ECE 4950 Project 2

Team 7

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Executive Summary

This project consisted of three main parts: the testing of a sensor and actuator subsystem, the initial brainstorm of design solutions, and the creation of a variety of documentation to aid in the planning of the final project. For the sensor and actuator demonstration, a photoresistor was selected as the sensor, and an electromagnet as the actuator. Using the Q4 Quanser board and Simulink, a system was built which would power the electromagnet while a flashlight was shined upon the photoresistor. From this project the team learned much about how to use Simulink to interface with external components. This included sending different outputs based on changing inputs. Documentation included concept evaluations, the engineering requirements, and a financial analysis. These helped the team decide upon the best design approach for the design of a washer mover which meets the requirements effectively.

Overall System Design

Customer Requirements were developed based on the Final Project Customer Requirements document.

Engineering Requirements for the Entire System

Customer Requirement	Engineering Requirements	Test
Inexpensive	Design should cost less than $500 to produce	Compare final expenses to $500 budget expectation
Quiet	60dB Goal	Computer Microphone Audio Level Test
Robust	Can solve any iteration of the problem in similar amounts of time	
Fast	Game Board should take less than 15 seconds to rotate 360 degrees	Time Game Board Rotation
	Electromagnet Carriage should take less than 30 seconds to traverse from fully retracted to fully extended	Time Electromagnet Carriage traversal
	Electromagnet should attach to a washer in less than 5 seconds	Time period between moment that electromagnet arm is rotated into position and time washer is attached to magnet
Efficient	Efficiency of Movement: Multiple movements occur at same time to minimize time between washer movements.	Test to confirm that electromagnet arm can rotate simultaneously with electromagnet carriage traversal.
	Efficiency of Power Usage - prolonged	Test power consumption: max power usage should never exceed 150% of the max power usage of both motors + electromagnet for period of more than 1 second.
	Efficiency of Power Usage - peak	Test power consumption: max power usage should never exceed 175% of the max power usage of both motors + electromagnet for any time period.
Safe	Sharp Edges	Test that no sharp edge is sharp enough to tear a piece of paper.
	Pinch Points	No pinch point should pinch powerfully enough to tear the skin

		of a slim-jim.
	Fire Hazards	Measure Temperatures with Thermal Imager: No temperature should exceed 150 degrees Fahrenheit.
	Electrical Shock Hazard	With lab bench multimeter, test that no exposed conductor should show a voltage above 0.5 V relative to ground .
User-Friendly	Operation with minimal technical knowledge	Test the ability of layman to understand functionality - One design team member should be able to explain to a person with minimal Matlab and Control System knowledge the functionality of the design such that that layman can explain the design to a second design team member well enough that it could be reimplemented into a working design.

Design Solutions

Multiple designs were considered and their pros and cons weighed. The group used heuristic techniques to approach the initial design. Once designs were selected for further development, models were constructed in SolidWorks to aid in the visualization of the designs in question.

These designs were then considered using both a discussion of their merits and complex decision matrices to pare down the designs to one which would be selected. Designs considered include systems similar to 3D printers which operate on a cartesian coordinate plane, and designs which act similar to tower cranes, operating on a polar coordinate plane.

Considerations for solutions included the number of actuators which would be necessary as well as the potential complexity of programming these designs. It was sought to limit the number of motors which would be used as motors would require encoders for positional measurements which could become more expensive and require more complex control

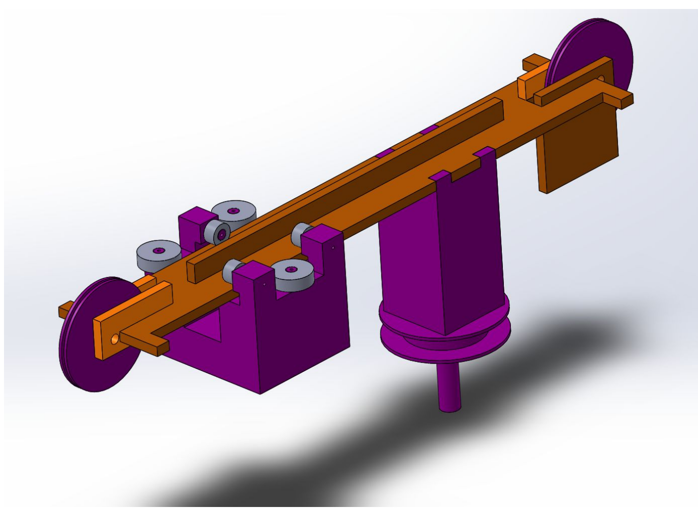

Figure #: A design considered which was found to not meet the engineering requirements

