# Design for Continuous Passive Motion Lumbar Support Roller

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**Abstract:**

Back pain affects a great number of people in the United States and is increased in part due to extended periods of unnatural sitting, such as in car seats. Continuous passive motion has been found to be beneficial in rehabilitating joints, so using it could also help alleviate back pain while improving the conditions to facilitate strengthening. Our design for the lumbar support device is a mechanical device that administers continuous passive motion to the lumbar spine. We chose a mechanical device rather than a pneumatic one for two reasons: the complexity of working with airflow and pressure and secondly, the existence of a similar pneumatic device on the market. Also, we were able to incorporate a massaging effect with the mechanical roller. The roller will be connected to a motor with variable speeds for different cycle settings based on individual needs. A wedge should supplement the use of the roller. This will lead to an elevation of the hips above or equal to the knee height, providing better flexion when rotating the hips. Currently, the exact benefit of the wedge is not conclusive as a necessity to the design's effectiveness. Therefore, further testing of the wedge with the mechanical prototype is recommended to further understand its effects on the performance of the lumbar roller.

**Design Problem Statement:**

To design a lumbar support device that undergoes continuous passive motion in a sitting position such as driving an automobile. This device should facilitate the movement of the lumbar spine through its normal range of motion with variable cycle durations.

**Introduction:**

Lower back pain has become a major issue effecting about 70% of the population of the United States (Hazard 1999). Lower back pain originates from a variety of causes including improper heavy lifting, falls, athletic injury, or simply from a gradual accumulation of stress and strain on the back over a long period (Bupa Foundation, 2001). It has been found that individuals with lower back pain find sitting in the same position for extended periods of time especially painful. In particular, the lumbar region of the back (the five vertebrae between the rib cage and pelvis) tends to conform to the shape of the seat that the patient is sitting in. Due to the flexibility of the spine, especially in 25-40 year olds, pain and discomfort often arise due to this unnatural position of the lumbar spine for extended periods of time. One particular seat, a car seat, tends to aggravate the lower back due to its overall design. Most front car seats are bucket seats with the sitting portion at an angle of declination between 5-10 degrees. The bucket seat configuration leads to a sitting position in which the knees are above the pelvic line, causing the person to be in a slouched postural sitting position. This leads to two main changes in the spine. First, the intervertebral disc pressure can increase due to the center of gravity shifting slightly forward. Secondly, the nucleus pulposus shifts posteriorly when sitting with kyphosis. Both of these effects lead to pain and discomfort which could have been minimized had they been sitting in a good postural position (Bupa Foundation, 2001). Also, pain can be alleviated through stretches, exercises and movement of the spine.

Continuous passive motion, CPM, has been proven to be effective in reducing muscle stiffness and promoting healing of joint tissue after major surgeries. In applying these same principles to the lumbar spine region, CPM could increase the range of motion, decrease stiffness, and allow for rehabilitation of lower back muscles (Center for Orthopedics, 1999). Another benefit of continuous passive motion would be the reduction of pain. Based on the pain gating theory, continuous movement of the cushion would stimulate fast conducting nerve fibers, counteracting slow conducting nerve fibers responsible for transmitting pain sensory signals. This thereby reduces a person's pain (John C. Liebeskind History of Pain Collection, 1996).

Based on the known benefits of continuous passive motion, the goal of this project is to design a lumbar support cushion that incorporates continuous cyclic motion. An individual could reduce their lower back pain by using a lumbar support cushion utilizing continuous passive motion when sitting for long periods of time, such as in an automobile.

Our client would like to provide support for the lumbar region with continuous passive motion. After talking to the client, this was understood to be a rotation of the lumbar region while also having forward rotation of the pelvic region. This design also should have adjustable cycling settings to better accommodate the user's needs. Lastly, the device's noise level should be kept to a minimum to prevent driver distraction (Sherry, 2001).

**Alternative Design Solutions:**

During the first half of the semester, the design team was split into groups of two. These groups worked individually to find a solution to this design problem. Many different ideas and solutions were conceived. Half way through the semester, each group presented their proposed solutions. Then, all the small groups were combined into one large group, with the goal of working together to find one solution to the problem. After combining all of the best qualities from the individual presentations and brainstorming a few new ideas, two distinct design solutions were conceived.

