Human-Powered Vehicle for Stationary Overhead Rail or High-Tension Cable

by

Ryan Anderson

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ABSTRACT

An alpha prototype of a human-powered vehicle was designed and manufactured. The machine is intended for use in Nepal on a system of suspended, overhead, high-tension cables and rails. The functional requirements, restrictions and parameters were identified based on existing infrastructures. Overall design concepts of the machine were presented and analyzed. A final concept was chosen. Design concepts of the different machine modules and assemblies were presented and analyzed. Final module concepts were selected and designs were specified. Manufacturing and assembly processes were defined and preliminary recommendations for a beta prototype were documented.

Thesis Supervisor: David Gordon Wilson
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Acknowledgements

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Introduction

Thomas Cableway Products®[1], based out of Slidell, Louisiana, has developed an overhead cable and railway system which is currently being used on banana plantations in Caribbean countries. The overhead cable and railway system provides a stationary infrastructure on which bundles of bananas can be transported. The bundles are hung on trolleys that roll along the high-tension cable. These trolleys can be linked together and pulled by hand or by a cable-mounted diesel tractor.

The use of this infrastructure on banana plantations has sparked interest in expanding the system for use in Nepal as a standard medium for transportation and transfer of goods. Currently, most Nepalese people in rural areas of Nepal get around by walking or riding a bicycle. The paths on which they travel are not ones of gravel or asphalt, but simply ones of soil. Rain can quickly make these paths a mess and paralyze bicycle transportation. In addition, many people have to walk miles up or down the banks of rivers in order to find a bridge they can cross. An overhead high-tension cable strung across a river could prove to be a relatively cheap and reliable means for crossing a river.

The simple application of the existing diesel tractors is not a feasible option as a vehicle for the transportation system. Most Nepalese people could not afford the diesel machine nor the scarcely available fuel it would burn. The cableways would also be shared by many people, so a machine that can not be easily removed from the cable would be unrealistic. Diesel tractors are designed for pulling heavy loads at low speeds and not for transporting people and goods quickly over long distances. It became evident that if a mass transportation system based on this cable-and-rail system is to work, a lightweight, human-powered alternative to the diesel engine must be incorporated into the system.

At the initiation of this particular MIT project, some work had already been done concerning the design and prototyping of a human-powered vehicle (HPV) for application on an overhead high-tension cable and railway system. The overall HPV project was initiated by David Sowerwine[2]. A small team of individuals (see Appendix A) located in the U.S., London and Nepal is involved in this project. Throughout the project, these members were consulted and updated.

The focus of this project was to design and manufacture an alpha prototype of the aforementioned HPV. To accomplish this, a systematic design approach was taken. The functional requirements, restrictions and parameters were identified based on the existing cableway systems on the banana plantations. Design concepts for the overall machine were presented and analyzed. An overall design concept was chosen. Design concepts of the different machine modules were then presented, analyzed and selected. Finally, the manufacturing and assembly processes were defined.

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[1] For contact information, see Appendix A

[2] David Sowerwine is a former employee of Product Development Division of IDEO® located in Palo Alto, California. He currently resides in Nepal. See Appendix A for contact information.

Design Considerations[3]

Functional Requirements

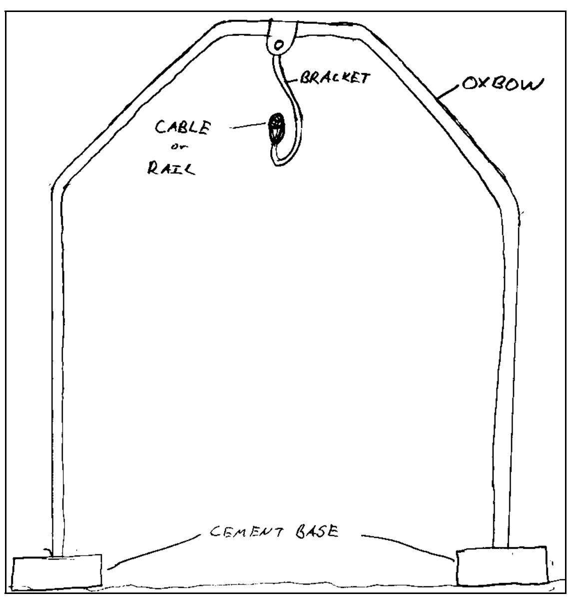
The HPV must be able to carry at least one Nepalese person (about 140 lbs. (65 kg)) and a small amount of goods along an overhead high-tension steel cable or railway system, and should be capable of towing one or more cable-supported "trailers". The machine must be removable by one or two people from the cable and capable of traveling in both directions. The HPV must be equipped with a braking mechanism. Drivers and passengers must be able to get on the machine without assistance. The HPV must accommodate persons of different heights and specifically leg lengths and also have different speeds for transit and load hauling.

Existing Infrastructure

The alpha prototype needs to work on the existing cableway systems so that it may be easily tested. The existing systems will impose some restrictions on the prototype.

The cable used in the existing system is 7/16" double-cold-drawn banana wire. The steel cable has a breaking load of 17,300 pounds and is stressed to a load of 10,000 pounds during installation. The cable is held in tension by anchors at each free end. It is also supported every 10 meters by a customizable oxbow and bracket assembly (Figure 1). The supports keep the cable about 2.5 meters (approx. 8 ft.) off of the ground.

