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FINAL REPORT
FOR THE BPM T9
Electronic Bicycle Power Meter

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Project Objective

During the course of this semester, BPM Technologies assumed the role of a startup company. The bicycle power meter was chosen for the design project due to the involvement required from both the Electrical Engineering and Mechanical Engineering team members. Through company research and the scheduled guest lectures, BPM Technologies soon realized the need to not only fill the Mechanical and Electrical engineering positions within the company, but to also assign positions for a marketing research analyst, a company budget coordinator, a team member in charge of parts and spending, as well as a team leader. This required that many of the team members double in their roles within the company. Because of the abundance of engineers within the company, and the lack of knowledge for start-up business operations, much of the needed information for forming an effective company structure was found through research and personal contacts.

BPM Technologies initially had proposed to complete a fully functional model of the T9 Power Meter, however during the course of the project period (3 months, 2 weeks) it was found that BPM's goal had been unrealistic. One of the circumstances that complicated the T9 development was locating the parts required for its construction. Obtaining the slip rings, magnetic proximity switch, microprocessor, etc. by mail order within a reasonable amount of time, and then assembling the parts to the design configuration consumed a large portion of the project period. An additional setback that BPM experienced was the alteration of the original design. Changing from a torque measuring device with a variable resistor to a torque measuring device which used a strain gage, altered both the mechanical and electrical portions of the design.

Despite these setbacks, the development of a device that measures the power output of a bicycle rider is not far from being finished. With the aid of the Labview software, and a digital oscilloscope, the T9 function is nearly observable. Given more time, the current function of the oscilloscope would be replaced by the magnetic proximity switch (already obtained). The Labview software would be replaced with the actual microprocessor programmed to read the input of the strain gage and magnetic proximity switch, digitally process the two signals, and then display the power via a liquid crystal display (LCD).

The members of the BPM Technologies team feel that the T9 Power Meter project was not only worthwhile, but given more time for development by a future engineering team, the T9 could possibly serve as a realistic and inexpensive alternative to the current power meters on the market. BPM has not ruled out the possibility of selling the T9 design idea, although at the current stage of development it is considered to be unlikely.

Component Overview

Torque measuring device

Currently, the torque applied to the pedal crank arms is transmitted to the drive sprockets through an intermediate set of coupling plates attached to the sprockets with five fasteners. The coupling allows for a small angular rotation between the crank and the front sprockets. A bracket to transfer the power from the crank to the front sprockets will regulate this rotation and the torque will be measured on this bracket with the use of a strain gage.

Slip Rings

Since the strain gauges are mounted on the drive mechanism, which rotates relative to the frame of the cycle, a slip ring is used to carry the signal from the rotating crank to the stationary bike frame.

Magnetic Proximity Detector

To determine the rotation rate of the drive mechanism, a small magnet will be attached to the rotating sprocket, and a proximity detector mounted to the frame. On each revolution, the magnet triggers the detector, a pulse is sent to the circuit board, and the voltage drop across the strain gage is read. Since the intent is to capture the maximum voltage, corresponding to the maximum force applied to the pedal during a cycle, the magnet must be mounted in a location to trigger the detector at the appropriate time.

Power Pack

Electrical power is to be provided by a battery pack. The initial intent of the design is to limit the voltage requirements to six volts, facilitating the use of four AAA batteries. However, until all of the components have been selected, the power requirements remain undetermined.

Data Acquisition

The output voltage of the strain gauge will decrease proportionally with an increase of applied torque. Because the magnetic proximity detector will measure the crank's angular frequency with a discrete impulse train, the analog output voltage must be converted to a digital signal so that it can be processed with impulses. The analog-to-digital conversion will be done with a Burr-Brown ADS931 8-bit converter with adjustable full-scale external references. For the testing phase of the project, the data acquisition will be done by a Hewlett Packard 54600A digital oscilloscope controlled through a Labview virtual instrument (VI).

Data Processing

To measure power, the torque of the crank has to be multiplied by its angular velocity. This was going to be accomplished by an Intel StrongArm SA-1100 processor, but there were unforeseen difficulties ordering the chip and the timeline for ordering parts expired. In place of the SA-1100, the LabVIEW VI will also handle the data processing.