*Design Solution #1: Pneumatic Driven Cushion*

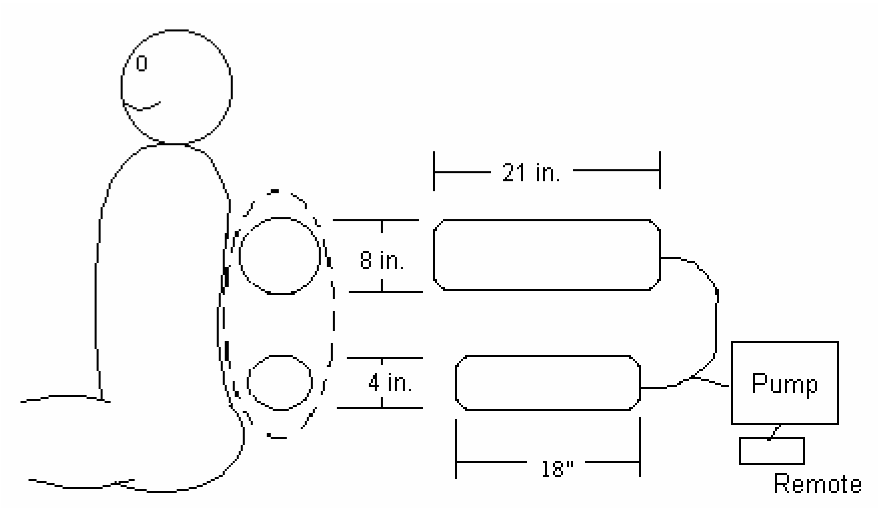


**Figure 1 Primary Pneumatic Design**
*This design focused on the inflating and deflating of air cushions to administer continuous passive motion.*

The pneumatic lumbar support cushion consists of two cylindrical chambers, each inflated by an air pump that would be placed on the center console or under the drivers seat. Figure 1 illustrates this design. The first chamber is positioned behind the hips of the person. When inflated, the cushion puts pressure on the back of the pelvis, rolling the pelvis forward, and thus beginning the alignment of the back. The next chamber inflates to create an arch in the lumbar region corresponding to the correct anatomical position. The chambers are inflated from the bottom up and deflated from the top down, meaning that the chamber behind the pelvis will begin inflating first followed by the inflation of lumbar chamber. Deflation will be the opposite, with the lumbar chamber beginning to deflate first and then the chamber behind the pelvis. This creates a natural flow of movement in the lower portion of the back. Both cushions are attached to the seat by straps that connect in the back of the chair. The pump will be powered by the cigarette lighter of the car so that the unit is easily interchangeable between different makes of cars. The remote control for the pump will be mounted (most likely by velcro) to the dashboard of the car in the proximity of the cigarette lighter to ensure easy access for the driver.