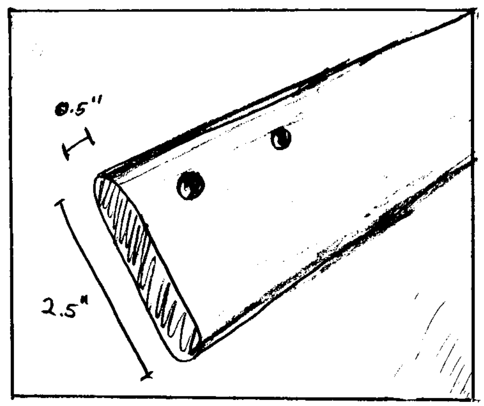
Figure 1: Oxbow and Bracket



[3] Specifications courtesy Michael Hess. See Appendix A for contact information.

For corners and connection points, steel rail is used. The rail is 0.5" thick and 2.5" tall (Figure 2). The smallest turning radius in any of the existing systems is 8.5 meters (approx. 28 ft.). It has been found that smaller radii create too much thrust on the existing, two-wheeled trolleys.

Figure 2: Rail



As can be seen in Figure 1, the cable or rail is supported by the bracket from the underside. An arm then extends to the side and then up to the oxbow. This means that a trolley hanging on the cable or rail can pass on only one side of the cable. This becomes a concern when designing so that the machine can travel in both directions. Also, the mounting bracket does not permit the trolleys to be clamped down to the cable or railway. This means that all of the driving force due to friction between the trolley wheels and the cable or rail, will depend directly on the weight of the machine.

The curve radius is of particular interest when you consider a machine using more than one trolley, which is most likely necessary for this design. For example, if the trolleys are 1.5 meters apart on a curve with radius 8.5 meters, the trolleys will be approximately 5 degrees off from each other. The design must allow for this flexing.

Nepal Environment

In the country of Nepal where this machine would be used, the slope of the terrain is normally less than 1.75 degrees (3% or 3 meter rise in 100 meters). This is the natural slope of many of the river valleys. River crossings may call for cables 50-100 meters long. The slope will affect the pull power of the machine by reducing frictional forces between the trolleys and the cable or rail.

The temperatures in Nepal fluctuate about 100°F, ranging from the teens to above 100°F. The materials which the HPV is made of must be able to tolerate this temperature fluctuation. The expanding and contracting of the material will also affect the tolerances at any interference points between parts.

Rainfall is a common occurrence in Nepal. The presence of water must not keep the machine from working. Also, the loss in frictional forces due to the water between the trolleys and the cable or rail must be taken into consideration.

Cost and Technology

The rural people of Nepal are fairly poor and also have limited manufacturing processes[4]. This means that if the machine is to be of use, it must be inexpensive. The machine must be made by a process which the Nepalese have available so that they can perform repairs or it must be so robust and durable that it won't require repairs in which case it can be made in the U.S. and shipped to Nepal.

Additional Considerations

Ideally, the HPV should incorporate some features to make it especially useful, safe and easily constructed. Whenever possible, especially with the prototype, existing bicycle parts and other standard parts should be used. The less machining required the better. The HPV should allow for passengers and/or goods. A parking brake and a governor would be excellent features to increase the safety of the machine when stopped or traveling on inclines. Lights and/or reflectors would better facilitate the HPV use and safety at night. Since the machine may be used to traverse waterways or gorges, some sort of safety mechanism should be incorporated so that the machine can not possibly come off of the cable.

[4] Available processes as reported by Balaju Yantra Shale Machine Works via Michael Hess: latheing, welding, sheet metal bending, galvanizing, power coating, and argon welding.

Alpha Prototype

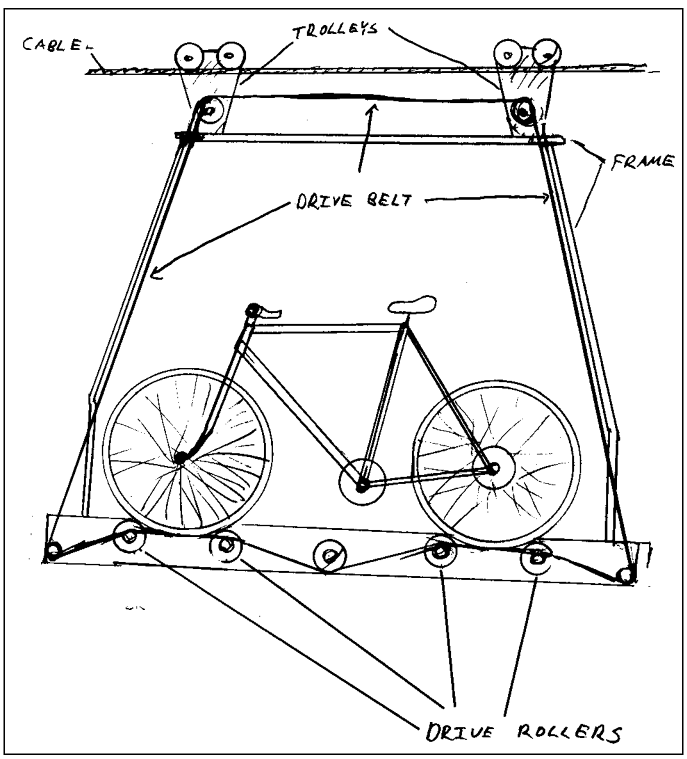
Concept Development

Over the course of the project, many design concepts were considered. Two major concepts categories were identified, those designs with riders in the recumbent position and those in the upright position. Multiple variations in these categories were also explored. The development of the design concepts will presented and discussed in this section.