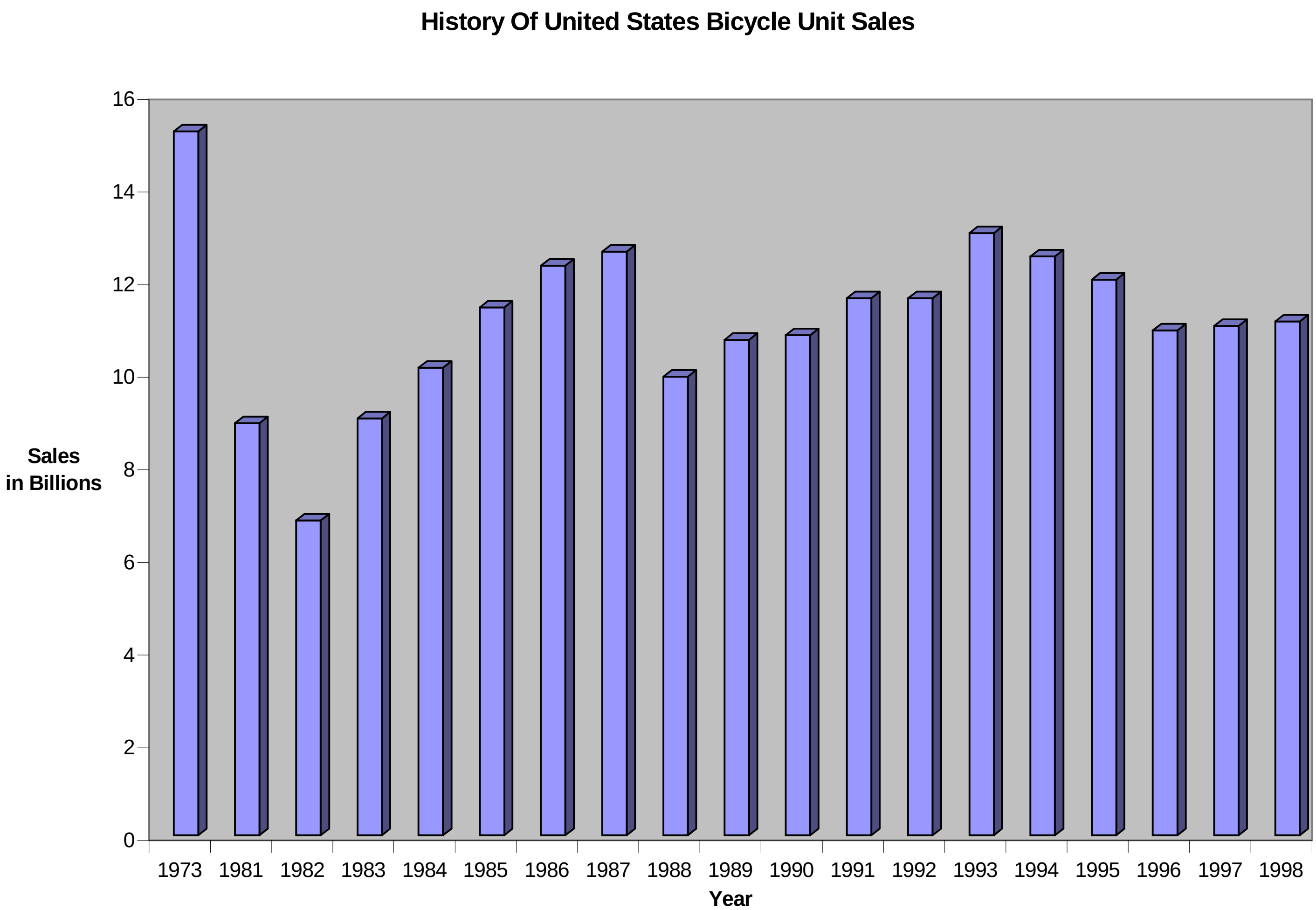
Display

The data processing unit will break down the power into four decimal digits and send an appropriate binary signal to the four Texas Instruments CD4543B BCD-to-Seven-Segment Decoder / Driver for Liquid-Crystal Displays. These decoder / drivers will send the appropriate signals to display the power on a 4-digit LCD. Without a microprocessor to drive the CD4543B chips, the power will be displayed on the front panel of the LabVIEW VI.

Marketing Research

Industry & Consumer Analysis

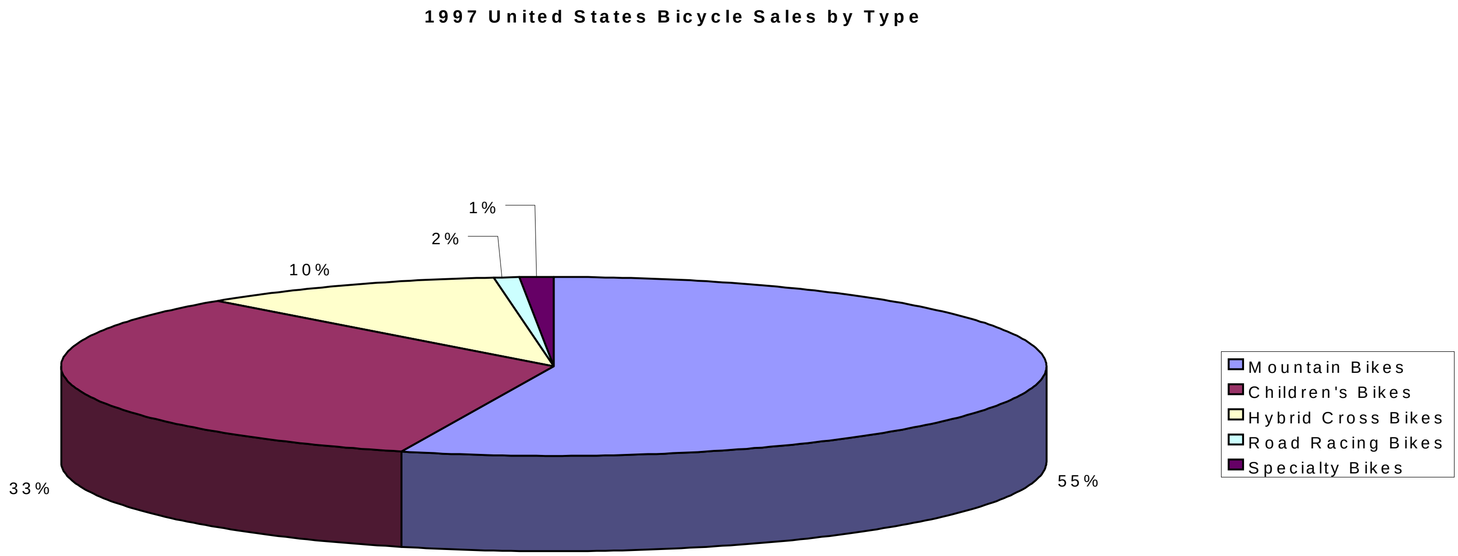
The US bicycle market is currently estimated to be a 5 billion-dollar industry [1]. In the United States, bicycles remain a popular medium for both fitness and leisure. The chart below shows the course of bicycle sales in the US over approximately the last two decades. This chart illustrates the continuing trend of the thriving bicycle industry in the US.



* National Bicycles Dealers Association [1]

According to the National Bicycle Dealers Association, approximately 50% of the average bicycle store's sales are reached through the sale of parts, accessories, and services [1]. BPM Technologies believes that there is an apparent market prospect for the sale of its low-cost bicycle power meter which could eventually complement the use of bicycles everywhere. The application combined with the affordability of this product will attract both the serious bicyclist, and possibly the traditional bicycle rider.

BPM Technologies' initial market aim for the bicycle power meter will be the performance orientated bicycle enthusiast. The proposed aspects of the power meter will give a useful indication of the cyclist's performance and will most conceivably accompany the rigid training and fitness programs of the competitive cyclist, although the possibility of capturing a portion of the casual recreational market may not be unreasonable. A substantial portion of the preferred bike designs for fitness enthusiasts are the traditional road bike arrangements, due to this, BPM Technologies' initial power meter configuration will be designed to accompany the common road bike. BPM Technologies plans to observe the road bike accessory performance, and will evaluate the feasibility of adapting the power meter system to eventually accompany the broader mountain biking sector of the market. The chart below shows the US bicycles sales by type for 1997.



* National Bicycle Dealers Association [1]

There are two major companies which are considered to be reasonable competitors for capturing the bicycle power meter market. Currently, the lowest price for a bicycle power meter is $750. With the introduction of the T9 Power Meter and its inexpensive price of $250, the potential for capturing this market is substantial.

