

AC 2007-655: SOFTWARE FOR MATERIALS EVALUATION

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Software for Materials Evaluation

Abstract

Multi-disciplinary team projects are an important element in the ABET accreditation of engineering programs. The basic manufacturing processes course in the Industrial Engineering Program at West Virginia University is one of the courses used to meet the multi-disciplinary team requirement with teams of industrial engineering, mechanical engineering, and other engineering disciplines working on a design project with strength and deflection requirements considering different materials and shapes. A software program was developed to assist the students to determine the costs involved in selecting a material and shape to meet specific load and deflection requirements. This software utilized Microsoft Excel® and Visual Basic® Macro's for performing the calculations to determine the product costs.

Introduction

The basic manufacturing processes course, taken in the junior year, was selected as one of two courses with multi-disciplinary student team projects to meet this element of the ABET accreditation. The course is required in the Industrial Engineering program, the Mechanical Engineering program, and the Aerospace Engineering and Mechanical Engineering dual major program, and over 50 percent of the students are non-industrial engineers. The lecture course is only two credits, so only a few class periods can be devoted to the project. The teams require that at least two different majors are represented on each team when formed, and the team size typically varies from two to five students.

The project starts with a design problem, such as the support beams for a cantilever deck, the rungs for a ladder or a footbridge across a small stream. The problem has a load requirement, either as a single load (center or end load) or as a uniform load, a deflection requirement, and weight requirement to avoid penalty costs. The students are to evaluate different structure shapes, such as a square, rectangle, circle, hollow box, hollow circle, I-beam, and etc. to minimize the overall cost (material cost + processing cost + penalty cost). In addition, the students evaluate 10 different materials provided in the program and they must select and insert an additional material for evaluation. The program determines a design parameter based upon the student inputs and calculates the cross-sectional area, volume, material cost, penalty cost, processing cost, and total cost.

The calculations are demonstrated manually in the class with notes to show the students how the analysis is performed for two materials on a simple square shape and the process is illustrated in

the course textbook¹. The purpose is to illustrate that when two different materials are involved with two or more constraints, the binding constraint can change because different materials have different mechanical and material properties. The two materials used to illustrate this are steel and aluminum, and steel structures tend to be constrained by the load (yield strength) whereas the aluminum structures tend to be constrained by the deflection (elastic modulus) requirement.

The course prerequisites are that the students have had courses on the strength of materials and on basic material properties. The strength of materials is necessary as the students must know how the moments of inertia and centroids are calculated. The material properties course is required so the students can find the required material properties of melting point, density, modulus of elasticity, yield strength and cost. The students have often had different instructors and thus are familiar with different units i.e. the US units or the metric units.

Initially, when only 3 or 4 shapes were required, the students developed their own spreadsheet or other software program. At that time, no penalty costs or processing costs were included. Although the students had exposure to Excel, most of their projects had serious programming errors and the results obtained by their programs were usually incorrect. Students also had difficulty in developing expressions for the moments of inertia and centroids, especially for complex shapes such as I-Beams, hollow boxes or hollow circle structures. It was expected that the Mechanical Engineering (ME) students would be good at determining the moments of inertia and centroids and that the Industrial Engineering (IE) students would be good at finding cost information on materials, and both students would be able to do the basic programming required, but this did not occur. Without correct formulae, data, and programming, the results were not useful in enlightening the students about the impact of mechanical properties, material properties and design requirements upon the total costs of producing parts. Thus it was decided to develop a user-friendly software^{2,3} to perform the majority of the calculations so the students would be able to obtain realistic results and observe the impact of various parameters upon total costs.

One requirement of the software was to permit the students to add additional materials and shapes to the program for evaluation. The addition of materials to the database was relatively easy, but the addition of additional shapes was more difficult as numerous potential shapes could be considered by the user. Therefore, a generic model was required to accommodate all the shapes that students may consider. This feature was incorporated into the model by allowing the user to input all the equations required for the shape in terms of one variable.

The program was designed in Microsoft Excel® since it was readily available to all the students and is used in most companies. It has seven screens that include Welcome, Input, Material Database, Calculations, Results table, Cost graph, and Weight graph. The calculation sheet is not visible to the user but can be explored by un-hiding the sheet using the Excel® toolbar. By default, only one screen is visible at a time and the program automatically hides/un-hides the sheets based on the user requirements. The calculations are performed using inbuilt Excel® functions through Visual Basic® Macros. For simplicity, the Macros are built into single click buttons and most of the screens are protected so that the user does not overwrite the formulae written in the fields. An instruction manual was required to make sure that the students understand the process of equation input and be able to use the software effectively. The flow diagram for the materials evaluation software program is given in Figure 1.