The first concepts were those of a machine that made use of existing bicycles in their entirety[5]. One would simply place an existing bike into the machine and operate the bike in exactly the same manner. The initial team, as mentioned in the introduction, had already done some development of one concept and presented us with a CAD drawing of the idea.

Figure 3 shows a sketch based on the CAD drawing. In this design, the wheels of the existing bicycle rest between drive rollers. The rollers in turn drive a belt or chain connected to the drive trolleys on the track causing the entire apparatus to move forward.

Figure 3: Upright with Bike



[5] later concepts use parts of bicycles as components.

This design is simple and makes excellent use of a bicycle's existing attributes such as multiple speeds and braking. It also allows the user to remove her/his bike and continue to ride where the cable and rail system does not exist, a definite plus. The unit also meets the bi-directional functional requirement in a very simple manner.

The design has its problems as well. Bicycles vary in frame size, wheel size and wheel base. This will cause difficulty when designing a means by which to fasten the bicycle into the machine. It also makes it hard to get the best performance out of the drive rollers. Ideally, each wheel would be centered between the two rollers, but with different wheel bases for different bicycle frames, this becomes extremely difficult.

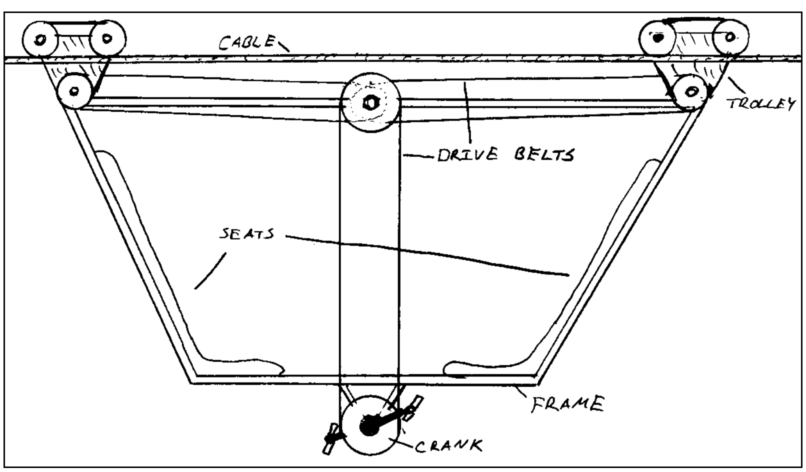
Another issue is the transfer of power between the bicycle wheels and the rollers. The weight of the bicycle and rider alone may not be enough to keep the wheels from slipping on the rollers.

Although it seems at first an excellent attribute to be able to remove one's bicycle and ride away, this also presents a problem. The machine must be left behind as it seems highly unlikely that one could carry it while riding one's bicycle.

The solution to this may be to leave the machine with the cable and rail system allowing others to use the machine. One would simply go to the cable system and expect to find a machine there to use. The problem is that machines will pile up on one end of the line and there may not be enough for everyone to use.

Figure 4 shows an example of the next major concept. In this concept, the drive-train is located in the center. The rider switches from one seat to the other when he or she wants to go the other way. Due to the fact that there are two seats for operation, the seat which is sitting idle can either be used for a passenger or for other cargo.

Figure 4: Two-Seater Recumbent



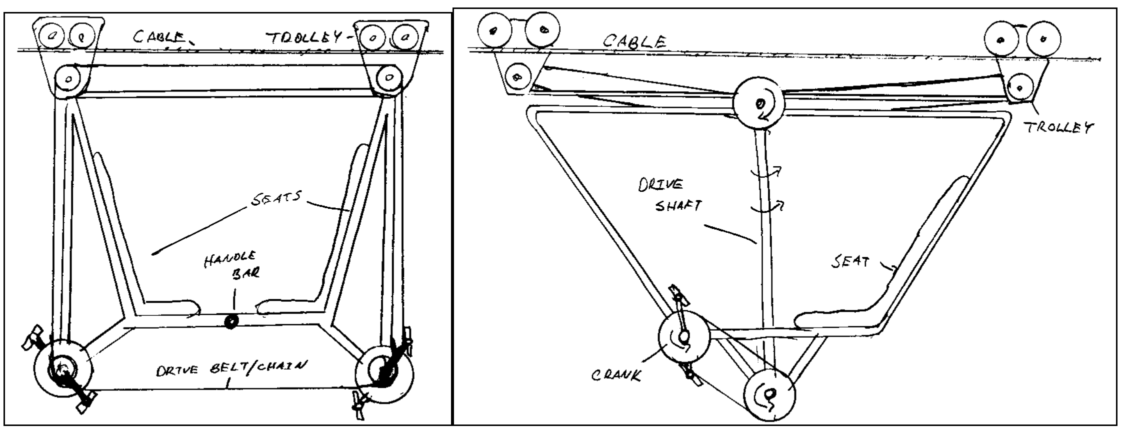
Although this concept meets the bi-directional requirement easily, it does not allow for multiple speeds. A transmission could most likely be designed so that there were multiple speeds, but it is important that it can be driven both ways. This introduces a big challenge especially when trying to work with existing bicycle drive-trains.