In order to get an idea of the local bicycle industry status, as well as a general idea of the overall industry outlook toward a product such as the T9 Power Meter, BPM conducted a survey of five of the major bicycle distributors in the Reno/Sparks area. A list of the questions that were distributed, as well as the results from each of the cycling shops are tabulated below.

Approximately what percent of sales revenues are made through the sale of bicycle accessories?

The Bicycle Warehouse:	50%-75%
Bikes Etc:	10%-25%
Reno Schwinn:	30%-35%
Great Basin Bicycles:	25%-50%
Mother Lode Bicycles:	25%-50%

Does your store currently carry a bicycle power meter?

The Bicycle Warehouse:	No
Bikes Etc:	No
Reno Schwinn:	No
Great Basin Bicycles:	No
Mother Lode Bicycles:	No

If your store does not currently carry a bicycle power meter, is it something that you would consider carrying?

The Bicycle Warehouse:	Yes
Bikes Etc:	No
Reno Schwinn:	No
Great Basin Bicycles:	Yes
Mother Lode Bicycles:	Maybe

What is the approximate percentage of road bikes and mountain bikes sold compared to your store's total bike sales?

The Bicycle Warehouse:	Road Bikes	10%
	Mountain Bikes	85%
Bikes Etc:	Road Bikes	0%
	Mountain Bikes	50%
Reno Schwinn:	Road Bikes	1%
	Mountain Bikes	99%
Great Basin Bicycles:	Road Bikes	20%
	Mountain Bikes	75%
Mother Lode Bicycles:	Road Bikes	10%
	Mountain Bikes	90%

Do you feel that your store would have more success selling a bicycle power meter that is designed for road bikes or mountain bikes?

The Bicycle Warehouse:	Road Bikes
Bikes Etc:	Mountain Bikes
Reno Schwinn:	Road Bikes
Great Basin Bicycles:	Road Bikes
Mother Lode Bicycles:	Mountain Bikes

What type of customer do you feel would be interested in purchasing a bicycle power meter?

The Bicycle Warehouse:	Competitive Cyclist Age: 26-35 yrs
Bikes Etc:	Bicycle Fitness Enthusiast Age: 26-35 yrs
Reno Schwinn:	Competitive Cyclist Age: 26-35 yrs
Great Basin Bicycles:	Competitive Cyclist Age: 18-40 yrs
Mother Lode Bicycles:	Competitive Cyclist Age: 26-35 yrs

This survey yielded results that were comparable to what BPM had anticipated. The local figures for the sales of both bicycles and accessories seemed to match BPM's nation-wide research results for the industry. The customer information gained through the survey has provided BPM with a better idea of its target customer when marketing the T9 Power Meter.

Marketing & Distribution Strategies

The initial approach for marketing the T9 power meter product will be through direct sales and advertisement. The continuation of the T9 power meter project would require introducing the T9 power meter through cycling magazines, and a company web page. According to Bill McCloud of Bicycling Magazine, the cost of magazine advertisements ranges from $225 to $21,400 per issue [2]. The cost involved with magazine advertisement can be great, although the customer exposure to BPM's target road bike market easily justifies the expense. Internet sales as well as cost of creating and maintaining a web page are comparatively less expensive.

Additional means of introducing the T9 power meter will be through the distribution of free models to recognized individuals within the cycling community, as well as bicycle magazine columnists and editors. This will help publicize and inform cyclists of BPM's product, and also provide BPM with important feedback for possible modifications or additions to the T9 design.

An additional means for both marketing and introducing the T9 power meter to the industry will be through racing events and trade shows. Major bicycle racing events commonly have product information and sales booths which can be rented at low costs. These product booths are a useful method for both the introduction of new products, as well as the advertisement for existing company products. Bicycling expositions such as the Cactus Cup exposition in Arizona, or the Interbike Trade Show, which takes place in Las Vegas annually, are other methods through which BPM Technologies could seek to introduce and achieve publicity for its product.

Once the T9 promotion campaign has been successfully launched, and a customer base has been established, additional product distribution can be sought through sales representatives or distributors. The advantages of product sales through distributors include the consequent decline of BPM's required marketing and advertisement costs. In addition to distributors assuming marketing costs, sales through a distribution network are commonly more far-reaching and often have a larger sales capacity [3]. Despite seeking marketing assistance for the T9 product through distributors, the importance of direct customer contact, brand name recognition, and industry status, shall be realized by the developing company. Thus, if BPM were to continue to pursue the development and marketing for its product, it would be crucial to continually maintain its independent company advertising and product promotion campaigns.

Business Financing

According to the Nevada Small Business Development Center (SBDC), personal assets are commonly a first source of capital for start-up businesses. Small business loans through local banks is another common method for obtaining the required financial funding of a start-up business. Venture capital financing can provide further means for obtaining investment backing for small businesses.

To successfully launch the T9 Power Meter product line, obtaining financial backing through small business bank loans is feasible, although, exhausting any personal assets or possible financial backing from friends or relatives is often the typical scenario. In order to seek and obtain the required resources, the company's initially gathered funding through personal means (checking/savings accounts, credit cards, stocks, bonds, retirement funds, etc. [4]) as well as monetary advancements from friends or relatives will serve as any personal equity investment which may be required by banks (typically 10-30% for a start-up business [4]) prior to obtaining a loan. Funding through venture capitalists is most often not readily available to first time business owners, although the possibility should not be ruled out. The developing company should prepare to present a business plan to interested venture capital financing groups in order to possibly seek and obtain additional fiscal resources.

As the developing company matures, and establishes a track record as well as develops a credit profile, obtaining outside financing will become a bit less challenging [4]. Once the company establishes itself as profitable, and also a safe investment, venture capital financing as well as lower interest rate loans from commercial banks will possibly provide additional sources for future financial backing.