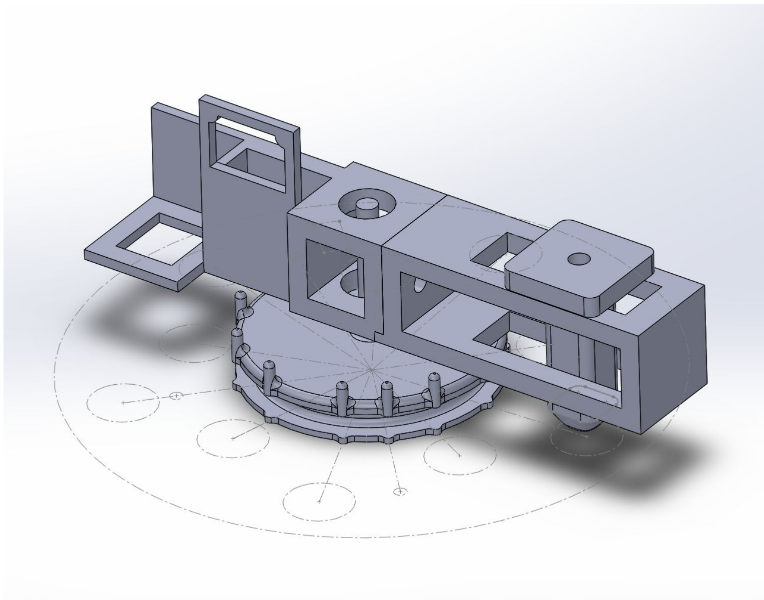

Figure #: A design considered which is under further consideration

Concept Evaluation

Concepts were evaluated using a complex decision matrix which had categories for the engineering requirements of the system. These engineering requirements were derived directly from the provided customer requirements. The designs considered were compared against each other and the engineering requirement to aid in the ranking of the design choices. The ranking of the designs considered was decided using the sum of the ranks given to the designs.

The Complex Decision Matrix uses a simple formula whereby each of 7 engineering requirements is weighted on a scale of 1 to 7.

Design	Robust		Weight	Rank	Fast		Weight	Rank
	Pros	Cons			Pros	Cons		
Rotating arm with electromagnet in servo-carriage; hall-effect sensors over permanent magnets for position	Moving parts tightly coupled together i.e. no pulleys/cables/belts prone to slipping; smallest ranges of motion; simple electromagnet housing makes lifting washers easier;	Could be prone to over-rotation	6	1	Fastest arm rotation	slow servo for electromagnet carriage traverse	1	2
Rotating arm with pulley-controlled trolley (similar to inkjet printhead); Motor/encoder-controlled rotation and position; motor mounted at base	arm rotation motor (and encoder for position) tightly coupled to arm	largest arm radius demands very precise encoder	6	3	faster magnet carriage traverse speed	greater magnet carriage traverse distance; slow arm rotation speed	1	3
Rotating arm with pulley-controlled trolley (similar to inkjet printhead); Motor/encoder-controlled rotation and position; motor attached to pulley at base of arm for rotation and position	most loose coupling on all degrees of freedom; most complex drive mechanisms	largest arm radius demands very precise encoder; arm rotation drive mechanism introduces inaccuracies in arm rotation position/encoder	6	4	faster magnet carriage traverse speed	greater magnet carriage traverse distance; even slower arm rotation speed due to arm rotation drive mechanism	1	5
Cartesian actuators similar to a 3D printer. Motor/encoder controlled x and y axes with electromagnet sled at intersection	Two axes of freedom which are programmed in very similar manners	More individual pieces which must work in concert	6	5	faster magnet carriage traverse speed		1	1
Rotating arm with electromagnet in servo-carriage; camera tracking of arm position & washer position	No sensors to break, can reinitialize at any point to get position	Programming may be more complicated to utilize computer vision properly	6	2	faster magnet carriage traverse speed	Camera detection may be a slower process to get accurate positional information	1	4