*Design Solution #2: Mechanical Lumbar Roller*

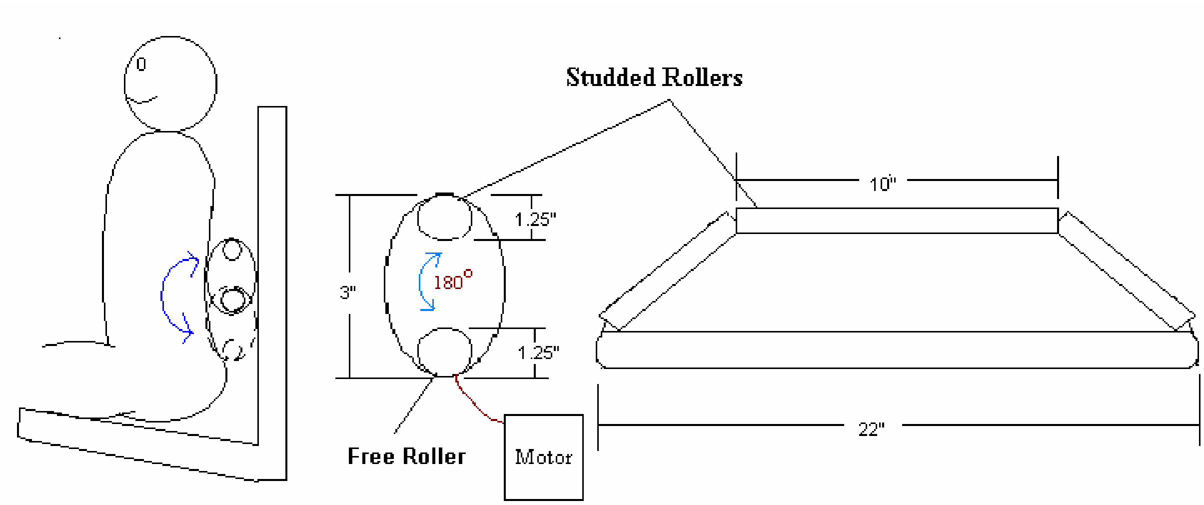


**Figure 2 Design Alternative**
*This design incorporates a reversible motor to sweep a support through the lumbar region of the back to administer the continuous passive motion.*

The mechanical lumbar roller makes use of a ovular shaped bar that is rotated up and down through the lumbar region of the back. Figure 2 is a diagram of this alternative. The two ends of the bar would be mounted to rigid backing material. Over the central part of the bar, a roller would be used to aid the motion of the device by allowing the device to move up and down the back with less friction. The roller would be made of a rubber material so that it is comfortable to the patient, providing a massage like feeling. A motor would be mounted along the axis of rotation in the device. This motor would have to be reversible in order for the device to move up and down through the lumbar region of the back. The motor could be set at variable speeds by a remote control, thereby providing the user with different speeds of oscillation. The overall device would be attached to the car seat with adjustable straps so that it is easily interchangeable between different makes of cars.

*An Additional Component: the Wedge*

In addition to the CPM delivering device, the use of a static wedge in conjunction was carefully considered throughout the semester. Wedges are currently available on the market in a variety of models, ranging in price from 30-60 dollars approximately. The main purpose of a wedge is to eliminate the bucket seat declination by elevating the pelvis equal to the level of their knees, thus extending the hip joint. This will lead to a sitting position close to 90 degrees, which can lead to increased comfort due to a less slouched postural position. For the most part, wedges are made of a polymer or a foam composite. Size ranges, but most will be around 12 x 18 x 2 inches to accommodate the entire seat.

**Design Evaluation:**

*CPM Delivery Device:*

There are many advantages and disadvantages to the pneumatic lumbar support cushion design. The most appealing aspect of the design is the double chamber combination because it successfully targets rotating the pelvis forward as well as extending the lower back. One focus of the project is making sure the pelvis is tilted forward when the lumbar region is arched. Without proper alignment of the pelvis, proper posture cannot be achieved. Using air is advantageous because it is comfortable by conforming to the back and providing even support across the entire back; and, once a pump is found, regulating the airflow for different speeds of inflation would be easy. On the other hand, an air pump that fits our needs is hard to find within our budget. The combination of a small, powerful and quiet pump is rare unless price is sacrificed. It is not feasible to produce a prototype of pneumatic design in the given time frame. In addition, an alternative design was sought because we wanted to create an innovative method from the pneumatic device of similar\ design already available.

The mechanical lumbar roller offers many advantages to the user. First of all, the motor would be variable so that the user could choose the speed of the oscillations. Also, the beads would provide a “massage” feeling to the user to enhance the comfort of the device as well as prevent clothing from being caught in the device. Since a product similar to the pneumatic design is already on the market, the mechanical lumbar roller might be a better option since currently there is no other product on the market like it. There are also a few disadvantages to this design. The biggest disadvantage is that the motor would be required to provide a lot of torque since the bar would essentially have to push the patient forward whenever the bar is at the top or bottom of its cycle. Also, mounting the motor so that it is out of the way of the driver may pose a problem. Lastly, the bar does not provide very even support, since most of the pressure from the bar would be focused directly around the bar rather than over the entire lumbar region of the back. This could be remedied with thick rollers reducing the pressure on the back, and by making the rollers out of a soft enough rubber to conform to the body but yet rigid enough to arch the back.

*Static Wedge:*

To supplement our CPM lumbar roller, the use of static wedge was seriously considered. One big worry addressed by our client, Julie Sherry, was a limited hip flexion motion due to the nature of bucket car seats. If this was not corrected for by some means, the beneficial value of the lumbar roller might not be as great.