Company Budget & Spending

BUDGET ESTIMATE (Revised April 23, 1999)

Direct Labor Cost				
Salaries				
Electrical Engineers (3)	$	12,528		
Mechanical Engineers (4)	$	16,704		
Classified				
Technical/Professional Support	$	1,350		
Administrative Support	$	1,071		
Fringe Benefit (20%)	$	6,331		
Travel	$	1,000		
Operating (Materials, Supplies)	$	500		
Consultants	$	1,000		
Equipment	$	1,000		
Miscellaneous	$	500		
Indirect costs (40%)	$	16,794		
Total R&D Cost			**$**	**58,778**

Expected Revenue / Income Statement for First Year

REVENUES					
Sales - Retail	(2200 units @ $250)				
Sales - Wholesale	(1100 units @ $125)				
Gross Revenues				**$**	**687,500**
OPERATING EXPENSES					
Accounting & Legal		$	17,188		
Advertising & Marketing		$	120,313		
Distribution		$	10,313		
Equipment & Tools		$	30,000		
Insurance		$	18,906		
Labor		$	36,000		
Licenses & Permits		$	5,000		
Miscellaneous Expenses		$	3,781		
Parts, Materials & Supplies		$	207,281		
Payroll Taxes - Fringe		$	91,000		
Rent		$	36,000		
Salary-Owners/Engineers		$	280,000		
Salary-Administrative Staff		$	48,000		
Subcontractors		$	66,000		
Utilities		$	6,000		
Total Operating Expenses				**$**	**975,782**
Income Before Taxes				**$**	**(288,282)**

Expected Revenue / Income Statement for Second Year

REVENUES				
Sales - Retail	(2750 units @ $250)			
Sales - Wholesale	(1375 units @ $125)			
Gross Revenues			**$**	**859,375**
OPERATING EXPENSES				
Accounting & Legal	$	21,484		
Advertising & Marketing	$	150,391		
Distribution	$	12,891		
Equipment & Tools	$	31,500		
Insurance	$	23,633		
Labor	$	37,800		
Licenses & Permits	$	5,250		
Miscellaneous Expenses	$	4,727		
Parts, Materials & Supplies	$	259,102		
Payroll Taxes - Fringe	$	95,550		
Rent	$	37,800		
Salary-Owners/Engineers	$	294,000		
Salary-Administrative Staff	$	50,400		
Subcontractors	$	86,625		
Utilities	$	6,300		
Total Operating Expenses			**$**	**1,117,453**
Income Before Taxes			**$**	**(258,078)**

Expected Revenue / Income Statement for Third Year

REVENUES			
Sales - Retail (4125 units @ $250)			
Sales - Wholesale (2060 units @ $125)			
Gross Revenues		**$**	**1,288,750**
OPERATING EXPENSES			
Accounting & Legal	$ 32,219		
Advertising & Marketing	$ 225,531		
Distribution	$ 19,331		
Equipment & Tools	$ 33,075		
Insurance	$ 35,441		
Labor	$ 39,690		
Licenses & Permits	$ 5,513		
Miscellaneous Expenses	$ 7,088		
Parts, Materials & Supplies	$ 388,558		
Payroll Taxes - Fringe	$ 100,328		
Rent	$ 39,690		
Salary-Owners/Engineers	$ 308,700		
Salary-Administrative Staff	$ 52,920		
Subcontractors	$ 129,938		
Utilities	$ 6,615		
Total Operating Expenses		**$**	**1,424,637**
Income Before Taxes		**$**	**(135,887)**

Expected Revenue / Income Statement for Fourth Year

REVENUES				
Sales - Retail (6185 units @ $250)				
Sales - Wholesale (3100 units @ $125)				
Gross Revenues			**$**	**1,933,750**
OPERATING EXPENSES				
Accounting & Legal	$	48,344		
Advertising & Marketing	$	338,406		
Distribution	$	29,006		
Equipment & Tools	$	34,729		
Insurance	$	53,178		
Labor	$	41,675		
Licenses & Permits	$	5,789		
Miscellaneous Expenses	$	10,636		
Parts, Materials & Supplies	$	583,026		
Payroll Taxes - Fringe	$	105,344		
Rent	$	41,675		
Salary-Owners/Engineers	$	324,135		
Salary-Administrative Staff	$	55,566		
Subcontractors	$	194,906		
Utilities	$	6,946		
Total Operating Expenses			**$**	**1,873,361**
Income Before Taxes			**$**	**60,389**

Expected Revenue / Income Statement for Fifth Year

REVENUES					
Sales - Retail	(9280 units @ $250)				
Sales - Wholesale	(4640 units @ $125)				
Gross Revenues				**$**	**2,900,000**
OPERATING EXPENSES					
Accounting & Legal		$	72,500		
Advertising & Marketing		$	507,500		
Distribution		$	43,500		
Equipment & Tools		$	36,813		
Insurance		$	79,750		
Labor		$	44,176		
Licenses & Permits		$	6,136		
Miscellaneous Expenses		$	15,950		
Parts, Materials & Supplies		$	874,350		
Payroll Taxes - Fringe		$	111,665		
Rent		$	44,176		
Salary-Owners/Engineers		$	343,583		
Salary-Administrative Staff		$	58,900		
Subcontractors		$	295,144		
Utilities		$	7,363		
Total Operating Expenses				**$**	**2,541,506**
Income Before Taxes				**$**	**358,494**

Five Year Cost Projection

Item	Year 1	Year 2	Year 3	Year 4	Year 5
Accounting & Legal	$ 17,188	$ 21,484	$ 32,219	$ 48,344	$ 72,500
Advertising & Marketing	$ 120,313	$ 150,391	$ 225,531	$ 338,406	$ 507,500
Distribution	$ 10,313	$ 12,891	$ 19,331	$ 29,006	$ 43,500
Equipment & Tools	$ 30,000	$ 31,500	$ 33,075	$ 34,729	$ 36,813
Insurance	$ 18,906	$ 23,633	$ 35,441	$ 53,178	$ 79,750
Labor	$ 36,000	$ 37,800	$ 39,690	$ 41,675	$ 44,176
Licenses & Permits	$ 5,000	$ 5,250	$ 5,513	$ 5,789	$ 6,136
Miscellaneous Expenses	$ 3,781	$ 4,727	$ 7,088	$ 10,636	$ 15,950
Parts, Materials & Supplies	$ 207,281	$ 259,102	$ 388,558	$ 583,026	$ 874,350
Payroll Taxes	$ 91,000	$ 95,550	$ 100,328	$ 105,344	$ 111,665
Rent	$ 36,000	$ 37,800	$ 39,690	$ 41,675	$ 44,176
Salary-Owners/Engineers	$ 280,000	$ 294,000	$ 308,700	$ 324,135	$ 343,583
Salary-Administrative Staff	$ 48,000	$ 50,400	$ 52,920	$ 55,566	$ 58,900
Subcontractors	$ 66,000	$ 86,625	$ 129,938	$ 194,906	$ 295,144
Utilities	$ 6,000	$ 6,300	$ 6,615	$ 6,946	$ 7,363
Total	$ 975,782	$ 1,117,453	$ 1,424,637	$ 1,873,361	$ 2,541,506

Project Development

Torque measuring device

A unit mounted between the pedal arm and the front sprocket will measure the torque applied to the crank of the bicycle. This unit is designed as two flanges that mount within each other and are free to rotate through a small angle relative to each other. One of the flanges mounts on the pedal arm and the other mounts on the front sprocket. By mounting a bracket with a strain gage from one flange to the other we have a single point where all the energy put into pedaling will be transferred and can be measured.