Another problem with having the two seats facing each other about a central drive is that of visibility. It may be very difficult for the driver to see where he or she is going, especially when the opposite seat is occupied by a passenger.

This design is also not very adaptable to different size people. There is no adjustment for leg length and such an adjustment would again cause complexities in the drive-train design.

Figure 5 shows some more examples of recumbent designs. Each of these concepts has their good points and bad points, but none of them seem to be capable of incorporating all the fundamental requirements.

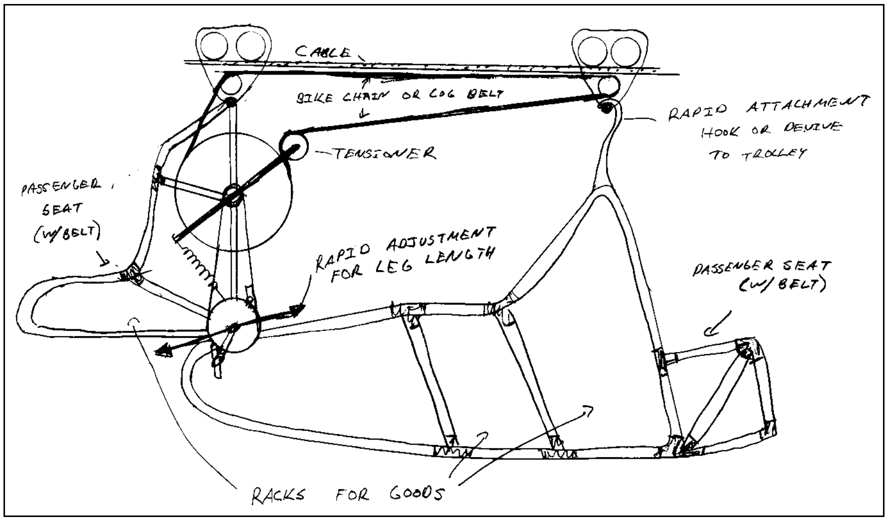
Figure 5: Other Recumbents



After some more brainstorming and iteration, a concept which met all of the functional requirements was developed. Figure 6 shows a redrawn sketch of the concept as first illustrated by MIT Prof. David Gordon Wilson[6]. This concept uses most of an existing bicycle as the drive-train. A drive chain runs around the tireless rear wheel of the bicycle and up over the trolley drive units. A tension device keeps the slack out of the chain and increases the chain contact area with the wheel.

[6] Project supervisor. See Appendix A for more information.

Figure 6: Wilson's Concept



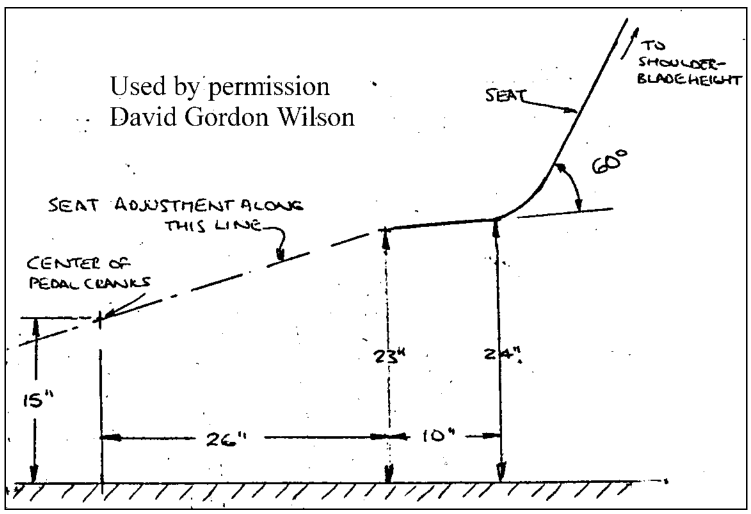
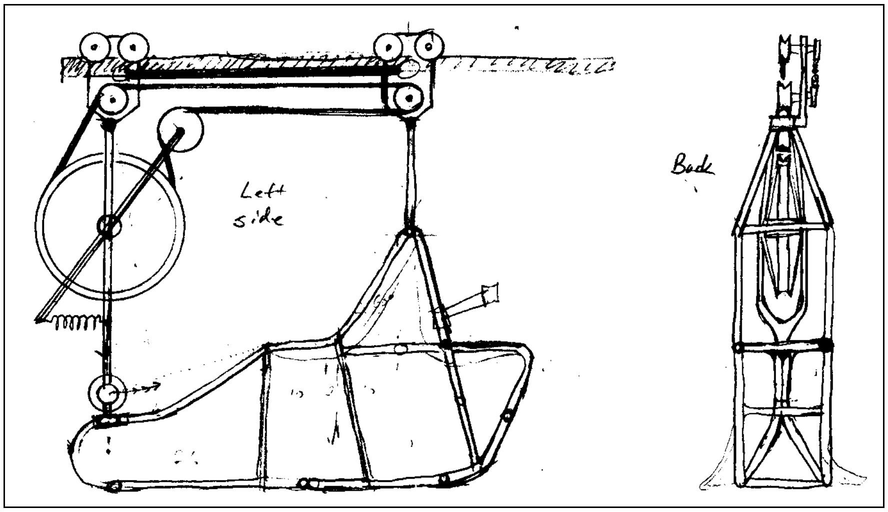


Figure 6 also has an illustration of which includes the dimensions which should be used for recumbent design, as found and published by Wilson. This profile has been incorporated into the concept

The most important feature of this design is that the lower frame and drive-train detach from the overhead trolleys. This is accomplished by releasing the spring on the tension device so that the chain can be removed from the sprockets. The lower frame is then lifted off of the trolleys, turned around and placed back on the trolleys in the other direction. Thus, the unit is bi-directional and can still incorporate multiple speeds, easy leg adjustment, and a recumbent design. The original braking mechanism can still be used as well. The design also incorporates other desired features. There is plenty of room for cargo as well as seats for two extra passengers.