Design	Efficient (power)		Weight	Rank	Safe		Weight	Rank
	Pros	Cons			Pros	Cons		
Rotating arm with electromagnet in servo-carriage; hall-effect sensors over permanent magnets for position	Smaller electromagnet carriage traverse distance; small arm radius/less arm rotational mass		3	2	few exposed moving parts	High electromagnet power	7	1
Rotating arm with pulley-controlled trolley (similar to inkjet printhead); Motor/encoder-controlled rotation and position; motor mounted at base	Less friction at joints due to smooth pulley operation	Friction on motor since its bearings bear entire weight of arm; Large arm radius = higher rotational mass; larger electromagnet carriage traverse distance; large power demands due to electromagnet	3	4	slow arm rotation speed	Potentially high electromagnet power; potential high arm-motor power	7	2
Rotating arm with pulley-controlled trolley (similar to inkjet printhead); Motor/encoder-controlled rotation and position; motor attached to pulley at base of arm for rotation and position	Even less friction at joints due to multiple pulley mechanisms	Large arm radius = higher rotational mass; larger electromagnet carriage traverse distance; large power demands due to electromagnet	3	3	slow arm rotation speed	Potentially high electromagnet power; potential high arm-motor power; most exposed moving parts	7	3
Cartesian actuators similar to a 3D printer. Motor/encoder controlled x and y axes with electromagnet sled at intersection	Two motors will draw more, but should be faster, could use less power overall if operating quickly	Two motors will draw more current than a single motor and a servo	3	5	Predictable movement	More pinch points than other designs, electromagnet power	7	4
Rotating arm with electromagnet in servo-carriage; camera tracking of arm position & washer position	Fewer sensors, fewer power draws, can reinitialize from any point in rotation	constant camera use may draw more power	3	1	few exposed moving parts	Electromagnet power	7	1

Design	User Friendly		Weight	Rank	Final Score (lowest = best)
	Pros	Cons			
Rotating arm with electromagnet in servo-carriage; hall-effect sensors over permanent magnets for position	Low complexity position system; simple electromagnet housing makes lifting washers easier; servo-based electromagnet carriage; simple photodiode for washer sensing	Rotating arm potentially occludes at least 1 washer well from webcam, more i/o to manage	5	1	38
Rotating arm with pulley-controlled trolley (similar to inkjet printhead); Motor/encoder-controlled rotation and position; motor mounted at base	Tried-and-true encoder for position system; simple electromagnet housing makes lifting washers easier; simple photodiode for washer sensing	Rotating arm potentially occludes at least 1 washer well from webcam; less-sophisticated stepper/dc motor for carriage traversal	5	2	71
Rotating arm with pulley-controlled trolley (similar to inkjet printhead); Motor/encoder-controlled rotation and position; motor attached to pulley at base of arm for rotation and position	Tried-and-true encoder for position system; simple electromagnet housing makes lifting washers easier; simple photodiode for washer sensing	Rotating arm potentially occludes at least 1 washer well from webcam; less-sophisticated stepper/dc motor for carriage traversal; loosely coupled arm motor for rotation	5	3	96
Cartesian actuators similar to a 3D printer. Motor/encoder controlled x and y axes with electromagnet sled at intersection	Can see how other systems work and build off current designs, arm will not block washers	may be more complicated to build than rotation methods	5	4	122
Rotating arm with electromagnet in servo-carriage; camera tracking of arm position & washer position	Low complexity positioning, can reinitialize whenever	more complicated to program than other solutions	5	1	39

After completing the complex decision matrix, it seems to be that the best design for our group to pursue will be a polar system. A primary question is the use of sensors to detect position or doing all position detection using a computer vision system.

Actuator Subsystem

Engineering Requirements for Key Actuator

Customer Requirement	Engineering Requirements	Test
Holding/Lifting Force	Lift Washer from distance of 1"	Perform test where magnet, when energized with 5 V dc, lifts 5g washer directly upward from a vertical distance of 1".
	Hold washer with lateral acceleration of 0.25 m/s^2	With electromagnet in electromagnet carriage in rotating arm of design and washer suspended by magnet energized by 5 V dc, apply rotational acceleration to arm such that suspended washer experiences lateral acceleration of 0.25 m/s^2
Inexpensive	Cost of single unit should not exceed $20	Compare final expenses to $20 budget expectation
Power Efficiency	Peak Voltage Draw should not exceed 24V dc.	Attach multimeter to electromagnet as Holding/Lifting Force tests are being performed, and ensure that tests succeed whilst voltage never exceeds 24V.
Lifting Ability whilst in motion	Electromagnet should have to pause over a washer for no more than 1 second to lift it.	Test that electromagnet, while in electromagnet carriage in arm, lifts and attaches to washer when rotating arm pauses rotation for only 1 second.