All the angular force applied to the pedal arms is transferred through this bracket and into the front sprockets. By measuring the strain on this bracket we will be able to obtain a value for the torque on the crank.

Power is defined as the time rate at which work is done, so if the torque is combined with a measuring of the angular velocity, we have the desired information for a power rating; i.e.,

> 1 watt = 1 joule per second = 1 Newton meter per second.
> For an angular force this is equivalent to power = moment * angular velocity or
> $P = M*\omega$.

The T9 torque-measuring device will transfer power through an aluminum bracket placed 65 millimeters from the center of the crank on the outer surface of the unit. The maximum tensile load of the bracket has been calculated as 2100 Newtons. The endurance limit for the bracket has been difficult to calculate since the maximum load of 2100 Newtons are only expected in extreme situations but if the fully reversed cyclic loading is staying within 1590 Newton the endurance limit will be 500,000,000 cycles.

The T9 torque-measuring device will be built in 7075-T6 aluminum with ultimate yield strength of 578 Mpa. A prototype of the unit has been build and the design of the torque-measuring device is finalized.

Weight of the prototype is 360 grams but the final production unit will be approx. 30% lower than that.

Cost Analysis

Production Cost of the torque-measuring device has been calculated to be $42.11 where the materials account for $9.61 of this value and the calculations are based on a production of 5000 units.

Illustrations of the torque-measuring device follow in Figures 1 through 3.

Slip Rings

One of our main problems with measuring the power output from the rider at the crank was transmitting electrical signals from the rotating crank to the stationary bicycle frame. There were several options that would have accomplished this task. We chose to mount slip rings to the crank and brushes to the frame in order to get a rotating electrical connection. This proved to be a more cumbersome procedure than was originally expected. Slip rings were ordered in two different sizes, however, due to the cumbersome nature of the brush mounting it was not possible to use the slip ring assembly, which was sent. The slip rings were disassembled and only the connection rings were used. These rings were then mounted into channel that had to me machined into our torque-measuring device. The rings then had to be machined down in order to have enough clearance to mount the crank and not interfere with the bicycle frame. Since the brushes that were sent with the slip ring assembly were large and cumbersome we decided to design our own brush assembly. This was done using on solid piece of Teflon with two carbon brushes spring mounted inside. This assembly was mounted close to the rings on the lower bracket of the bicycle.

Cost Analysis

The cost of the slip ring would be $14.05 at one piece. Bulk order discounts are given at 500 pcs the price would be 10% less, with a maximum discount given of 20% at 5,000 pcs. This cost includes only what we used on the prototype, which is the ring, wires, and brushes. Brushes were included only for completeness.

Total cost for a production run of 5,000 pieces would be $11.24 @ 5,000 = $56,200

Magnetic Proximity Switch

For measuring the pedal crank revolutions per minute, a sample VW110 SPST proximity sensor with matching magnet was obtained from Reed Switch Developments Company. The purpose of the sensor is to supply a pulse signal on each revolution of the crank. The voltage through the sensor corresponds to the torque applied at the crank as sensed by the strain gauge. Since it is desirable to measure the torque at its maximum, the proximity sensor mounting location gains importance.

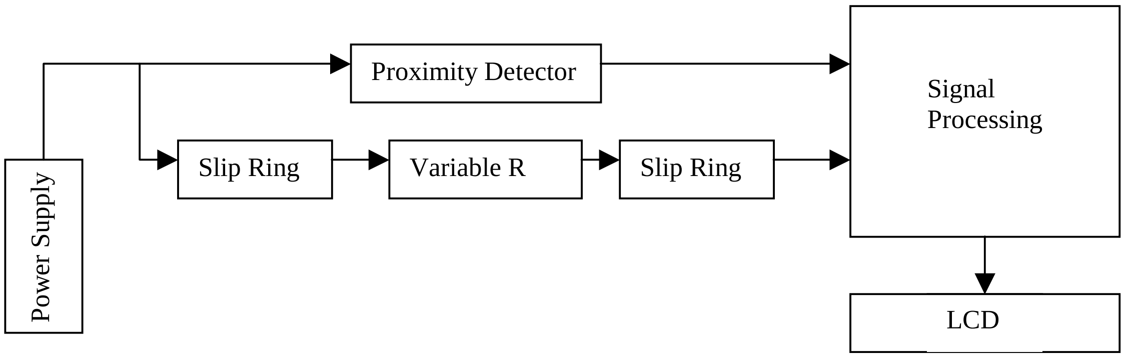
Installing the magnet on the inside of the right pedal, defining top dead center (TDC) of the pedal crank as the position in which the right pedal is up, and calling positive crank direction as that of crank movement when the cyclist is pedaling the cycle allow definition of the pedal angle. When the sensor is installed, a slotted mount on the right side of the cycle will allow it to be adjusted over a range from 45 to 135 degrees to cover the most likely maximum torque angle. Alternately, the magnet could be installed on the left pedal and the slotted mount installed on the left to cover the corresponding range of angles from 225 to 315 degrees.

Electrical System

The electrical design got off to a slow start and ran into many obstacles along the way. This prevented a final prototype of the electrical system from being completed as originally proposed. As mentioned in the proposal written at the beginning of the semester, the goal was to electronically read the power input of the bicyclist and display it on a LCD. The electrical components were to be surface mounted on a circuit board and injection molded along with the LCD to produce a simple prototype ready to mount on bicycle handlebars.

Before an electrical design could begin, it was necessary to determine how and where the power measurements would be taken. There were only a few feasible locations to measure the power supplied by the rider – the rear hub, the chain, or the crank/sprocket assembly. It was decided before the proposal was handed in that the crank would be the most practical. But it was yet to be determined at the time of the proposal exactly how the power would be measured, so at that point in semester, the electrical design was in limbo.