When an individual sits in a bucket seat, their hip is in flexion close to the end of the range of motion. Since the CPM roller is causing periodically more hip flexion during its cycling, the benefits may not be as great for an individual in a bucket seat as compared to an individual sitting in a better postural configuration. Normally, an individual's hip flexion has a range of motion around 120 degrees. When in a level sitting position, a person will be in 90 degrees of hip flexion, leaving 30 degrees available to tilt into a better spinal alignment. If the individual sits in a bucket seat, hip flexion is now already over or around 100 degrees, leaving less flexibility to achieve lumbar lordosis (Sherry, 2001). Therefore, by the addition of a wedge, the used hip flexion of an individual would be decreased, thereby allowing more flexibility with the CPM lumbar roller to achieve lumbar lordosis for the individual.

There are some issues concerning the use of a wedge. If the user's car has a low ceiling, the wedge would most likely boost them too high, causing an added discomfort with driving. Also, bucket seats range in angle of declination; therefore the effects of a wedge would be different in each seat configuration. Lastly, the effect of boosting the hip changes the amount of extension in the knee and the tension in your hamstrings. The overall degree of each factor has not been thoroughly determined, though it was discussed with the client as well as the advisor in an effort to achieve a better mechanical perspective of the lower back.

**Final Design Solution:**

After the evaluation of both the pneumatic driven cushion and the mechanical lumbar roller, we decided to use the mechanical lumbar roller as our final design. Figure 3 illustrates the modified prototype and our idea for a final product. The final design is fully described as design alternative number two earlier in the paper. Compared to the pneumatic driven cushion, the mechanical lumbar roller eliminates concerns about the air pressure inside the pneumatic cushion. It would have been very difficult to correct for the air pressure differences caused by different weights of drivers (Air pressure in the cushion = Force applied by people / Surface area of cushion). If the air pressure in the cushion is unable to balance the forced applied by the driver, the continuous passive motion cannot work effectively. Also, through research on this topic, it was discovered that there already exists a pneumatic cushion for the lumbar region of the back that undergoes continuous passive motion. The only difference between that machine and the one that we want to use is that the continuous passive motion is not adjustable; meaning it only oscillates at one rate, which is not what the client wants. For the sake of achieving the constraints of the design given to us by the client, the variable continuous passive motion and supporting to the lower back, we chose to pursue the mechanical lumbar roller design.

Through the rotation of the roller, drivers feel the rubber rollers moving up and down their lumbar region of the back, similar to the feeling of a massage. The rotation of the roller gently arches the back and rolls the pelvis forward, flexing the surrounding

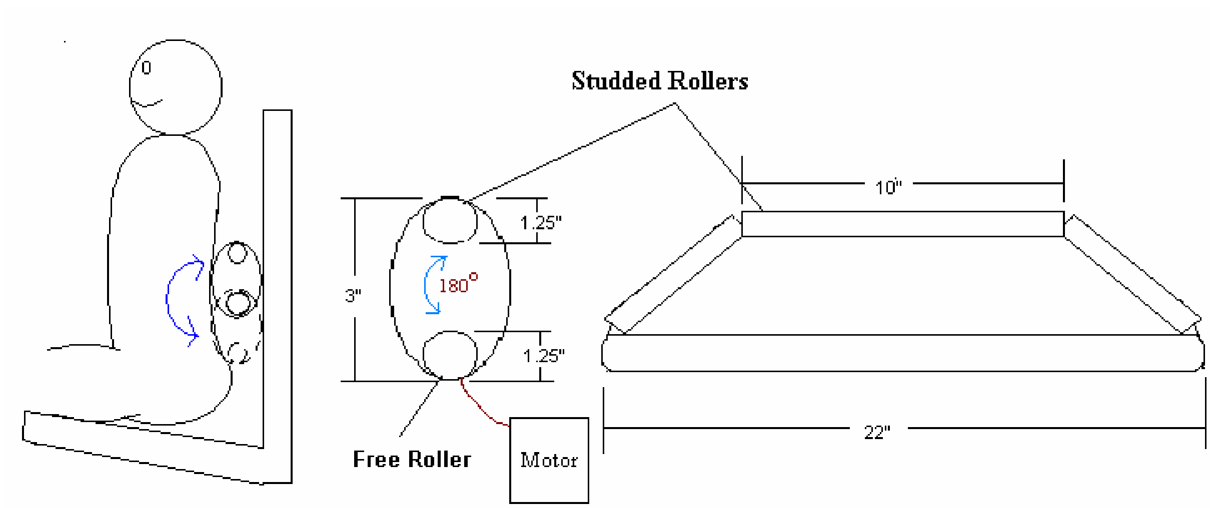


**Figure 3 Final Design Idea**

*This design incorporates a reversible motor to the mechanical prototype and also modifies the general design. It still involves a sweeping arm to administer the continuous passive motion.*