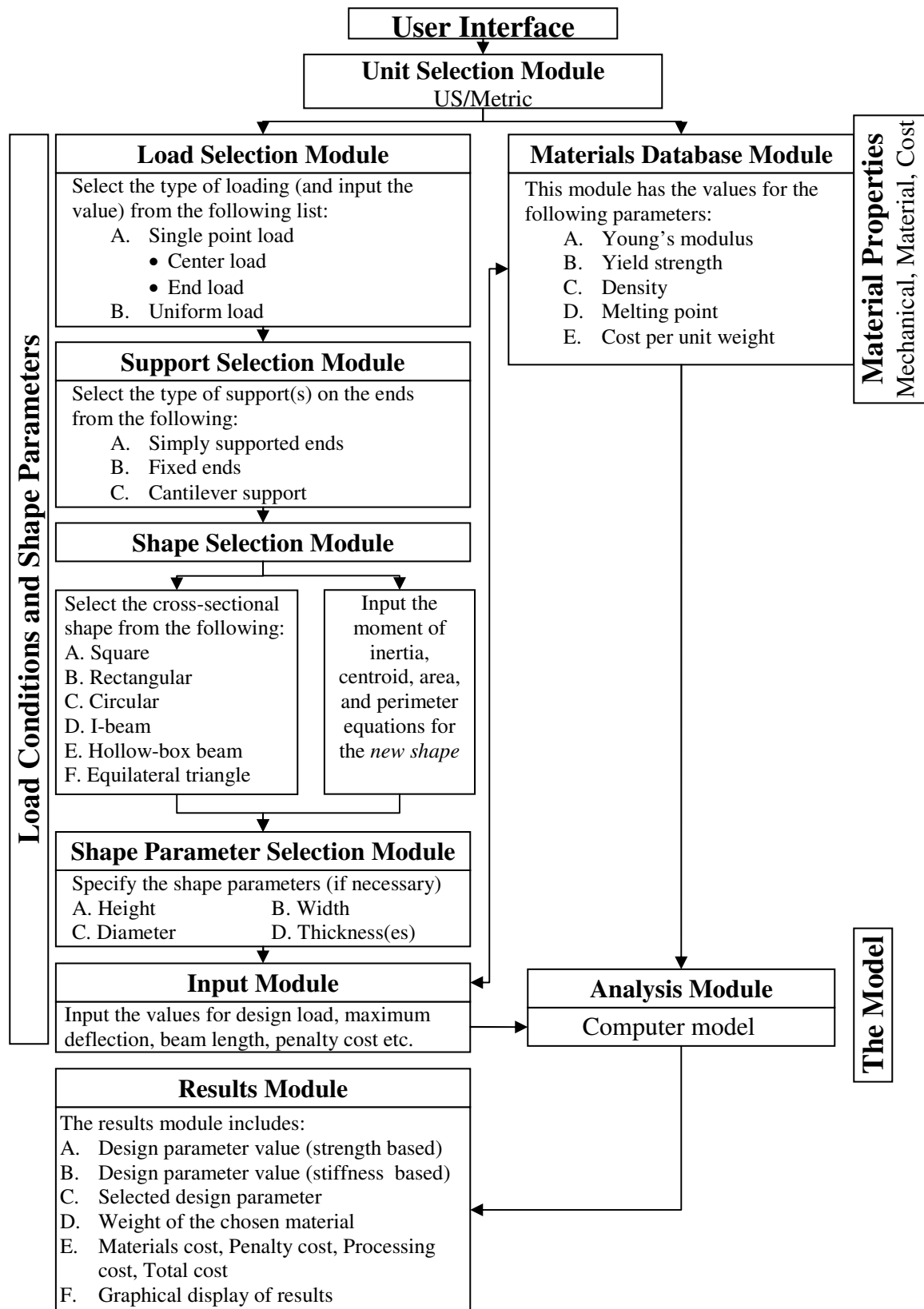


Figure 1: Flow Chart of Material Evaluation Program

Program Procedure

The steps to work with the software are as follows.

1. The software starts with the selection of units (metric or US) since some of the students may be comfortable with the US units while others prefer metric units. The user can go to the material database section after the first step if needed.
2. The next step defines the load profile (single point center load, single point end load, or uniform load) followed by the structure support (simply supported, fixed ends, or cantilever support).
3. This step is the major improvement over the previous version of this software. In the initial version, the user had to choose one of the shapes already defined in the software; but this version allows the user to analyze new shapes that are not built into the system. This feature is incorporated by providing an interface where the user can input the equations for the new shape in terms of a single variable. An example will be provided later on how to input the equations for a shape not defined in the system.
4. Next, the user is required to input the parameters required to get the solution. This module is based on the Shape Selection Module. As an example, for square shapes, there is only one variable that is unknown; therefore, no parameters are required to find the solution. On the other hand, for rectangular shapes, the length and width are unknown variables; therefore at least one of them or their ratio is needed to define the equations in terms of a single variable. The program displays the list of required parameters based on the cross-sectional shape selected in the last step.
5. The Input Module defines the operating characteristics of the problems i.e. design load, maximum deflection etc.
6. Finally, the user is required to define the processing characteristics of the material (heat treatment, cold working, and hollow internal section).
7. The program analyzes the materials sequentially (currently there are 12 materials in the database and 88 more can be added by the user) and finds the design parameter that satisfies both the constraints (strength and deflection). It displays the results in terms of table and graphs (cost and weight).

Software Requirements to Use Program

The program requires Microsoft Excel®. Before the user starts the programs, the macro security level should be reduced to medium or low; otherwise the software may not perform well. This can be done by opening Excel® program and going to Tools-Macro-Security or Tools-Options-Security-Macro Security and setting the level to medium or low. The program size is approximately 235 KB but it is recommended that 5 MB or more space be available on the hard drive to execute the program.

Example Problem

An example calculation will be performed in this section. The input values for the problem are given in Table 1. The beam has single point center load and is simply supported. The design load is estimated as 400 lbs and the cross-sectional shape is a square. There is no heat treatment or

cold working performed on the material under consideration and no hollow sections are present in the design.

Table 1: Example Problem Input Parameters

Value	Parameter	Units
0.2	Maximum deflection	inches
16	Beam length	inches
0.6000	Maximum weight without penalty	lbs
\$0.50	Penalty per pound over maximum limit	\$

After all the input sections are complete, the user clicks on “Analyze the Materials” button and the results are displayed in tabular format (Table 2). It may be noted that the database had 12 materials and there were two user defined material which have been shown in the table as well. The results can be displayed in terms of cost (Figure 2) and weight (Figure 3) graphs by using the buttons in the results table screen.