After the proposal, a decision had to be made on which mechanical design was going to be used to measure the power. It was obvious that the force applied by the bicyclist would have to be converted to a torque and then multiplied by the angular velocity of the crank in order to calculate the power. There were several electrical considerations that needed to be resolved before the mechanical design could be finalized. The most important of these were (1) how to measure the force exerted onto the pedals, (2) how to measure the angular frequency of the crank, and (3) how to get electrical signals off a rotating crank. By the time the first progress report was submitted, the mechanical and electrical engineers worked together to design a system that would: (1) measure the force on the pedals by using a linear variable resistor that would change proportionally to the exerted force, (2) use a magnetic proximity detector to send a pulse for every crank revolution to measure angular frequency, and (3) use a set of slip rings to get the electrical signal from the rotating crank. At six weeks into the semester, the foundation was set for the electrical system as shown in the block diagram below.



With the first progress report complete, the electrical design team was finally off and running. Selecting a variable resistor sensitive enough to the match the small linear displacement was the first priority. Along with choosing a variable resistor, it was necessary to learn more about LCD's and these were found to be more involved than anticipated. It was discovered that driving a simple 4 digit LCD requires 40 pins to be addressed. Texas Instruments makes a CMOS BCD-to-Seven-Segment Latch/Decoder/Driver specifically designed to drive Liquid-Crystal Displays (part number CD4543). The one problem with these chips is that they are only manufactured in dual-in-line packages (DIPs), but it was worth sacrificing space on the circuit board to simplify addressing the LCD. Therefore, several TI-CD4543 chips were ordered along with a Veritronix 4 digit LCD (part number VI-415-DP-RC-S). Because the pulses created by the magnetic proximity detector are essentially a digital signal, it became apparent that the analog voltage across the variable resistor would have to be converted to a digital voltage before the two signals could be processed together effectively. To accomplish this, a simple 8-bit analog to digital converter was to be used. The digital signal processing was to be handled by the least expensive microprocessor that could meet the design requirements. It was agreed that the microprocessor would be required to (1) relate a change in voltage across the linear resistor to the torque applied, (2) be able to convert the pulses sent from the proximity detector into an angular frequency, (3) multiply the two signals in order to calculate power, and (4) convert the calculated power to a 4-digit decimal number for the LCD drivers.

As the second progress report approached, the T9 went through a major design change. A strain gauge arrangement replaced the linear resistor for obtaining the torque measurements. The strain gauge setup affected some of the major components in the electrical design, which required alternate products to compensate for the difficulties inherent in strain gauge measurements. Selecting the strain gauge became a top priority. A problem with using a slip ring is that only one signal can be sent onto the crank and only one signal can get off. Thus, a traditional four strain gauge "bridge" configuration could not be used because it would require two signals to be sent onto the crank and two off. One of the characteristics of a strain gauge is its gain factor (GF), which relates the change in resistance to the stress (ε) on the specimen.

$$GF = \frac{\Delta R / R}{\Delta L / L} = \frac{\Delta R / R}{\varepsilon}$$

Being limited to a single strain gauge made choosing a strain gauge with a high gauge factor imperative for an accurate detection of the change in resistance. Entran's model ESB-020-500 strain gauges were selected for the reason of their astonishingly high GF of 155, as opposed to a GF of 2 more commonly found. Another advantage to using strain gauges with a high gauge factor is the ability to avoid powering active components to amplify the signal.

To accompany the strain gauge, a more versatile analog-to-digital converter had to be selected because the expected amount of strain was virtually unknown. Due to this unpredictability it was necessary to select an analog to digital converter flexible enough to resolve a multitude of input voltage ranges. A 100-ohm change in resistance through the strain gauge was a desirable goal, but a 5-ohm change (or less) may be all that is possible. Burr-Brown's ADS931 8-Bit analog-to-digital converter offers an adjustable, full-scale range with external reference. This would provide the flexibility to adjust to a wide range of resistance values.

Much research went into selecting a microprocessor to handle the signal processing in an efficient and cost-effective manner. The StrongArm SA-1100 processor from Intel has several features that make it an attractive choice. Some of these features are: a DSP multiply unit that would efficiently handle the power calculation; a large on-chip cache, including a 16KB instruction cache; a variety of operating systems, including the user friendly Windows CE system; and the SA-1100 incorporates an LCD controller plus all required timer and system functions. However, we encountered a major setback during the ordering process. We researched ***all*** of Intel's distributors to find only one that carried the SA-1100 microprocessor. After several unsuccessful attempts were made to contact this sole distributor of the chip, the timeline for ordering parts expired. A schematic of the electrical design at the time of the second progress report is attached as figure 5.

While waiting for the parts to arrive, a method for testing and calibrating the mysterious strain gauge measurements was developed. It was calculated that the bracket, on which the strain gauge is mounted, would undergo a maximum stress of 4000 μstrains corresponding to a 300Ω change in resistance but the average strain would be approximately 500 μstrains providing a significantly smaller 30Ω change in resistance. For this test phase, a "virtual instrument (VI)" was created using the graphical programming language "G' and the software package Labview. It was expected from data presented by SRM that the voltage through the resistor would be a sinusoidal function of the crank angle. The VI would use an HP54600A digital oscilloscope to read the analog voltage across the strain gauge and convert the analog signal to a digital signal read by the PC. This sinusoidal digital voltage could then be graphed in Labview to determine the RMS value of the signal and the frequency as well as calculate and display the power. The VI would allow the strain gauge to be calibrated with a known force to provide the linear relationship between change in resistance of the strain gauge and the torque applied on the crank. Also, the VI would aid in determining the final reference levels to be used with the ADS931. The simulation proved to be very successful. Attached as figures 6, 7, and 8 are the front panel of the VI, the graphical program, and the hierarchy of the VI. The front panel of the VI showing the sinusoidal voltage across the strain gauge, the Vrms and frequency of the voltage, and the calculated power. Appendix I contains the basic theory and calculations used to derive the model used for the VI.

The T9 prototype had a major setback when the Entran strain gauges arrived. The set of gauges did not come with the necessary hardware for bonding and soldering as anticipated. With no way to mount the strain gauges, an alternative strain gauge was sought. Faruk Taban, the lab TA for MECH 391 provided us with one along with the mounting supplies (with the permission of Dr. Greiner). This borrowed gauge did not have the most desirable characteristics such as a high gauge factor, but it was better than nothing. The replacement strain gauge was mounted to the bracket and the leads from the slip ring were soldered on. The first crank revolution was unfortunately also the last because contact with strain gauge leads tore the bonding pads off the strain gauge.