Design Solutions

(Not gonna be in report, just pasting the specs in the same place)

UXCELL EMAG

- Input Voltage: 5V DC
- Peak Force :50N
- Overall Size : 25 x 20 mm / 1 x 0.8 inch(Dia. *T)
- Lead Length : 24cm/9. 5 inch
- Price : $9.29

Sukragraha

- Lifting Force: 100N
- Input Voltage: 5V DC
- Overall Size : 30 (diameter) x 22 mm / 1.18 (diameter) x 0.87 inch
- Lead Length : around 24cm / 9.5inch
- Price : $11.49

For only $2 more, can have twice the lifting force with a larger magnet that can pick up a greater variety of washers than the UXCELL

Concept Evaluation

Design	Inexpensive		Weight	Rank	Accurate		Weight	Rank
	Does the design offer maximum accuracy, precision, power efficiency, and reliability for the cost?				How closely does output strength match input voltage?			
	Pros	Cons			Pros	Cons		
SUKRAGRAHA Electric Lifting Magnet Electromagnet Solenoid Lift Holding Force WF-P30/22 5V DC 100N	Most mass-produced; available through multiple suppliers even including amazon.	Large corporation and shipping and handling overheads.	4	2	Manufactured to highest design specifications; must pass quality assurance at manufacturer.		3	1
Wrapped 12 Gauge stranded Copper Wire around 3/8"x2" Machine Screw	Assembled by hand from cheap mass-produced component parts.	Not Mass produced	4	1	Hand assembled to user specifications; must meet user needs.	Wild variations in design due to design criteria that cannot be accounted for at this scale of production.	3	3
uxcell 5V 50N Electric Lifting Magnet Electromagnet Solenoid Lift Holding	Mass-produced; available through multiple suppliers including amazon.	Large corporation and shipping and handling overheads.	4	3	Manufactured to highest design specifications; must pass quality assurance at manufacturer.		3	2

Design	Precise		Weight	Rank	Low-Power		Weight	Rank
	How tightly can output strength be fine-tuned?				How efficiently does the actuator use power?			
	Pros	Cons			Pros	Cons		
SUKRAGRAHA Electric Lifting Magnet Electromagnet Solenoid Lift Holding Force WF-P30/22 5V DC 100N	Manufactured to highest design specifications; must pass quality assurance at manufacturer.		2	1	Production grade materials; skilled/experienced engineer-designed.	Capable of lifting more than is necessary for this project.	1	1
Wrapped 12 Gauge stranded Copper Wire around 3/8"x2" Machine Screw	Hand assembled to user specifications; must meet user needs.	Wild variations in design due to design criteria that cannot be accounted for at this scale of production.	2	3	Chosen conductor originally designed for best conductive qualities.	Machine screw not best inductive core material; insulation on wire dictates tightness of coil windings.	1	3
uxcell 5V 50N Electric Lifting Magnet Electromagnet Solenoid Lift Holding	Manufactured to highest design specifications; must pass quality assurance at manufacturer.		2	2	Production grade materials; skilled/experienced engineer-designed.	Capable of lifting more than is necessary for this project.	1	2

Design	Reliability		Weight	Rank	Final Score (lowest = best)
	How repeatable are results using this actuator, and how likely is it to stop working or encounter a fault?				
	Pros	Cons			
SUKRAGRAHA Electric Lifting Magnet Electromagnet Solenoid Lift Holding Force WF-P30/22 5V DC 100N	Manufactured to highest design specifications; must pass quality assurance at manufacturer.		5	2	24
Wrapped 12 Gauge stranded Copper Wire around 3/8"x2" Machine Screw	Hand assembled to user specifications; must meet user needs.Most-robust designed due to over-specification of components that were available.	Wild variations in design due to design criteria that cannot be accounted for at this scale of production.	5	1	27
uxcell 5V 50N Electric Lifting Magnet Electromagnet Solenoid Lift Holding	Manufactured to highest design specifications; must pass quality assurance at manufacturer.		5	3	39

Sensor Subsystem

Dr. Kapadia stated that we do not need a weighted decision matrix for the sensor system.