Table 2: Results for the Example Problem

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
3	Min	Cost Graph	Weight Graph				Go to Input Sheet			0.26079	0.89	0.59	0.00	0.85	2.24
4	Material	Young's Modulus (E)	Yield Strength (σ)	Density (ρ)	Cost	Melting Point	dm (deflection constraint)	d (strength constraint)	md (Design parameter)	Area	Material Cost	Weight	Penalty Cost	Processing Cost	Total Cost
5		(Mpsi)	(Kpsi)	(lb/in ³)	(\$/lb)	(K)	(in)	(in)	(in)	(in ²)	(\$)	(lb)	(\$)	(\$)	(\$)
22	Magnesium AS91C-T6	6.50	21.00	0.066	3.00	923	0.7491	0.7703	0.7703	0.59343	1.88	0.6267	0.0133	0.99	2.88
23	Magnesium AK60A-T5	6.50	41.00	0.066	3.30	923	0.7491	0.6164	0.7491	0.56114	1.96	0.5926	0.0000	0.96	2.92
24	Aluminum 2024-T861	10.50	66.00	0.100	2.30	933	0.6643	0.5259	0.6643	0.44132	1.62	0.7061	0.0531	0.86	2.54
25	Aluminum 3003-H18	10.20	29.00	0.099	2.30	933	0.6691	0.6918	0.6918	0.47854	1.74	0.7580	0.0790	0.90	2.72
26	Aluminum 7175-T66	10.40	76.00	0.101	2.50	933	0.6659	0.5017	0.6659	0.44342	1.79	0.7166	0.0583	0.86	2.71
27	Titanium Ti-6Al-6V-2Sn	16.00	140.00	0.165	9.00	1933	0.5976	0.4093	0.5976	0.35707	8.48	0.9427	0.1713	1.20	9.85
28	Titanium Ti-13V-11Cr-3Al	16.00	160.00	0.175	9.38	1933	0.5976	0.3915	0.5976	0.35707	9.37	0.9998	0.1999	1.20	10.77
29	1015 Steel	30.00	50.00	0.285	0.60	1700	0.5107	0.5769	0.5769	0.33281	0.91	1.5176	0.4588	1.07	2.44
30	4140 Q&T Steel	30.00	252.00	0.285	0.90	1700	0.5107	0.3365	0.5107	0.26079	1.07	1.1892	0.2946	0.95	2.31
31	304 Stainless Steel	28.00	85.00	0.287	3.00	1700	0.5200	0.4834	0.5200	0.27043	3.73	1.2418	0.3209	0.96	5.01
32	Gray Cast Iron	15.00	20.00	0.258	0.55	1425	0.6078	0.7830	0.7830	0.61305	1.39	2.5307	0.9653	1.31	3.66
33	Ductile Cast Iron	30.00	50.00	0.258	0.65	1425	0.5107	0.5769	0.5769	0.33281	0.89	1.3739	0.3869	0.96	2.24
34	Steel Low C	30.00	50.00	0.280	0.80	1800	0.5107	0.5769	0.5769	0.33281	1.19	1.4910	0.4455	1.11	2.75
35	Al	10.00	35.00	0.100	2.20	900	0.6724	0.6497	0.6724	0.45213	1.59	0.7234	0.0617	0.85	2.50

Software Evaluation Results

To evaluate the benefits from the proposed software program, students were asked to complete an anonymous survey with questions such as whether or not the software was better than their own program to complete the project and understand the concepts, and whether or not it should be given to the students in the future semesters. The results from this evaluation were promising with a score of 4.47 and 4.24 respectively (with “1” as worst and “5” as best) for these questions and the same was reflected in the quality of reports submitted by the students. It was noted that even the weak students in the class had minimal mistakes in the solution which supports the underlying concept behind the development of this software.

