbf{Volts X } \frac{\textbf{milliamps}}{\textbf{1000}} \textbf{ = Watts}$$

	Milliamps	**Volts**	**Power in watts**
Series			
Parallel			

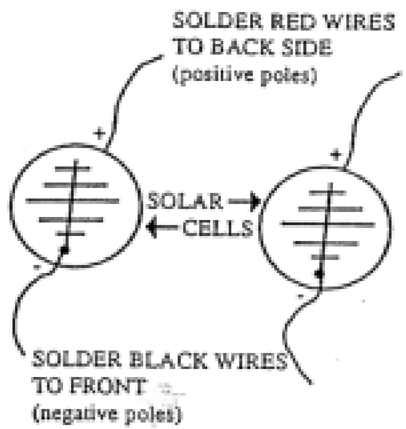
Conclusion:

Which circuit produced a higher voltage?

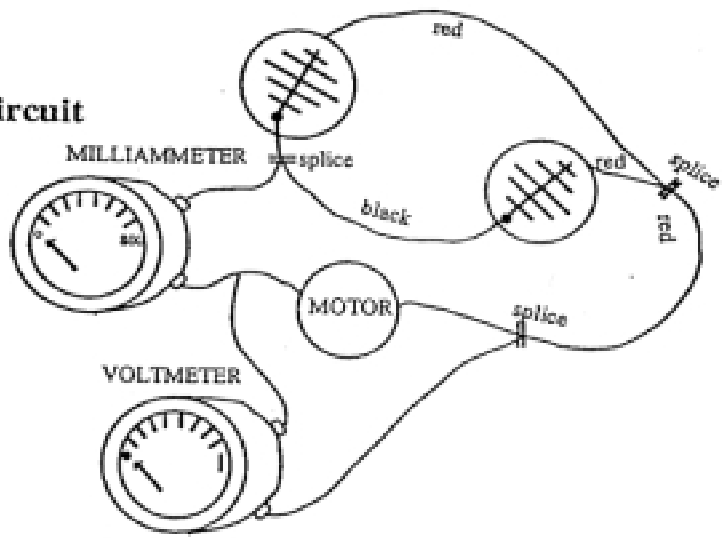
Which circuit produced the greatest power in watts?

Teacher Note: Cells wired in series produce a higher voltage (charge). Cells wired in parallel produced a stronger current. No more energy is produced in either wiring method. Just different voltage and current conditions occur.

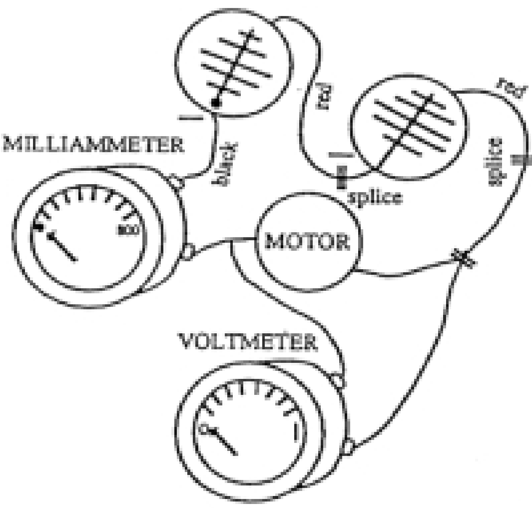
GEAR INFORMATION



Parallel Circuit



Series Circuit



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Activity Four

Topic Generalization: Drive belts are a form of pulley system that can be used to turn wheels and gears.

Materials Needed:
Hammer, nails, board
Rubber band
Large spool and small spool

Procedure:
1. Hammer two nails into a board far enough apart to lightly stretch the rubber band between them.
2. Place the small wooden spool over one nail and the larger spool over the other nail. The spools should turn freely.
3. Slip the rubber around both spools so when one spool is turned the other moves.
4. Place a mark on the top edge of each spool.
5. Beginning to the mark, turn the large spool through one complete turn.

Conclusions:

How many times did the small spool turn?

In which direction did the spools turn?

Expansion:

Does the length of the drivebelt make a difference?

Activity Five

Topic Generalization: Gears can be used to transfer forces from one part of a machine to another part. With gears, the direction or speed of rotation of other objects can be changed.