Not ready to give up yet, four different strain gauges were ordered, this time with the leads pre-soldered. But, similar to the strain gauges borrowed from the MECH 391 lab; these new strain gauges also had a small GF of only 2. It was obvious that the simple voltage divider circuit that was originally going to be used to measure the tension on the strain gauge would have to be replaced by a “dummy bridge” configuration so that the small signal could be amplified. Using simple inverting LM471 operational amplifier a gain of 100 can be easily achieved. A test circuit, shown in figure 9, was constructed and tested for use with the new strain gauges.

Unfortunately the strain gauges did not arrive until 2 days before final projects were due to be submitted. They were mounted immediately and left to set over night. When the complete system was finally assembled and tested, the results were disappointing. The signal was far to noisy to resemble a sine wave. Without a clearly defined waveform, it was impossible to determine both the torque and the frequency. Consequently, the power could not be calculated. After troubleshooting the possible reasons for the excessive noise, the problem was identified in the slip rings. The resistance of the slip rings varied wildly between 5 and 10 ohms. Compared to the change in resistance of the strain gauge, which was likely around 0.25 ohms, the unpredictable fluctuations in resistance of the slip rings dominated the signal. With only a few hours left before the end of the project, it was decided that this signal to noise ratio problem would be left for the next E-team!

Key Personnel

Michael Sigvardt - President / Project Engineer

After graduating in 1985 with a degree in tool making from Denmark's Copenhagen Technical College, Michael held a variety of jobs relating to production tooling and plastic injection molds. Moving to Los Angeles in 1989, he worked as a prototype machinist until relocating to Reno in 1990. In Reno, Michael spent a year working in the furniture industry before returning to school for an Associate of Arts degree from Truckee Meadows Community College.

A senior in Mechanical Engineering with graduation in December of 1999, Michael also works as an independent contractor for the Cavist Corporation where he builds plastic injection setups to seal electronic equipment. After graduation, Michael will return to Denmark with the intention of working with medical or other precision equipment.

Brian Anderson – Product Engineer

Brian is a senior in Mechanical Engineering with a graduation date of December 1999. He attends the University of Nevada Reno and plans to enroll in an Aerospace Engineering Masters degree program within the California State system after receiving his BS degree.

Brian has held two engineering internship positions within the Reno area. Brian has functioned as a technical assistant to Oxbow Power Corporation which designs and builds both geothermal and coal burning power plants. While holding this position Brian was responsible for: steam flow rate measurement calculations, data base design, cooling tower energy balance calculations, and heat transfer and heat exchange rate calculations and analysis.

Brian held an engineering internship position at The Clarkson Company. The Clarkson Company is a leading manufacturer of slurry valves used in the mining industry. Some of the responsibilities that Brian had during his internship position at The Clarkson Company include: slurry valve performance testing, valve gate deflection analysis based on slurry pressure differential and flow properties.

Blair Richardson - Design Engineer

Blair is a senior in Mechanical Engineering with an expected graduation in August 1999. He was born in Colorado and moved to Nevada in 1982. Blair is interested in the design and development of off-road motorcycles and all-terrain vehicles.

After graduating high school with honors, Blair came directly to the Mechanical Engineering program at the University of Nevada, Reno. While attending classes, he also worked for the University's Athletic Program as both a Student Manager for the Football Program and as an Athletic Study Center Operator. During his summers he worked for industrial companies such as PloyPipe, National Seal Company, and most recently Round Mountain Gold Corporation where he received an Internship for Mechanical Engineering. Blair gained knowledgeable experience in designing pumping, piping, and filtration systems, foundations, and structures. He also learned many different control systems that where operational at the mine sight and became familiar with programs such as Wonder Ware and Allen Bradley. He was also MSHA trained for safety.

Blair is a member of ASME and the recipient of the E.J. Questa and Coverston Momorial scholarships and was also on the Fall '98 Deans List. Blair enjoys outdoor sports, lifting weights, automobiles, and riding and racing motorcycles and ATV's with friends.

Eric Rubio - Design Engineer

Eric is a senior Mechanical Engineering student with a graduation date set for December of 1999. Eric is interested in off-road vehicle design and innovation. Eric was born in California and moved to Nevada in 1995 to attend the Civil Engineering College at the University of Nevada, Reno. He switched his discipline to Mechanical Engineering in the January 1997. Eric joined the A.S.M.E. in 1997 shortly after changing majors.

Eric has worked at the University for the Industrial Assessment Center since May of 1998. His responsibilities include researching methods to increase productivity and decrease energy usage in manufacturers. He has had experience writing and editing technical reports, and analyzing cost savings due to efficiency increases.

Eric is planning to attend Graduate School after completing his bachelor's degree. His main concentration will be either in Mechanical Design or in Thermodynamics.

Tim Schulte - Design Engineer

Since graduating high school from Grand Island, New York in 1994, Tim has been a student of electrical engineering at the University of Nevada Reno. His major concentration has been in the fields of electronics, fields, and signals.

Tim has been a student worker at the University throughout his five-year college career. He first worked as a telecommunications technician where he installed and maintained telecommunications equipment such as dial-up-modems, telephone registration system, and video conferencing. Tim has also been a math, physics, and engineering tutor at the Academic Skills Center for three years.

After graduation, Tim has signed a four your contract with the US Navy to be an Instructor at the Naval Nuclear Power School in Charleston, South Carolina. There he will teach electrical engineering courses to both enlisted nuclear technicians and nuclear officers. He also plans to pursue a master's degree while in the Navy by attending graduate school at either the University of South Carolina or Clemson University.

Tim is a member of a number of national honor societies including Golden Key National Honor Society, Etta Kappa Nu, and currently holds the office of recorder for Tau Beta Pi. Tim has remained on the Dean's List every semester since the College of Engineering re-established the tradition in 1996.

Pat Sendelweck - Product Engineer

With over thirty years of automotive-related experience, Pat returned to college to obtain a four-year degree in Electrical Engineering. Working in the parts departments of various General Motors dealerships and independently as an automotive mechanic provided the experience to qualify for a position with the Arizona Department of Transportation. Promotions resulted in a progression through various positions beginning with Assistant Acquisition and Disposal Supervisor through Fleet Manager. After twelve years with the state, Pat moved to Nevada, enrolled at the University of Nevada, Reno, and is currently a senior studying Electrical Engineering. Subsequent to graduation in the fall of 1999, Pat intends to secure local employment allowing for continued education.

Honor society memberships include Alpha Sigma Phi, Eta Kappa Nu, Golden Key, and Tau Beta Pi.