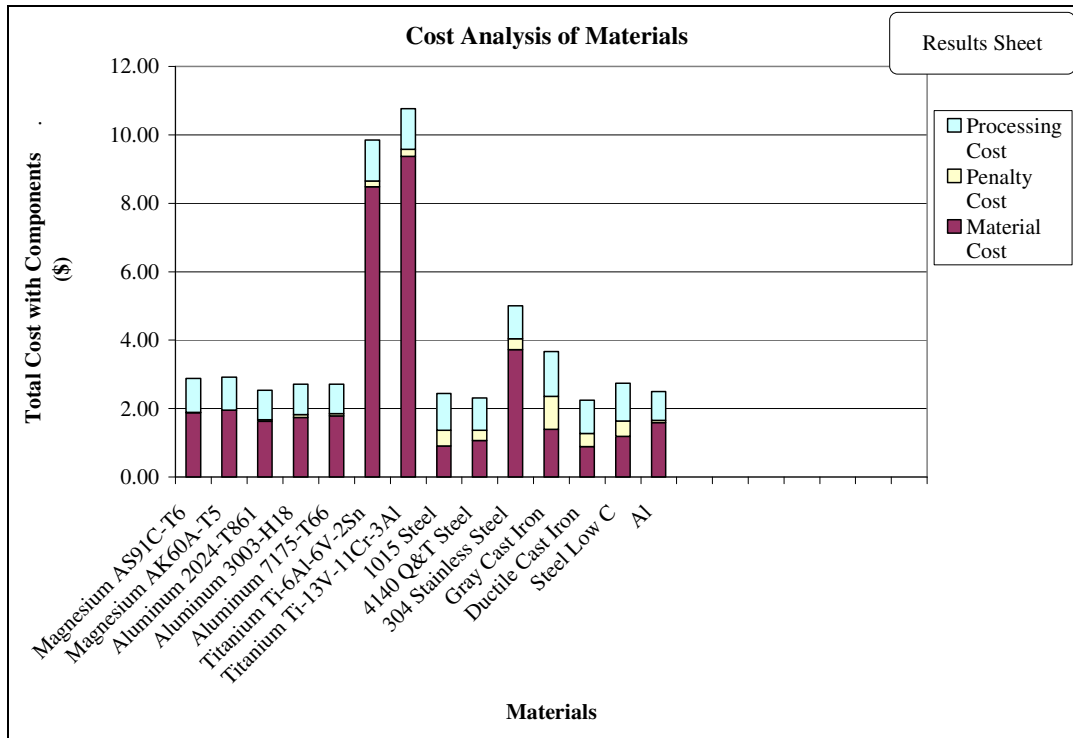


Figure 2: Material Cost Components

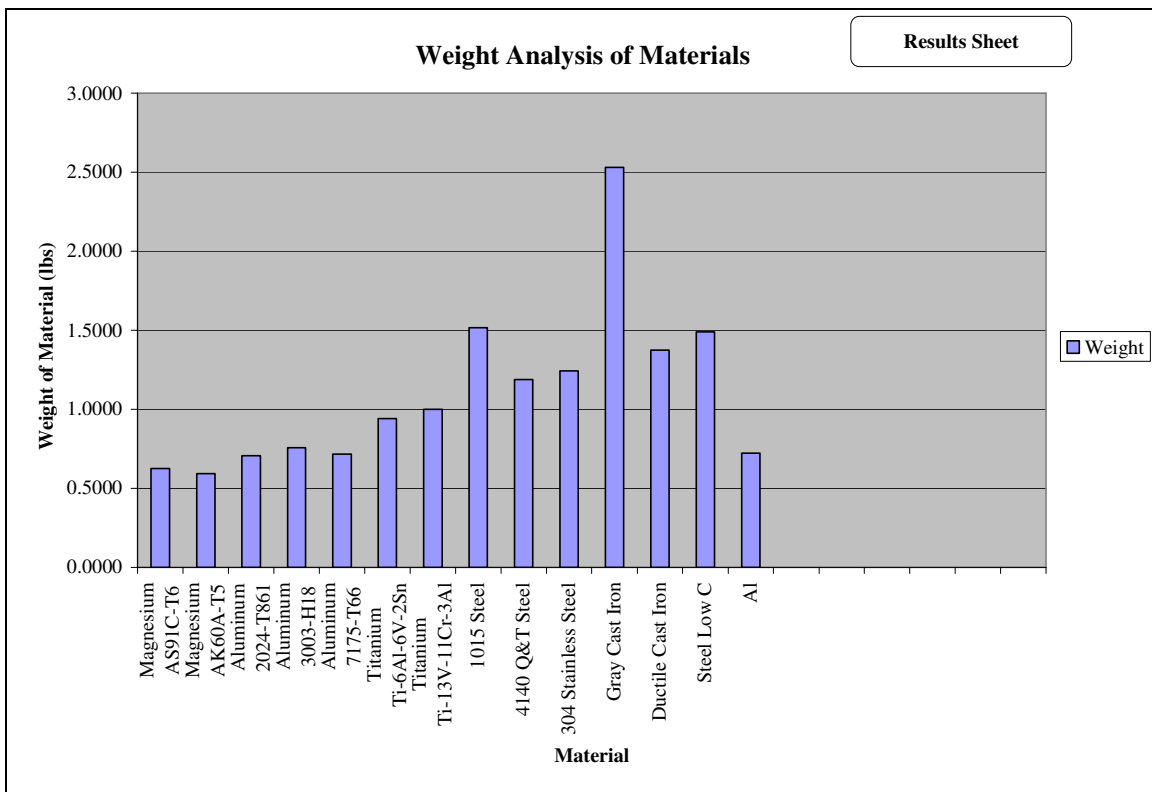


Figure 3: Weight of Materials

Problems and limitations

One problem with the software is that the students do not take time to seriously evaluate the results. For example, to reduce costs it is desired to have a high moment of inertia for a given cross-section, but student do not examine their results. They will use a flat rectangular section (small height and large width) rather than a high modulus section (large height and small width). Students need to sketch the results to make certain they have used the correct inputs, but often do not and come up with silly looking structure, such as I-beams with flange widths smaller than the flange thickness. They conclude that the results are correct since the program made the calculations, but do not realize that “garbage in” results in “garbage out”.

A second problem with the software is that it uses the “Goal Seek” routine in Microsoft Excel® and requires a starting parameter. This is required for matching the calculated yield strength and deflection values to the user defined values and this starting parameter may need to be revised for different shapes. This parameter must be changed by the user to a different level in the input sheet if the program yields absurd values for the design parameter (e.g. very high/low value or negative). Usually, a value between 0.1 and 1.0 (e.g. 0.1, 0.5, or 0.9) yields the correct results and it can be changed easily by changing this value in the input sheet, but when students delay the project to the last minute, this can cause them to panic.

Another problem is that the project teams are formed at the beginning of the semester with 3-5 students per team and the teams must have students from at least two different majors. As the semester proceeds, some students drop the course and thus some of the teams no longer are “interdisciplinary” as a result of the reduction in the team membership.

Educational Aspects

The initial hypothesis was that students would benefit with the use of the software by focusing on the solution to the problem rather than focusing on the development and testing of the software. The students have 8-10 weeks, but they do not schedule their time wisely. Prior to the development of the software, few of the teams would have “correct” solutions because of programming errors. Although a problem example was presented to the students which was solved via paper, students would not verify their programs for the additional shapes. After the software development, students would obtain correct solutions to most of the shapes desired. The software also permitted consideration of different types of loading (center, end, or uniform loading) and different types of supports (simple supported, fixed or cantilever). It was observed that all the students understood the underlying concepts and obtained better solutions with minimal mistakes in the projects. In fact, the weak students in the class could also do much better as similar students in the previous semesters.