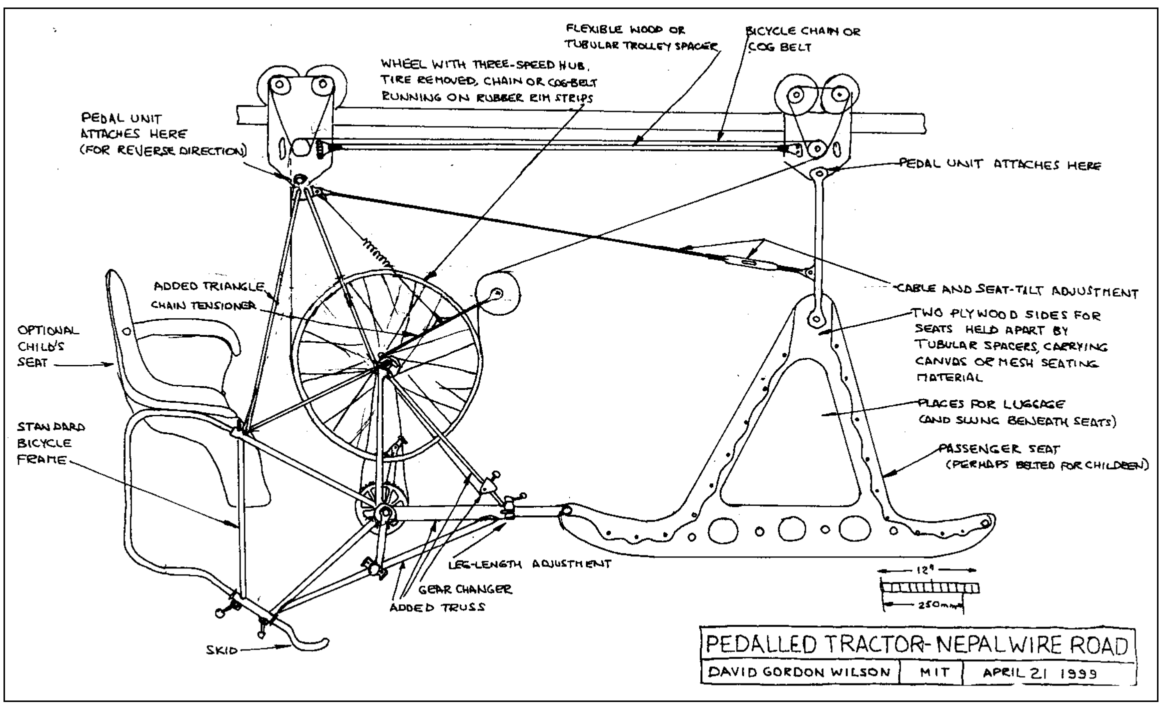
Figure 7 shows another sketch of the concept without the front passenger seat and with some simple modifications to the frame.

Figure 7: Recumbent w/o Front Seat



After analyzing this concept, it was decided that we were nearing our final design for the alpha prototype, but that it still needed some fine tuning and detailing. The existing concept required a lot of bending and welding of tubes. One more concept was developed by Wilson which incorporated plywood and greatly simplified the manufacturing process. Wilson's final overall design concept is shown in Figure 8. The alpha prototype is based on this sketch and design concept.