Computer experience includes: spreadsheets (Excel, lotus 123), word processors (Microsoft Word, Word Perfect), databases (dBase IV), math (Matlab, Program CC), application specific (LASI, VHDL).

Asif Shahzad - Electrical Engineer

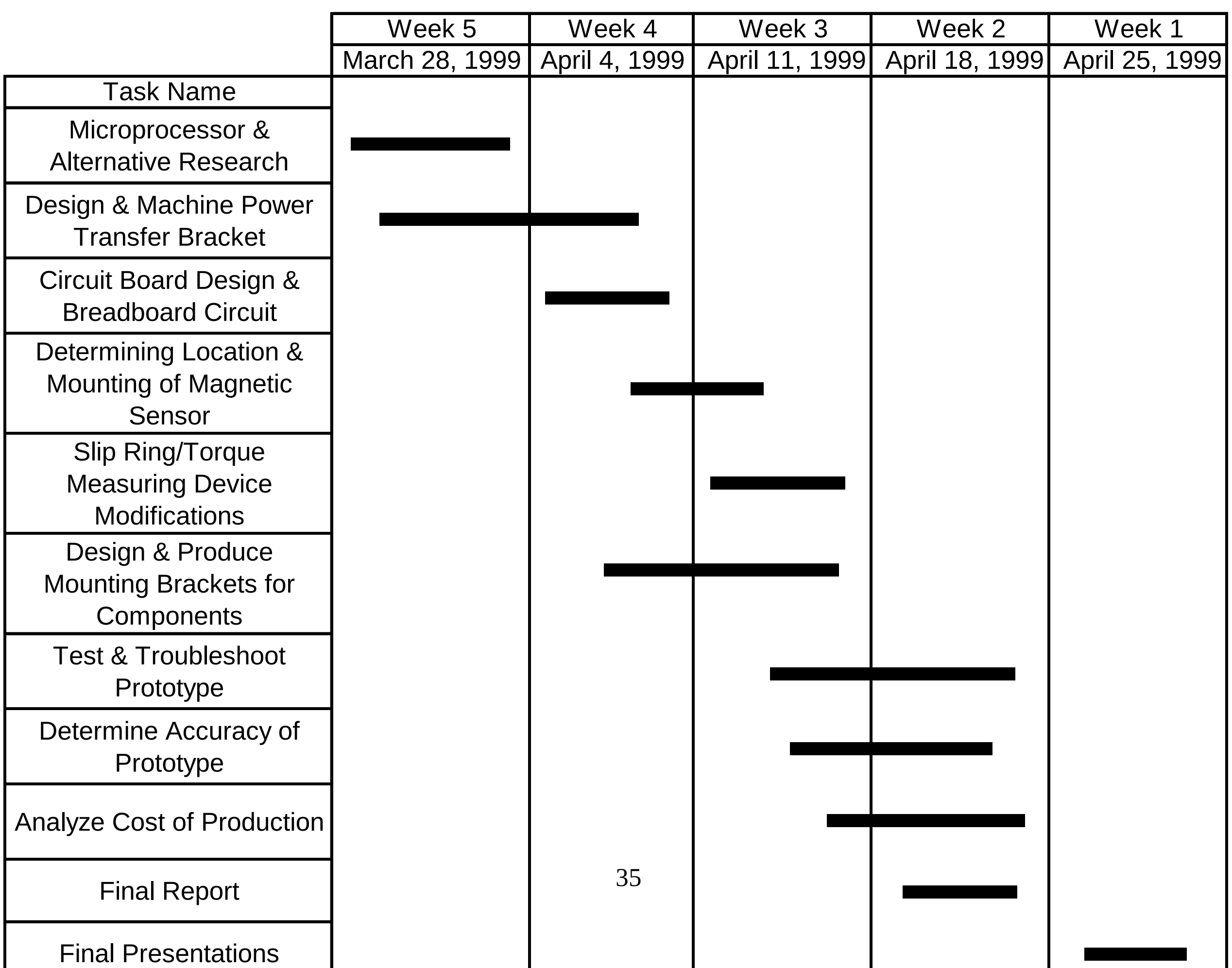
Asif is a senior in Electrical Engineering with an expected graduation date of December 1999. He was born in Pakistan, and spent first half of his life in Pakistan, and the last half of it has been travelling, ending up in America. Asif is interested in a position as an electrical engineer to help him gain some experience in the work field.

Asif graduated from high school in 1995 with a full ride scholarship for the first four years of University. After graduation he has worked as a technician for his uncle's company (Stereo City). He has worked at the Flamingo Hilton Reno as a front desk manager. Some of his duties included providing customer service, and monitoring the reservation computer system used by Hilton Corporation. He has also volunteered at the Washoe medical center.

Asif has a lot of experience with programming languages used by companies nationwide. Those languages include C, C++, Assembly language, Matlab, BASIC, and FORTRAN. He also has experience with software programs such as Pspice, Labview, Word, Excel, EEEsoft, and Windows. Asif is also fluent in Arabic, English, Hindi, Punjabi, Spanish, and Urdu.

Asif is a member of IEEE. He has received the Reno Hilton Scholarship and the Rita Haller Scholarship. His interests include travelling, running, exercising, and spending time with family. He also is familiar with plumbing, due to spending spare time with his cousin that is a plumber.

Progress Timeline



Appendix

Project Expenditures

Parts

Qty	Description	Cost Ea	Total
5	Four digit LCD	$ 10.92	$ 54.58
12	BCD-to-7 segment decoder driver	$ 1.02	$ 12.24
3	8-bit ATD converter	$ 3.12	$ 9.36
10	Strain gauge	$ 10.00	$ 100.00
2	Strain gauge set	$ 60.00	$ 120.00
4	Slip ring assembly	$ 50.00	$ 200.00
1	Modified crank assembly	$ 70.00	$ 70.00
5	Barrel nut sets	$ 2.00	$ 10.00
	Total		$ 576.18

Labor

Qty	Description	Weeks	Hrs/Week	$/Hour	Total
7	Student engineers	$ 13	10	12	$ 10,920

References

[1] "Bicycle Dealers Association Homepage", http:/www.nbda.com/statisti.html, March 3, 1999

[2] Bill McCloud, Bicycling Magazine, Sales Representative

[3] Elizabeth Weigel, Karpiel Bicycles, Co-Owner

[4] Financing a Small Business In Nevada. Nevada Small Business Development Administration, 1997