The software would be available at little or no cost (\$5 -\$20) versus the commercial packages at much higher cost (\$500-1,000). This software is for an introduction to the integration of costs, materials and mechanical properties and takes only one week to implement whereas the commercial software will take several weeks to implement. Although the commercial software offers many additional properties and design capabilities, it does not give a simple basic cost

comparison of the alternative materials for the selected shape. The commercial software is designed for more sophisticated design considerations and the selection of materials and would be utilized in design courses rather than the emphasis upon costs.

Conclusions

The program was used in the undergraduate and graduate classes in the IMSE Department at the University. It was well received by all the students and was evident by the review form given to them. It may be noted that this program was first developed in the Spring 2005 semester; and addition of a new shape was the major concern among all the students. Most of the students were not able to modify the program and add new shape, which was one of the requirements in their project. The proposed version of the software enabled the students add custom new shapes quickly and thus giving them more time to do the analysis and understand the concepts better. All the students recommended that this software should be given to the future students in these classes.

Bibliographic Information

1. Creese, Robert C., Introduction to Manufacturing Processes and Materials, 1999, Marcel Dekker, Inc, pp 97-115.
2. Creese, Robert C and Gupta, Deepak, "Economic Evaluation of Structures of Different Shapes and Materials with Processing Considerations", Proceedings of the 2005 American Society for Engineering Education Annual Conference & Exposition, 2005, American Society for Engineering Education.
3. Creese, Robert C and Gupta, Deepak, and Zhi, Yang, "Team-based Design Using Custom Designed Software", Looking Forward: Innovations in Manufacturing Engineering Education, CIMEC(CIRP) 2005, 3rd SME Intl, Conf. on Manufacturing Education, Copyright 2005 Society of Manufacturing Engineers, ISBN 0-87263-824-3, pp 320-327.

Appendix

Instruction manual

0. Password for Model is FARFAR
1. Click on the “Click to Start The Program” part of the Welcome Screen
2. Select the unit (US or metric) to be used.

1	Go Back to Welcome Screen		Analyze the
2	Unit Selection		
3	Please select the measuring unit to be used for the analysis:		
4			<div style="border: 1px solid black; padding: 2px;"> Please select one ▼ Please select one US units Metric units </div>
5			

Figure 4: Unit Selection in the Program

3. Input the values for all four design parameters (Maximum deflection, beam length, maximum weight without penalty and penalty per unit weight over the maximum weight limit).

6	Input Module			
7	Please input the values for following parameters:			
8				
9				
10				

Value	Parameter	Units
3	Maximum deflection	inches
1200	Beam length	inches
200000.0000	Maximum weight without penalty	lbs
\$0.10	Penalty per pound over maximum limit	\$

Figure 5: Input Module of the Program

4. Review the material database for different properties of materials. The user can enter the information for new materials and the model is able to accommodate upto total of 100 materials in the database for the analysis. Please note that this database can be accessed directly by the user before starting the procedure. The original database has 12 materials which cannot be edited at this time (it may be edited but will be explained in the later section).

12	Material Database		
13	Please click on this button if you would like to review or add materials to the database for analysis:		
14	(note that clicking on the "Add Materials" will erase all the data other than standard materials already in the database.)		

To start fresh → **Add Materials**

To review (edit) → **Review Materials**

Figure 6: Material Database Options

It may be noted that the default database is automatically changed from the US to metric units and vice-versa. In case the user has the new values in one unit and wants the analysis in other unit, the conversion can be done by clicking one of the buttons “Metric to US” and “US to Metric”.

2					Back to Input Sheet				
3	S.No.	Material	Young's Modulus (E)	Yield Strength (σ)	Density (ρ)	Cost	Melting Point	Metric to US	US to Metric
5			(Mpsi)	(kpsi)	(lb/in ³)	(\$/lb)	(K)		
6	1	Magnesium AS910, T6	6.50	21.00	0.07	3.00	923		

Figure 7: Unit Conversion Feature in the Material Database

5. Select the load profile. The load profiles included in the model are as follows:

- A. Single point load
 - Center load
 - End load
- B. Uniform load

18	Load Selection Module		
19	Please select the type of load from the drop-down list:		
20			Single point center load
21			
22			
23			Single point end load
			Uniform load

Figure 8: Load Selection Module

6. Select the type of support acting on the structure and the design load. The types of supports considered in the model are as follows:

- A. Simply supported ends
- B. Fixed ends
- C. Cantilever support

28	Support Selection Module		
29	Please select the support type from the following drop-down list:		
30			Simply supported ends
31			
32			Fixed ends
33			
			Cantilever support

Figure 9: Support Selection Module

34														
35	Please input the value for the following design parameters:	<table border="1"> <thead> <tr> <th>Value</th> <th>Parameter</th> <th>Units</th> </tr> </thead> <tbody> <tr> <td>100.0000</td> <td>Design load</td> <td>lb</td> </tr> <tr> <td></td> <td></td> <td>lb</td> </tr> <tr> <td></td> <td></td> <td>lb</td> </tr> </tbody> </table>	Value	Parameter	Units	100.0000	Design load	lb			lb			lb
Value	Parameter	Units												
100.0000	Design load	lb												
		lb												
		lb												
36														
37														