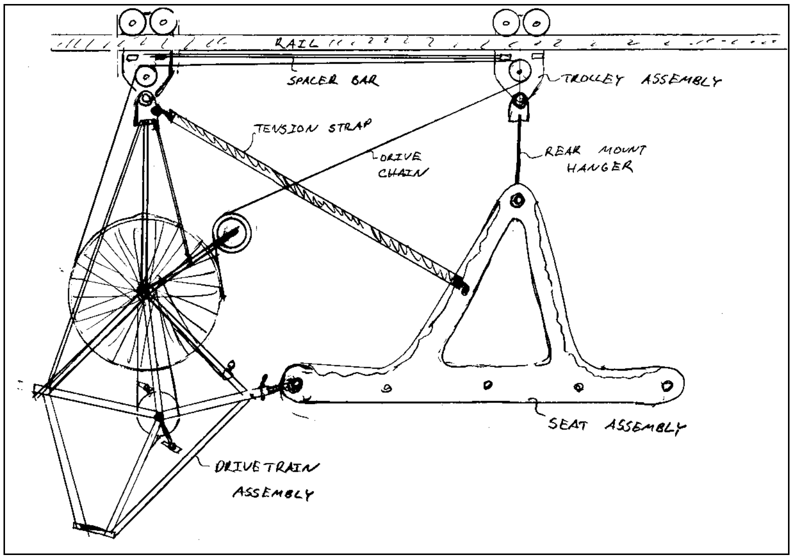
Figure 8: Final Concept



Module Designs and Details

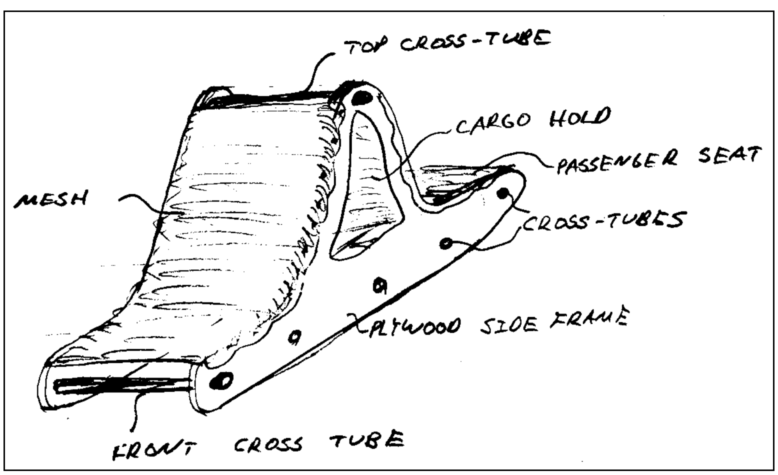
After deciding on an overall design concept, we then focused on defining the details of each module or component of the machine. Some of the components had been evolving along with the overall design while others where considered only once the overall concept was selected. The same process was used to develop these details as was used with the overall concept; however, only the final designs will be presented here. The modules are labeled in Figure 9 using a sketch based on Figure 8.

Figure 9: Modules



The first design is the driver's seat, passenger seat, and cargo module. This assembly is designed to have three major types of parts: the side frames, the cross-tubes, and meshing for seats and cargo hold. Figure 10 shows a sketch of the module.

Figure 10: Seat Assembly



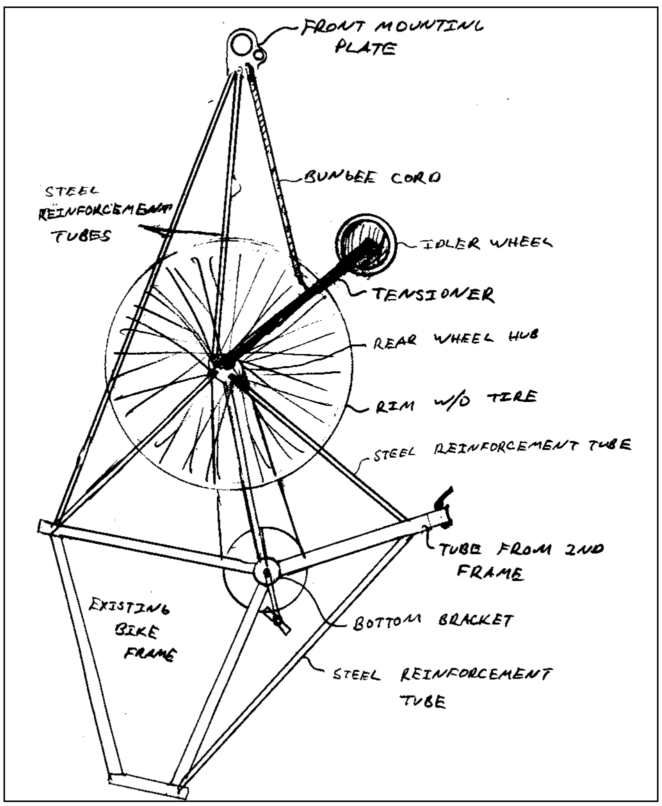
This design calls for the side frames to be cut from 3/4" plywood. The outer edge will provides the profiles for the seats and the bottom of the machine. The side frames will be held together by the four aluminum cross-tubes (1" diameter x 18" long) and two steel cross-tubes (1" diameter x 19" long). A large triangular hole will be cut in each side frame to reduce the weight and to create the cargo hold.

The aluminum cross-tubes are designed to be press fit and glued into holes drilled through the plywood side frames. The steel tubes, on the other hand, are specified as clearance fit as they must be free to rotate in side frame holes. Locking collars can be fitted around the tubes to hold them laterally in place while still allowing for the tubes to rotate. The steel tubes are also each part of other assemblies. The top tube is part of the rear mount hanger and the front tube is part of the T-bar assembly.

The meshing is to be pulled tight between the two side frames and fastened using grommets and screws. A piece can be used for the driver's seat, the passenger seat, and also under the frame to serve as the bottom of the cargo hold. Large items will rest on the cross-tubes, but small items that will slip through the cross-tubes will rest on the meshing.

The drive-train module is the component that transfers the force from the rider's pedaling legs to the drive chain which will be connected to the drive wheels on the trolleys. Figure 11 shows a sketch of the alpha prototype drive-train.

Figure 11: Drive-Train



This drive-train design makes use of two existing bicycle frames. The first is left intact, but the front wheel, fork and handlebars are to be removed, as is the tire on the rear wheel. Only one part is to be used from the second frame. This is the tube that runs up from the bottom bracket to the seat. In this assembly, the tube will be brazed to the bottom bracket on the first frame. The clamp which is used for seat height adjustment on this tube can then serve as the adjustment for different leg lengths.