Materials Needed:
Board and spools from Activity Four
Hammer and nails
Rubberband

Procedure:
1. Drive another nail farther away from the large spool and move the small spool onto it.
2. The rubberband will now stretch tighter around both spools.
3. Turn the large spool around once again to see if the smaller spool turns the same distance as before.
4. Twist the rubberband so that it forms a cross between the spools.
5. Turn the larger spool again.

Conclusions:

How many times did the smaller spool turn?

In what direction did it turn?

Activity Six

Topic Generalization: The mechanical advantage in gears is determined by the ratio of the number of teeth on the gears.

Materials Needed:
Pieces of heavy cardboard
Compass, pencil, scissors
Board, nails, hammer

Procedure:
1. Cut a 3" gear with 8 teeth and a 6" gear with 16 teeth from heavy cardboard.
2. Mount the gears on the board with the nails so the teeth mesh and they turn freely.
3. Mark one tooth on each gear.
4. Turn the small gear to the right. On the chart, record how far the large gear turns.
5. Turn the large gear. Note how the small gear turns.
6. Now cut a 12" gear with 32 teeth and test it as you did the other two gears.

RECORD NUMBER OF TURNS OBSERVED

3" Gear	1	2	_	1	2	_
6" Gear				XXX	XXX	XXX
12" Gear	XXX	XXX	XXX			

RECORD NUMBER OF TURNS OBSERVED

3" Gear				XXX	XXX	XXX
6" Gear	1	2	_	1	2	_
12" Gear	XXX	XXX	XXX			

RECORD NUMBER OF TURNS OBSERVED

3" Gear				XXX	XXX	XXX
6" Gear	XXX	XXX	XXX			
12" Gear	1	2	_	1	2	_

Conclusions:

What is the ratio of the small gear to the middle-sized gear?

What is the ratio of the middle-sized gear to the largest gear?

So You're Building A Model Solar Car...

Here are some tips on the construction process from teachers and engineers.

Materials and Design

Weight is crucial. Solar cells do not provide much power to move heavy vehicles. Choose materials that are light as well as easily formed. Examples: Balsa wood, construction insulation foam, and cellophane on a frame.

Aerodynamics is also important. Drag and crosswinds should be considered. The chassis should provide for stability and allow for the placement of the components (e.g., motor, solar panel, and eyelet).

The choice of materials for the wheels and the wheel alignment can make a big difference on the amount of friction. There should be minimal rolling resistance.

Mechanization

The drive train, tire, and gear assembly can be collected from old toys or snap together car kits. On four-wheel-drive kit vehicles it is best to disconnect the front wheel drive as it increases the amount of friction to be overcome.

A gear is a wheel with teeth on the outer edge. By itself a gear does not do much of anything. Gears must be teamed up with other gears in order to provide torque. Gears can change speed of rotation and direction.

In a car, the crankshaft revolves in line with the car's direction of travel. So the work done by the engine has to change direction in order to turn the driving wheels. The direction is changed by having two gears that are set at right angles. A good demonstration of this would be seen in a rotary egg whisk. The handle turned is connected to a gear on the spindle of a whisk. This changes vertical movements to horizontal movements for the whisk to beat an egg.

Imagine you have two gears that mesh together - one with ten teeth and the other with twenty teeth. If you turn the smaller gear, the driven gear, it will go around once with the twenty-toothed gear has made only half a revolution. With an arrangement like this you would be able to lift a heavy weight with a small amount of effort. Exactly one-half the force has been expended over twice the time. But if you turn the larger gear, it will go around once while the ten toothed gear has done two revolutions. You would use this arrangement for speed. See Fig. 1