Figure 10: Design Load Input

7. Select the cross-sectional shape from the ones included in the model:

- A. Square
- B. Rectangular
- C. Circular

- D. I-beam
- E. Hollow-box beam
- F. Equilateral triangle
- G. NEW

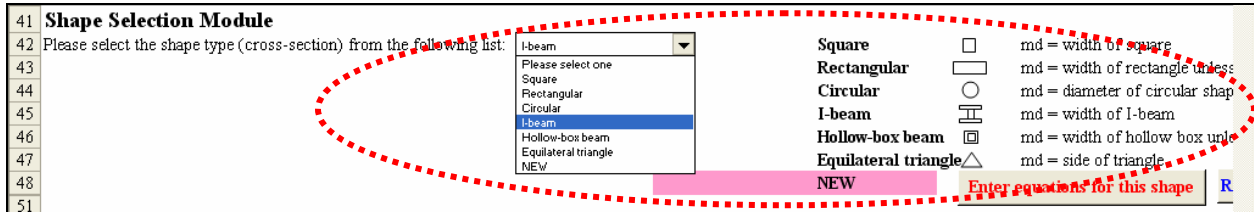


Figure 11: Shape Selection Module

The steps to perform for adding a new shape is as follows. Let us say, the user needs to add “xyz” shape to the current model. The user can change the name “NEW” (as shown in the Figure 12) to xyz (as shown in Figure 13) or leave it as it is.

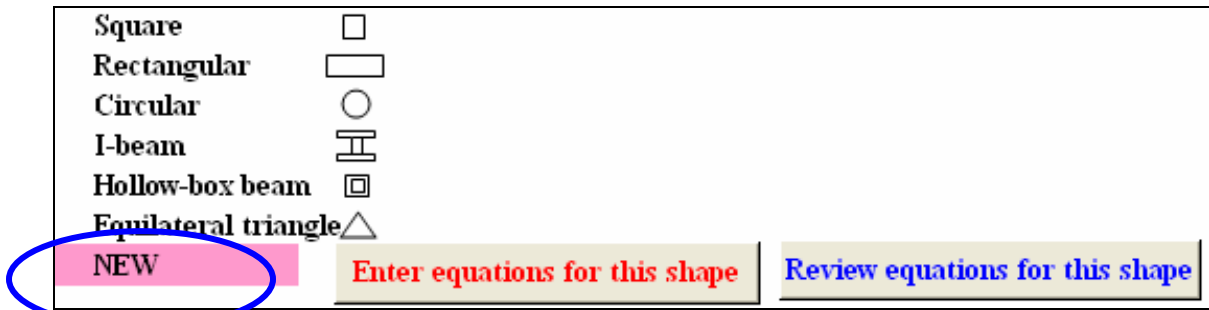


Figure 12: Original Name for NEW Shape

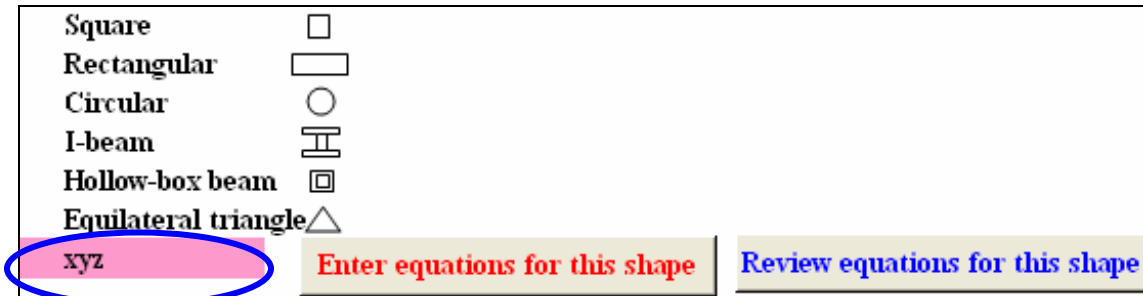


Figure 13: “xyz” is Modified Name for New Shape

Currently, the default equations for this new shape are the ones for square. They can be changed to the appropriate equation for the new shape of interest. After the user clicks “**Review equation for this shape**” button, the following screen (Figure 14) is displayed:

	Moment of inertia	Centroid		
Shape	I	C		Enter e var
xyz	8604.297109	8.962809492	use variable name: dm	Go Back to I
xyz	5756.398024	use variable name: d		
	Shape	area	perimeter	
	xyz	321.327816	71.70247594	use variable name: md

Figure 14: Review Equation Screen

The cells in color have equations for the moment of inertia, centroid, area and perimeter. For example, the highlighted cell with the ellipse has an equation for moment of inertia for a square cross-section. The equation in the cell D24 (Figure 15) is written as “=dm^4/12”. Note that the variable name in this cell is “dm” as pointed at the end of the row. Similarly, the equation for centroid is “=dm/2”, the moment of inertia in second row is “=d^4/12”, area in last row as “=md^2” and finally the perimeter in the last highlighted cell in last row is “=4*md”. In case the user wants to change the equation, it can be done here in the respective cells.

	D	E	F	G
16	Moment of inertia	Centroid	use variable name: dm	use variable name: dm
17	I	C		
24	=dm^4/12	=dm/2	use variable name: dm	
57	=d^4/12	use variable name: d		N
74	Shape	area	perimeter	
81	name: d	=md^2	=4*md	use variable name: md
99				
100	variable name: md	use variable name: md		
101				
102				

Figure 15: Equation in the Cells

Similarly, if the user wants to start fresh i.e. all these cells will be empty to prevent confusion, it can be done by clicking the “Enter equation for this shape” button in the input sheet. It will take the user to the same sheet in Figure 15 but with no equations in it (Figure 16). Any equation with any power or type can be written in the cells. The only constraint for the equations is that they should be in terms of a single variable; and finally the variables should be named as pointed out in respective rows (“dm” for first row, “d” for second row, and “md” for the last row).