Steel tubes are to be used for reinforcement and mounting beams. Two tubes will be brazed to the existing frame at the rear wheel hub and run up along the sides of the wheel to the front mounting plate. Two more tubes will run between the front mounting plate and the seat post junction on the intact bicycle frame, again straddling the wheel. Another two tubes will be brazed again to the existing bicycle frame at the rear wheel hub and run along side the wheel down to the tube from the second bicycle frame. Finally, a seventh tube will provide extra reinforcement between the second bicycle frame tube and the first bicycle frame along the bottom of the module.

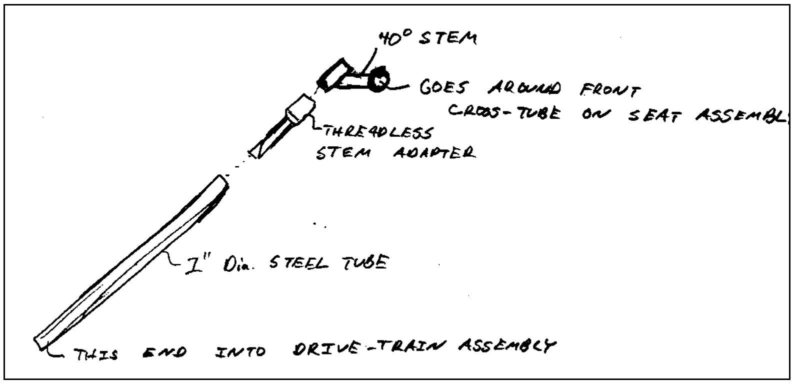
The front mounting plate is designed to simply be a piece of 1/8" steel with three holes in it . The largest hole will fit over a mounting bar on the trolleys. The medium size hole is where stabilizer straps will fasten. These straps will run down to the seat assembly. The smallest hole is where the bungee cord from the tensioning device will attach.

The last component of this assembly is the tensioning device. This device is designed to simply be an idler wheel on a shaft mounted between to steel or aluminum bars. The bars will run down to the frame at the hub of the rear wheel and fasten so that they may move freely. A spring or bungee cord can then be strapped between the bar and the front mounting plate. A drive chain will run around the rim of the rear wheel, through the tensioning device and then around the drive gears on the trolley assemblies.

The hub of the rear wheel will contain an internal 3-speed transmission. The gears are changed by pulling on a cable coming out of the center of the hub. The cable will run down the one support beam to a shifter lever mounted on one of the tubes near another lever used to adjust for different leg lengths. It may also be mounted on the side of the driver's seat if the cable length permits.

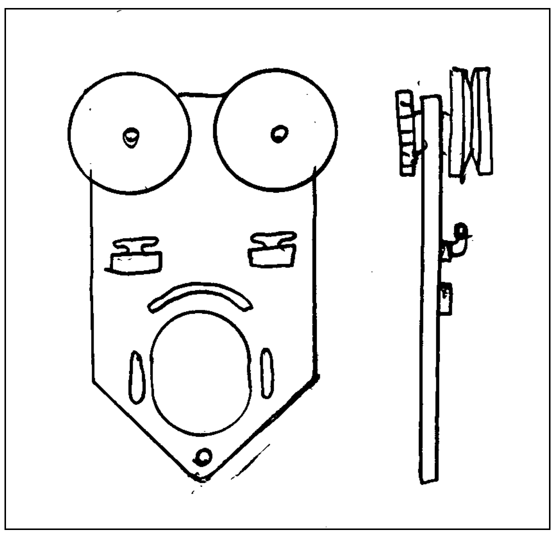
Figure 12 shows a sketch of the T-bar assembly. This assembly is very simple and will contain only four parts. A standard threadless stem adapter for bicycles will be fastened inside a steel tube. A standard 40-degree handlebar stem, will then be attached to the top of the stem adapter. The stem can fasten around the 1" steel cross-tube at the front of the seat assembly. This will create the T-bar. The other steel tube in this assembly is designed to be inserted into the seat-adjustment tube on the drive-train assembly.

Figure 12: T-Bar



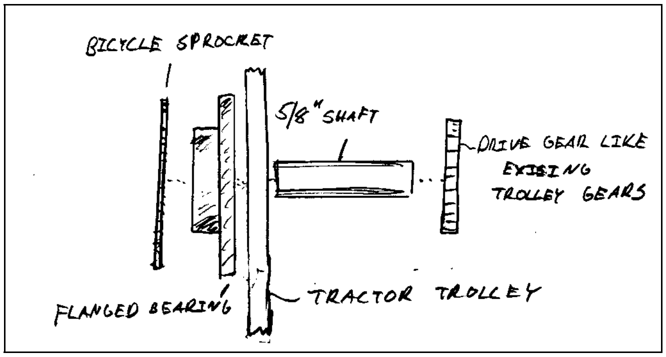
The trolley assemblies will not only support the entire weight of the HPV, but they will ultimately be responsible for the basic functionality of the machine. In order to save time and manufacturing costs, the alpha prototype will make use of existing drive trolleys used by the previously mentioned diesel tractor. Figure 13 shows a sketch of the tractor trolley.

Figure 13: Tractor Trolley



In order to create the whole trolley assembly for use with the HPV, a flanged bearing, roller chain, shaft and two drive gears needed to be incorporated (see Figure 14). The flanged bearing can be fastened directly to the tractor trolley. A 5/8" shaft will then be put through the bearing. Placed on one end of the shaft will be a gear of the same type as those existing on the original trolley. On the other end of the shaft, a standard bicycle sprocket will be fastened. The roller chain is to be fitted around the three similar gears. The bicycle sprocket will be driven by the drive chain coming from the gear train. This will then cause all of the sprockets and pulleys to turn resulting in motion along the rail or cable.