Sensor and Actuator Demonstration

For this demonstration, a photoresistor was used as the sensor and an electromagnet as the actuator. The goal was to have the electromagnet activate only when a light was shined upon the photoresistor. As the light level changed, the resistance of the photoresistor changed with it. An increase in the light level was associated with a decrease in resistance. A 10 kΩ resistor was placed in series with the photoresistor, and its voltage measured with the Q4 analog input. As the resistance of the photoresistor decreases with the flashlight, the voltage across the photoresistor also decreases, causing the voltage of the 10 kΩ resistor to increase. By experimenting with the measured values, it was decided that when the voltage of the 10 kΩ resistor rose to a minimum of .7 V, this would indicate the light was being shined on the resistor and the electromagnet should be activated. From Figure 1 and Figure 2 below, the voltage drop across the 10 kΩ resistor can be seen to increase with the flashlight, causing the output signal to be sent to the electromagnet. This system will continue to be refined for the final project, as there is currently no way to control the strength of the magnet. This would be helpful to implement, as currently the magnet is somewhat weak and could use some adjustment to enable it to lift a washer from a further distance away.

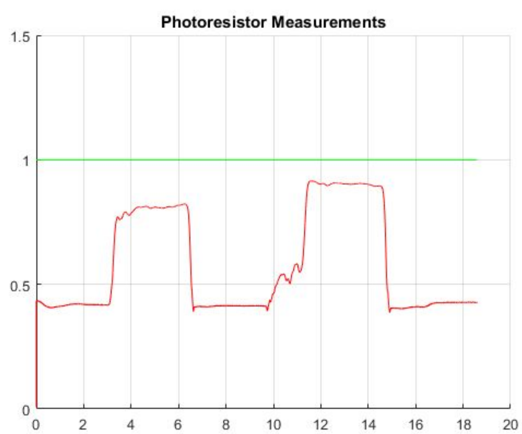

Figure 1: Graph of Voltage Measurement

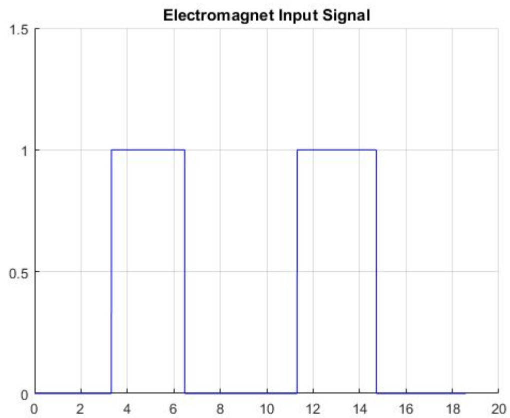

Figure 2: Graph of Signal to Electromagnet

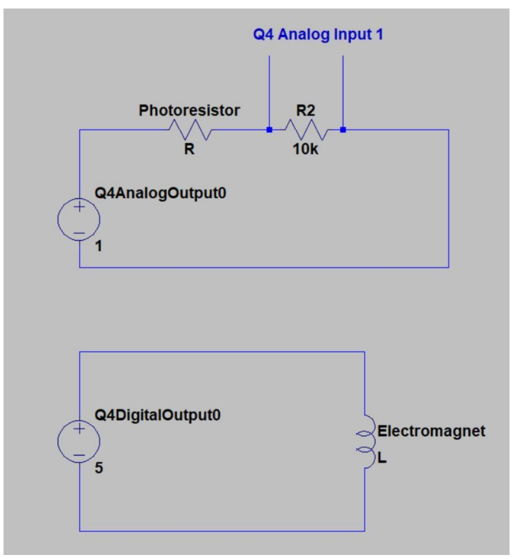

Figure 3: Schematic of Sensor/Actuator Circuit

Financial Analysis

Big -TEK Engineering
Estimated Financial Scenario

Start-up Costs

Personnel	___5___ Engineers @ $85K/yr + President @ $75K/yr + Admin. Asst. @ $25K/yr = $ _525,000___
Fringe Benefit (FB)	A fringe benefit is a form of pay for the performance of services. For example, you provide an employee with a fringe benefit when you allow the employee to use a business vehicle to commute to and from work. Assume Fringe Benefit Package @ 36% (incl. employee's SS tax, vacation, holidays, medical, retirement (401K), dental, life insurance, relocation, unemployment insurances, etc): (____5____ x $85,000 + $75,000 + $25,000) x 0.36 = $ __189,000___ *Note: Federal Insurance Contributions Act (FICA) tax (Social Security and Medicare) is imposed by the federal government on both employees and employers. The entire FICA percentage of 15.3%* ● *Employee's pay 6.2% for SS and 1.45% for the Medicare (this is not included in your cost)* ● *The employer is liable for 6.2% Social Security and 1.45% Medicare taxes=7.65%*
Building	Initially rent a suite of offices with 2 engineers/office (12' x 14'), an office/conference room for President (12' x 20'), and a reception/office area of 16' x 20'. (_3_ cubicles) x (12' x 14'/cubicle) + President office of (12'x 20') + Reception/office area of (16' x 20') = _1064_ sq ft Use nominal figure for office space in industrial park sectors of` Clemson area, $9.50/sq ft/mo. Then the lease rate for office space will be $20.00/sq ft/mo x ____1064____ sq ft = $___21,280____ /mo. = $__255,360__ /yr.
Furniture	Rental of a desk, chair, credenza set will run about $60/mo. Need ___7____ sets for a total monthly expenditure of $____420____/mo = $____5,040____/yr The remaining equipment, furniture and software expenses are estimated to be about __7___ computers @ $1500/computer $__10,500__ __7___ sets of general software @ $1000/set $___7,000___ Specialized software $4,000 Copier, printer $690 Table and chairs for conference room $900 __7___ telephones @ $35/ea $___245___ Total $__28,375___