	Moment of inertia	Centroid		
Shape	I	C		Enter e var
xyz			use variable name: dm	Go Back to I
xyz		use variable name: d		
	Shape	area	perimeter	
	xyz			use variable name: md

Figure 16: Screen to Enter Formulae in the Cells

As an example, if the shape is a rectangle which has the equation for moment of inertia as $bh^3/12$ and the height to width ratio is (assumed or given) 1.5 (i.e. $h/b = 1.5$ or $h = 1.5*b$), the equation for moment of inertia is given as:

$$\begin{aligned} I &= bh^3/12 \\ &= b*(1.5*b)^3/12 \\ &= 1.5^3*b^4/12 \end{aligned}$$

Therefore, the user can write the first equation in column D (Figure 17) as “ $=1.5^3*dm^4/12$ ”. Note that the term “b” (as shown in the equation derived for moment of inertia) has been replaced with “dm” since the first cell should have the variable as “dm” (as indicated in this row and column F).

D	E	F	G
Moment of inertia	Centroid	use variable name: dm	use variable name: dm
<i>I</i>	<i>C</i>		
$=1.5^3*dm^4/12$	$=0.75*dm$	use variable name: dm	
$=1.5^3*d^4/12$	use variable name: d		Note:
<i>Shape</i>	<i>area</i>	<i>perimeter</i>	
name: d	$=1.5*md^2$	$=5*md$	use variable name: md
variable name: md	use variable name: md		

Figure 17: Screen with New Formulae in the Cells

The user should be careful while entering the equations to make sure that right equations are entered in appropriate places. Some of the common mistakes may be as follows:

1. The user forgot to write “=” sign in front of the equations.
2. Use of generic symbols such as “b”, “l” etc. rather than ones required in the equations i.e. “dm”, “d” or “md”.
3. The user forgot to input the equations in the last row.
4. Once the user is done with this input and hits the “enter” key, the cell value is “0” or “#NAME?”. This results from incorrect input of the variable symbols such as “dn” in place of “dm” or “s” in place of “d” etc.
5. The user refers back to cell in previous column for moment of inertia

Once entering/modifying these equations is completed, click the “Go Back to Input Sheet” button to get back to the input sheet to continue with the analysis.

8. The user will be asked to input values for required parameters (Figure 18) based on the shape selected in Step 7. The required parameters may be one or more from the following list:
 - A. None
 - B. Height
 - C. Width

- D. Height/width ratio
- E. Diameter
- F. Thickness(es)

52	Shape Parameter Input Module			
53	Please input the values for the following shape parameter	Parameter	Value	Units
54	(if any)	Total beam height/flange width ratio	1	N/A
55		I-thickness	1	inches
56		Flange thickness	10	inches

Figure 18: Shape Parameter Input Module

- 9. Input the information on the material processing such as required heat treatment etc. (Figure 19).

Is it required to heat treat the material?

Do you require the material to be cold worked?

Is it required to have hollow internal section in the shape?

Figure 19: Material Processing Questions

- 10. Click the “Analyze the Materials” button on top of the sheet (Figure 20).

	A	B	C	D	E	F	G	H
1	Go Back to Welcome Screen						Analyze the Materials	

Figure 20: Analyzing the Materials

- 11. Finally, the model will display the results in tabular format and options to see the graphical format (Figure 21) with the best material highlighted with respect to each criterion (Material cost, weight, penalty cost and total cost of the material selected).

3	Min	Cost Graph	Weight Graph	Go to Input Sheet					5.55647	1,118.18	1,720.28	22.03	165.90	1,306.12	
4	Material	Young's Modulus (E)	Yield Strength (σ)	Density (ρ)	Cost	Melting Point	dm (deflection constraint)	d (strength constraint)	md (Design parameter)	Area	Material Cost	Weight	Penalty Cost	Processing Cost	Total Cost
5		(Mpsi)	(kpsi)	(lb/in ³)	(\$/lb)	(K)	(in)	(in)	(in)	(in ²)	(\$)	(lb)	(\$)	(\$)	(\$)
22	Magnesium AS91C-T6	6.50	21.00	0.066	3.00	923	2.1682	1.0024	2.1682	25.5382	6066.36	2022.1204	52.2120	265.47	6384.04
23	Magnesium AK60A-T5	6.50	41.00	0.066	3.30	923	2.1682	1.0011	2.1682	25.5382	6673.00	2022.1204	52.2120	265.47	6990.68
24	Aluminum 2024-T861	10.50	66.00	0.100	2.30	933	1.6684	1.0006	1.6684	14.99432	4138.43	1799.3179	29.9318	194.12	4362.48
25	Aluminum 3003-H18	10.20	29.00	0.099	2.30	933	1.6884	1.0017	1.6884	15.45720	4223.52	1836.3152	33.6315	197.33	4454.49
26	Aluminum 7175-T66	10.40	76.00	0.101	2.50	933	1.6736	1.0005	1.6736	15.14527	4589.02	1835.6062	33.5606	195.17	4817.74
27	Titanium Ti-6Al-6V-2Sn	16.00	140.00	0.165	9.00	1933	1.4204	1.0002	1.4204	9.82819	17513.84	1945.9823	44.5982	245.07	17803.50
28	Titanium Ti-13V-11Cr-3Al	16.00	160.00	0.175	9.38	1933	1.4204	1.0002	1.4204	9.82819	19349.26	2063.9206	56.3921	245.07	19650.71
29	1015 Steel	30.00	50.00	0.285	0.60	1700	1.2170	1.0009	1.2170	5.55647	1140.19	1900.3123	40.0312	184.43	1364.65
30	4140 Q&T Steel	30.00	252.00	0.285	0.90	1700	1.2170	1.0001	1.2170	5.55647	1710.28	1900.3123	40.0312	184.43	1934.74
31	304 Stainless Steel	28.00	85.00	0.287	3.00	1700	1.2331	1.0005	1.2331	5.89477	6090.47	2030.1578	53.0158	187.79	6331.28
32	Gray Cast Iron	15.00	20.00	0.258	0.95	1425	1.4505	1.0025	1.4505	10.46133	1781.35	3238.8267	173.8827	209.76	2164.99
33	Ductile Cast Iron	30.00	50.00	0.258	0.85	1425	1.2170	1.0009	1.2170	5.55647	1118.18	1720.2827	22.0283	165.90	1306.12