ligaments and tissues. This flexing process increases the blood flow to the tissue area, and based on “the vicious circle of pain” (described to us by our client), would effectively reduce tissue breakdown and lower back pain. Also, based on the information gathered this semester and previously presented, the use of a static wedge in conjunction with the CPM lumbar roller is recommended.

**Prototype:**

In order to illustrate the basic ideas and components of the mechanical lumbar roller, a prototype was constructed. The prototype is shown in figure 4.

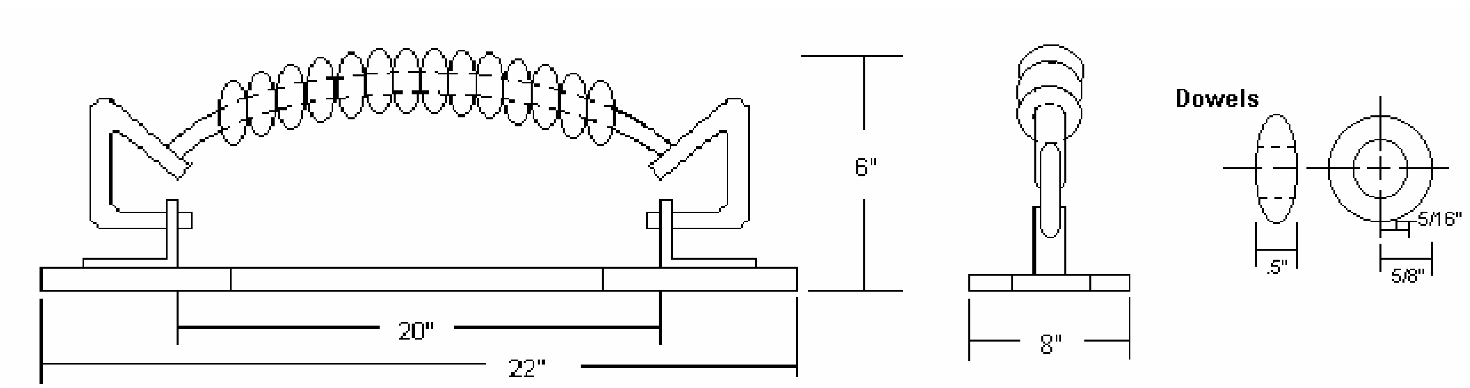


**Figure 4 Mechanical Design Prototype**
*This design is the beginning stage of the mechanical design. It illustrates the sweeping arm that administers the continuous passive motion.*

This prototype for the mechanical lumbar roller uses an aluminum rod that has been bent to have an arch height of roughly six inches. The rod was then threaded with wooden discs to ensure that the device would roll up and down the back of the patient. The device was mounted on a piece of plywood since it was available at no charge. Although not shown in the picture, a lever was attached to the bracket on one side so that the support can be oscillated up and down the back. The device is rather crude, but it effectively shows the concepts behind our design. After a little informal testing of the prototype, we found that the bar should have less arc because it was pushing the back of the patient out a little too far. We also found that we should have used a wider piece of plywood because the device was sitting below the lumbar region of the back.

**Ethical Concerns:**

One ethical concern is if this mechanical roller would impair driving ability. This product would need to undergo further testing to see how it would affect people in a driving simulation. Another concern is people using it without proper guidance, and trying to use this product to fix any problems that they might have without having it checked out by a professional, to get the best advice. The mechanical device eliminates the problem of using air pressure and having problems with valves and other parts not working correctly. If air was used it could have potential concerns of overfilling and bursting possible hurting the individual.