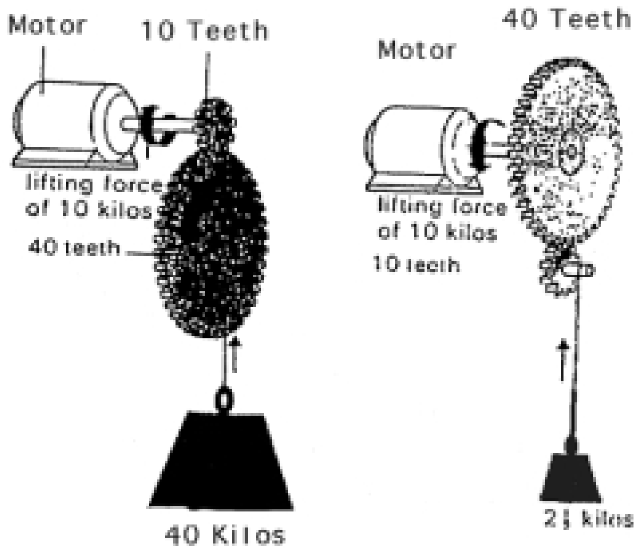

Figure one

In this machine, the smaller wheel - the pinion - has only a quarter as many teeth as the larger, so it will turn four times as fast. The left-hand machine will lift the heavier weight. When the positions are reversed, only a smaller weight can be lifted, but a greater speed.

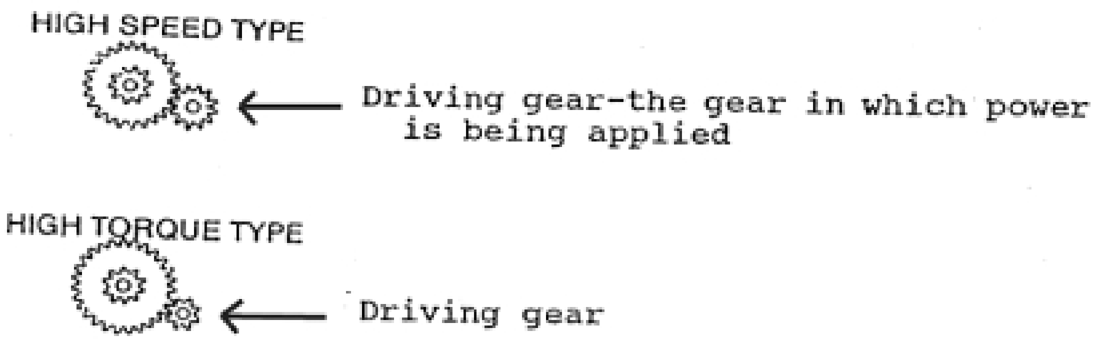

Figure 2

Biography

Bright Ideas published by the Arizona Energy Office, 3800 North Central Ave., Suite 1200, Phoenix, AZ 85012.

Lowery, Thomas. The Everyday Science Book, Palo Alto, CA: Seymour Publications, 1985.

American Tour de Sol pamphlet published by the Northeast Sustainable Energy Association, 23 Ames Street, Greenfield, MA 01301.

Pollard, Michael. How Things Work, New York, NY: Larousse & Co., 1978.

Helpful Hints for Transmission Design

1. **How should I design the transmission?**

   Be creative. There is no one solution to the problem.

2. **How should I get power from the motor to the wheels?**

   Experiment with several different ways such as gears, pulleys, or some other method of drive, to get power to the wheels. Don't be discouraged --- your first try may not work.

3. **What should I know about gears?**
   The pitch of a gear describes the number of teeth that can be put on a 1 inch diameter gear. Gears with different pitches will not fit together well, so the same pitch must be used throughout the transmission. Gears in 48 and 64 pitch are the ones most often used in slot cars. You can buy gears for the 1/24 scale slot cars at several slot car tracks in the Denver area or possibly through your local hobby shop.

4. **Where can I find parts?**

   Cheap, motorized toys, old cassette/8 track tape players, old motorized can openers, recycled materials and small gear reduction boxes will have gears and pulleys that may work in your transmission. Look for them in second hand stores, discount stores like Target and Wal-mart, or your brother's toy box.

5. **What else should I think about as I design the car?**

   Think about the friction of the following components:
   - Gears moving against each other
   - The stretching or slipping of a belt
   - The tires on the track
   - All the other moving parts of the car

Theoretical Calculations for a Solar Car

en• er• gy\'en-ə r-jē\ *n, pl*-**gies**[LL *energia,* fr. Gk *energeia* activity, fr. *Energos* active, fr. *en* in + *ergon* work - more at work] **1 :** the capacity of acting or being active <intellectual~> **2 :** natural power vigorously exerted <work with ~> **3** : the capacity for doing work.