Phone and Internet	According to AT&T, the cost of a combined voice/data line, is $550.00/mo for operation. For ____7_____ telephones the total cost will be $__10,800___ /year.

	Assume that long distance calls add another 40% to this to get a total estimated annual phone cost of $___4,320___
Travel	Another cost item which will be important is travel. There will have to be continual contact with potential clients, attendance at selected technical conferences and workshops, and visits to plants or other locations where potential clients might be. Assume (modestly) that this will that the cost per local trip is $______250_ and the cost per out-of-state trip is $_____3250_ there will be 2 of each trip each month $__7000_/mo for the first year, or an annual total of $__84000_.
Interest	Capital (i.e. money) is needed to fund these initial purchases as well as to underwrite operating expenses until a revenue stream is established by selling engineering services to customers. Assume that through personal contacts a credit line of $810,000 has been established. This is to be repaid over the period of a year with 11 equal payments starting 1 month after the loan date. The negotiated interest rate is 5% per year. The monthly payment M is calculated from = $_____75660_____ Where P is the principal amount ($800,000), I is the interest rate (5%), and q is the number of payments to be made (11). From this, Debt Service = Total interest paid in year = 11 x M - P = $___22258_______.

Cost Estimate

Salaries	$__525000__
FB @ 36%	$__189000__
Building	$__255360__
Furniture	$____5040__
Debt service	$___22258__
Travel	$___84000__
Internet and Phone Service	$___15120__
Total Costs	$ _1119113__

Overhead Calculation

Now we will estimate the Overhead (Indirect Technical Expense) we must charge to recover our costs. This cannot be too large, or else we will price ourselves out of business. On the other hand, we must be realistic, or else we will go broke, and therefore out of business.

Assume that the first year, the ___5__ engineers will be at least 75% "sold", i.e., 75% of their total time can be charged to customers. Then we can bill

___5_ engineers @ 75% sold (salaries billable to clients)	$__318750__
FB @ 36% (FB billable to clients)	$__114750__
Total Billable to Clients	$__433500__

The remaining salary dollars and FB's must be charged to overhead.
Total Expenses = Total Costs - Total Billable to Clients = $__685613______ (Overhead Number)

This implies an Overhead rate of
OH rate = ($__685613__/$__433500____) x 100% = __158.16___%
= (Overhead Number / Total Billable to Clients) x 100%

This implies that every labor dollar (at the "loaded" rate, i.e. with FB's) must be increased by a factor of ___2.61____ (1+ (OH rate/100%) + (5% profit/100%)) in order to recover the costs of doing business and make a profit (assuming a 5% profit). This is the figure that you will use when estimating the cost of a contract to a customer in a proposal. An overhead rate of 150% means that for each $1.00 of direct labor budgeted for a project; $1.50 needs to be budgeted for overhead costs.

Using the Overhead Number

You estimate that a project will take 1 week (40 hours) of your time, i.e. what does it cost for one week of an engineer's time. How much do you bill your client for this time?

Bill to Client

$$= \left[\frac{\text{1 week work}}{\text{52 weeks per year}} \bullet \left(\frac{\text{salary} = \$55\text{K}}{\text{year}} + \frac{\text{FB} = 0.36\square\$55\text{K}}{\text{year}} \right) \bullet \left(1 + \frac{\text{overhead rate}}{100\%} + \frac{\text{profit} = 5\%}{100\%} \right) \right]$$

= $ _________5802__