**Future Development:**

In the future, a motor would be incorporated into the design rather than the lever shown in the prototype. This motor would be mounted alongside the right pivot point of the lumbar support or even slightly behind the driver to insure that it is out of the way and not distracting or cumbersome for the driver. The motor would be variable speed and allow the driver to change the rate of oscillations while driving the car. The reason that the motor was not included in the prototype is that there was not enough time to adequately research and/or build a motor that would do the job. Our group could not justify spending $50 on a motor that wasn't assured to adequately rotate the lumbar support. With more research, a motor could be built or modified for the specifications of this project. Also, a rigid sheet of plastic would be used to mount the support cushion to in order to reduce the thickness of the backing material as well as to make the device have a professional look to it. This would make the device lighter in weight to allow for easier transport and installation. Along with the plastic, velcro or elastic straps would be used to secure the device to the back of the driver's seat to ensure that the device would not move around while operating. In addition, with more research time, we would determine the best shape for the lumbar support. A uniform circular shape was used in the prototype since we felt it would give the most support and provide the most comfort to the patient.

Once all these components have been incorporated, a great deal of testing is required to work out any kinks or problems before the device is actually ready to use on a patient. This testing would also help provide a better understanding of affects on pain in the lumbar region of the back and the wedge's added benefit for the range of motion with regard to hip flexion. From these test results, slight modifications can be made to ensure proper back support in being obtained via this device. It is estimated that roughly one more semester would be needed to build a motorized lumbar cushion, adequately test the device, and make changes and corrections as they present themselves.

**Appendix A: References**

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**Appendix B: PDS Report**

BME 200/300
12/14/01

Product Design Specifications

**Title:** Adjustable lumbar support cushion with continuous passive motion.

**Function:** To design a pneumatic lumbar support cushion that undergoes continuous passive motion for a variable duration of time when a patient is in a sitting position such as driving an automobile.

**Client requirements:**

- Provide passive motion to the lumbar region of the spine.
- Not be distracting to the driver or difficult to operate.
- Be comfortable and ergonomic.
- Be adjustable to different automobile seats and batteries.
- Use cigarette lighter as power source if possible.

**Design requirements**

**1. Physical and Operational Characteristics**

a. *Performance requirements*: Easily operated while driving and use 12 V cigarette lighter socket, car battery or battery pack. The motor should also be quiet and non-distracting to the driver.

b. *Safety*: Must not distract driver in any way or put too much pressure on lumbar spine. Components of motor must be self-contained and safe.

c. *Accuracy and Reliability*: Must provide support to the lumbar spine. Timer cycles must be fairly accurate (±10 sec).

d. *Life in Service:* Depends on motor used.

e. *Shelf Life*: N/A

f. *Operating Environment*: Must operate within an automobile, and not be affected by a broad temperature range while not in use (in case patient leaves device in car, roughly 0 – 150° F).

g. *Ergonomics*: Controls should be easy to use and require the use of only one hand.

h. *Size*: Cushion must be able to attach to a car/truck seat and be large enough to provide support to the entire lumbar region of the spine. Motor should be mounted so that it is not in the way of the driver and does not distract them.

i. *Weight*: Light enough for easy transport and installation into different vehicles (roughly 10 pounds).

j. *Materials*: Materials should be non-hazardous and not be dangerous to touch.

k. *Aesthetics, Appearance, and Finish*: Should be professional looking, with no jagged edges or surfaces that could catch clothing or cut the skin.

**2. Production Characteristics**

a. *Quantity*: One (prototype)

b. *Target Product Cost*: Under $30, not including motor. Motor would range from $20 to $100.

**3. Miscellaneous**

a. *Standards and Specifications*: Needs to be certified as safe to use while driving.

b. *Customer*: Patients using this device will have lower back pain, usually between the ages of 25-40.

c. *Patient-related concerns*: Must be easy to use, install and move from vehicle to vehicle. Also must be supportive, comfortable and non-distracting while driving.

d. *Competition*: Lumbar support cushions already exist, but none are known to provide continuous passive motion with variable cycles of oscillation.

## Appendix C:  Cost of Materials for Prototype Construction

***<u>Cost of Materials</u>***

| | | |
|---|---|---|
| 1. | Aluminum Rod | $3 |
| 2. | Triangle Shaped Connectors | $3 |
| 3. | Brackets | $2 |
| 4. | Plywood | Free (Donated by Dr. Gruben) |
| 5. | Epoxy | $2 |
| 6. | Wooden Discs | $8 |
| 7. | Future cost of motor | $10 - $300 |