A solar car takes electromagnetic radiation (light) from the sun and converts it into *electrical energy* with its solar panel. It then converts that electrical energy into *mechanical energy* using a motor. Finally, the motor converts mechanical energy into *kinetic energy* and the car moves forward. Energy can easily be converted from one form to another although there is usually a loss of energy with each conversion. For instance, if you connect your motor to a AA battery, it will run and slowly begin to heat up. This heat is lost energy! If the motor were converting the electrical energy into mechanical energy without any losses, the motor would not heat up at all. There are so many possible sources of lost energy in a real-world situation that we often simplify the problem by assuming that there are no losses at all.

Problem:
If we assume that there are no loses in the conversion of energy from the solar panel to the forward motion of the car, how long will it take our car to travel the 20 meter length of track?

What additional information do we need to make our calculations? Clearly if the car weighs more, we would expect it to travel slower. Therefore we would expect that the velocity of our car will depend upon its ***mass,*** *m.* We can measure the mass of our car by weighing it on a scale.

In addition, we need to be familiar with the concept of ***power.*** Power takes into account how quickly a given amount of energy is released. We could find a candle and a firecracker that has the same energy content, but the way in which that energy is released is quite different. In this case, the firecracker has considerably more power than the candle.

For the solar cell array, we can calculate the power output, *P.*

The panel is rated at 3Volts, 1.5Amps. How does this correspond to Power? *Electrical power* is the product of voltage and current:

$$P(\text{watts})=I(\text{amps})\cdot V(\text{volts})=\frac{\text{kilogram}\cdot\text{meter}^2}{\text{Second}^3}=\frac{\text{kg}\cdot\text{m}^2}{\text{s}^3}$$

Electrical power is usually expressed in units of ***watts.*** A watt is 1volt x 1amp. Therefore our solar panel produces:
1.5 amps • 3volts = 4.5 watts
Compare this to a 60 or 100 watt light bulb. Our solar panel produces very little power!

The amount of energy contained in sunlight is approximately 1000W/m^2. That means that in a

square area of land 1meter on each side, the available power is 1000 watts. The single crystal silicon solar cells in your solar panel are approximately 15% efficient. Therefore if we had a $1m^2$ silicon cell, it would produce approximately 15% of 1000W=150Watts/m^2. Your solar panel has 6 individual cells connected to one another in series. Their combined area is about 6 cells x 2in x 4in = $48in^2$ = $0.03m^2$. If we multiply this area by 150W/m^2 we get:
150W/m^2 x $0.03m^2$ =4.5W. This is precisely what we calculated above!

Using some basic equations of motion from physics, we can now calculate the time, *t*, it will take our car to travel the 20m of track.

Equation 1, one of the most fundamental equations in physics, is that a force acting on an object is a function of the mass, *m*, of the object and the acceleration, *a,* that the object is experiencing.

$$F = m \bullet a \qquad \textbf{(1)}$$

Acceleration is simply the rate at which the velocity changes. For example, when a car accelerates, its velocity starts at 0mph and it ends up at 55mph. If it reaches 55mph in 8 seconds, the average acceleration is:

$$\bar{a} = \frac{v}{t}$$

$$\frac{55mph}{8s} = \frac{55miles}{hour} \bullet \frac{1}{8s} \bullet \frac{1h}{3600s} = \frac{0.0019miles}{s^2} = \frac{3.074meter}{s^2} \qquad \textbf{(2a)}$$

The line over the *a* in Eq. 2 means average. In order to keep the units consistent I have used some conversion factors. I have also expressed the answer in English and metric units. The calculations you will make below will use metric units. We can rewrite our expression (2a) for acceleration and solve for the velocity, *v*.

$$v = \bar{a} \bullet t \qquad \textbf{(2b)}$$

The third equation is an expression relating distance traveled, *d*, to acceleration and time.

$$d = \tfrac{1}{2} a \bullet t^2 \qquad a = \frac{2d}{t^2} \qquad \textbf{(3)}$$

Which can be rewritten in terms of the acceleration.