Figure 14: Trolley Gear Assembly



The HPV must also be supported by the trolleys. To do this, a threaded bolt will be placed through the existing 0.5" hole on the tractor trolley. Then a number of washers will be put on the threaded end of the bolt to act as spacers and guide bushings. A collar will then be placed on the bolt to protect the threads. Finally another washer or two is to be placed on the bolt and a nut will be tightened and locked in place. Figure 15 shows a sketch of the assembly. The front and rear mounting plates will fit over the end of the bolt and washer and then hang on the collar. This design allows for a loose fit. Consequently the machine will be able to go around corners as the mounting plates will stay in line with the frame and the trolleys will align with the rail.

Figure 15: Trolley Mounting Bar

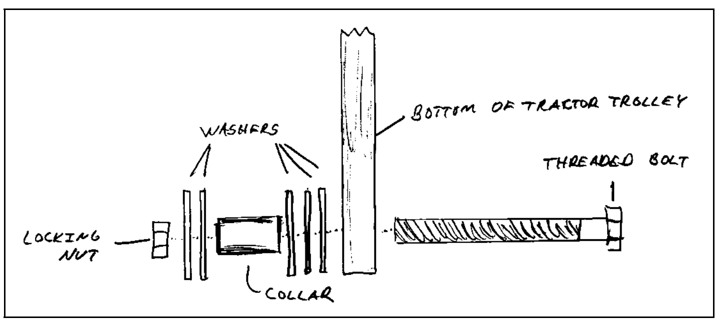
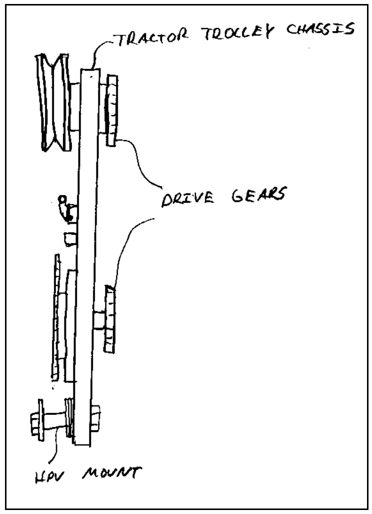


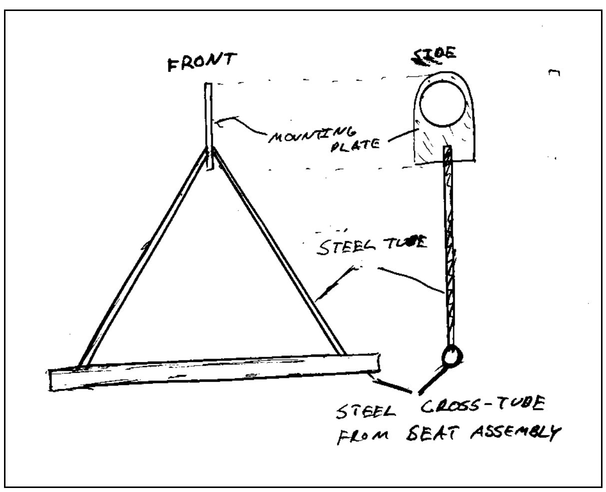
Figure 16 shows the completed trolley assembly.

Figure 16: Complete Trolley Assembly



The seat assembly will be fastened to the rear driving trolley by the rear mount hanger. The hanger is designed to have only four parts. Two steel tubes will be brazed to the rear mounting plate on one end and then to the final steel cross-tube on the top of the seat assembly. Figure 17 shows the assembly. The rear mount plate is much like the front except in only has the large hole for mounting and not the other smaller holes.

Figure 17: Rear Mount Hanger



The tractor trolleys each have two t-shaped attachments which are used for linking to other trolleys by means of a bar. Thomas Cableway Products® makes these connecting bars in standard lengths. The bars keep the trolleys apart from each other and allow one to tow the other. They also allow for the misalignment of the trolleys encountered on corners. The standard 1.5 meter bar will be used to connect the front and rear drive trolleys of the HPV.

The final part are the previously mentioned tension straps that will run from the seat assembly to the front mounting plate. Adjustable motorcycle tie down straps will be used as they are cheap, readily available and perfect for this application. The straps can be disconnected for loading and unloading and can be easily tightened or loosed to adjust seat angle and machine stability.

Status

At the time this report was written, the alpha prototype was still in production. Not all of the parts and materials had been acquired. Once all of the materials and parts arrive and are manufactured, the prototype will be assembled and some preliminary testing will be done at MIT. A piece of rail has been acquired and mounted[7] so that the machine may at the very least be hung and tested on very-short, very-low speed runs.

Upon the completion of preliminary testing and minor modifications based on those preliminary runs, the prototype will be shipped to Nepal for on-site testing. Specifications for the beta prototype will be defined both from the in house preliminary tests and the on-site Nepal testing.

[7] See Appendix B for sketches of test apparatus.

Appendix A: HPV for Nepal Team Members and Contact Info

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Appendix B: Test Rail Apparatus

Figure B1: In House Test Apparatus