The only other equation we need is an expression that relates power and acceleration. Remember that power takes into account the speed with which energy is released. As you can see, the Eq. 4 has the velocity term in it for this reason.

$$P = F \bullet v \qquad \textbf{(4)}$$

Now, we want to make substitutions in this final equation until we are left with variables we know and can solve for the time, *t*. We know *P*=4.5watts, *d*=20meters, and we'll speculate that our example car weights *m*=0.5kilograms (about 1.1pounds). Pay close attention to the units we've used here because the equations assume that you are using these units. In the following section we will substitute Equations 1-3 into Equation 4.

$$\begin{aligned} P &= F \bullet v = (ma) \bullet (at) \\ &= ma^2 t \\ &= m\frac{\{2d\}^2 t}{\{t^2\}} = \frac{m4d^2 t}{t^4} = \frac{m4d^2}{t^3} \end{aligned}$$

We've done it! We have successfully eliminated the force, acceleration and velocity from our equations and have arrived at an equation with only one unknown quantity, *t*. We can rewrite our result and solve for *t* as follows:

$$t = \sqrt[3]{\frac{4(0.5kg)(20m)^2}{(4.5W)}} \qquad \textbf{(5)}$$

Using a calculator we can solve the problem.

$$t = \sqrt[3]{\frac{4(0.5kg)(20m)^2}{(4.5W)}} = \sqrt[3]{177.78} = 5.62\sec onds$$

So, if our car weighs 0.5kg, and there are no losses in the transmission of power, it will make the 20m trip in less than six seconds!! Using the mass of your own car and Eq. 5 above, you can determine how quickly your car should run the track. On race day you will undoubtedly find that the actual time is much more than this. If you time your car on the 20m track and compare that time to your theoretical time in order to estimate the efficiency of your car. If your car takes twice as long as you thought it would, it is 50% efficient. Good luck and enjoy yourselves!

Design Considerations for a Solar Car

Howard Wilson, Program Manager, GM Sunraycer Project

A solar car, whether full sized or a smaller model, must perform with very little energy available from the solar panel. Since the energy is limited, the designer must do everything possible to make the car efficient so that the maximum amount of energy is used to make the car go. In a car like Sunraycer, we had to consider many things. With the solar panel area limited, we wanted to have the most efficient solar cells possible. The electrical load on the solar panel had to be continuously adjusted by electronic controls to maximize the power under any condition of sunlight. The motor for driving the wheels had to be very efficient, too.

Aerodynamic Drag is very non-linear with speed. At very low speeds, below 10 mph, it doesn't have to much effect, but as speed increases to more than 30 mph, aero drag gets important. The magnitude of drag depends on the frontal area of the car, i.e., maximum cross section looking at the car from the front, multiplied by the coefficient of aero drag, which depends on the car's shape, multiplied again by the velocity squared. It is this velocity squared term that makes the drag increase quickly with velocity or speed. So the designer should make the frontal area of the car as small as possible and make the body as streamlined as he or she can. A poorly designed shape might have a coefficient of 0.5, and a very good shape might be as low as .012. So you can see that the drag could range over four to one. Make a smooth teardrop shape as well as you can considering that the solar panel has to be included. Use the wheels with the disc structure, not spokes. If spokes are used, they should be covered on both sides. Be sure the underbody is smooth, too, not open like a regular car. Make the openings for the wheels (if the body covers the wheels) as small as possible. If the wheels are not enclosed in the body, consider wheel pants.

Rolling Resistance is another energy waster. It is the energy lost in the wheel bearings and in the tire deformation. The tires on the Junior car are probably solid rubber so tire pressure is not a factor, but the rubber should not be very soft and the tires should be smooth (no tread) and very narrow. The bearings should be given careful attention. The shafts should be straight and the bearings (if they are sleeve bearings) should be made from a low friction material like Teflon or oilite (bronze). The lubrication should be very light - no grease.

The Drive Train can waste energy, too. Gears can be particularly wasteful if they aren't precision made. Some form of belt drive may be best, but be sure the belt doesn't slip, and that it is not overly tight. The drive ratio is important. You will want to experiment to see which drive ratio gives the best results with your car. It may be that different ratios are best for different sun conditions. You may want to be able to quickly change ratios to do best on a cloudy day from that ratio that is best on a sunny day.

The Weight of the Junior car is a very important design consideration. Since the car is probably accelerating most of the run, the weight is more important that if the car was traveling at a constant speed. Also the weight is a direct multiplier on rolling resistance. Twice the weight means twice the rolling resistance for the same wheels, tires and bearings. So use light-weight materials, built-up construction, or other lightening techniques. Remember though, that there must be enough weight on the drive wheels so that they don't spin.