Figure 21: Results Screen

Note: all the calculations are done in “sheet 2” which can be accessed/modified through the following steps:

1. Click on “format” in the toolbar on top in Microsoft excel®.
2. Choose “sheets” and then “unhide” from the selection (Figure 22).

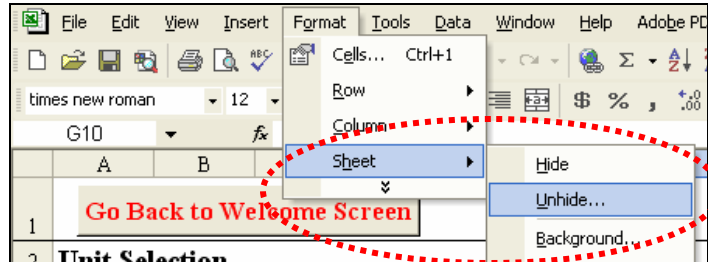


Figure 22: Unhide a Sheet in Microsoft Excel®

3. Select “sheet 2” to unhide (Figure 23) and click “OK”.

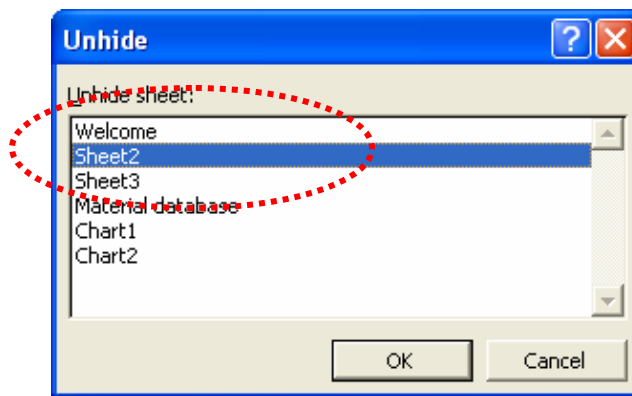


Figure 23: Selecting a Sheet to Unhide

4. The first table (Figure 24) titled “Moment” contains the formulae for moment equations for all the combinations of load and support types, the second table (Figure 25) contains the equations for moment of inertia and centroids for different shapes to be used in moment equations.

4	load type	Moment			
5	2	Support type	Load type		
6			2	3	4
7	support type		Single point: center load	Single point: end load	Uniform load
8	2	2 Cantilever support	60000	120000	7200000
9		3 Fixed ends	15000	N/A	6000000
10		4 Simply supported ends	30000	N/A	1800000

Figure 24: Table for Moment Equations

15		Design Parameter: (dm)	1.000904472	1.000904472
16	5		Moment of inertia	Centroid
17		Shape	I	C
18	2	Square	0.083635233	0.500452236
19	3	Rectangular	0.083635233	0.500452236
20	4	Circular	0.049265219	0.500452236
21	5	I-beam	0.600542683	0.500452236
22	6	Hollow-box beam	0.000602982	0.500452236
23	7	Equilateral triangle	0.018107559	0.288936233

Figure 25: Table for Moment of Inertia and Centroid Values

5. Similarly, the next table titled “Max deflection” contains the formulae for maximum deflection with different load and support combinations followed by the table for moment of inertia to be used in these equations.
6. Other tables on this sheet are automatically evaluated and can be verified by the user by going to that cell and following the formulae in terms of cell references or variables.
7. After all the modification are done in this, go back to “format/sheets/hide” (Figure 26).

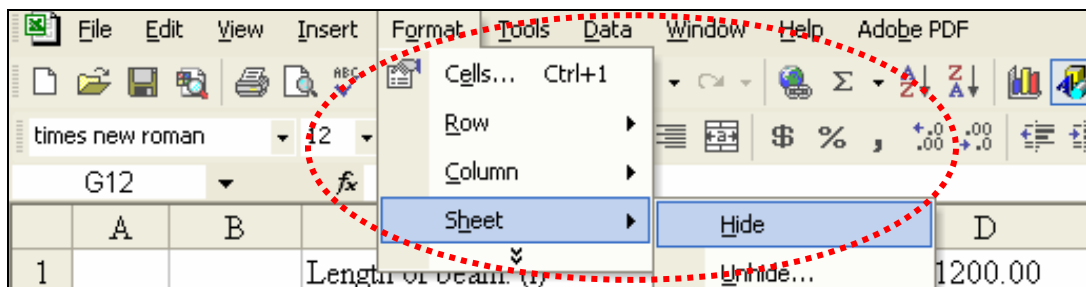


Figure 26: Hide a Sheet in Microsoft Excel®

Another point to keep in mind is that some of the sheets e.g. “result sheet” are protected. Therefore the user cannot modify the cell content in the protected cells. In case the user wants to see the formula or modify the sheet, s(he) can go to toolbar and follow “Tools/protection/unprotect sheet” (Figure 27). Once the user is finished modifying the values/formulae, s(he) can follow the same path with “protect sheet” option (Figure 28) and clicking “OK” in the popup screen (Figure 29).

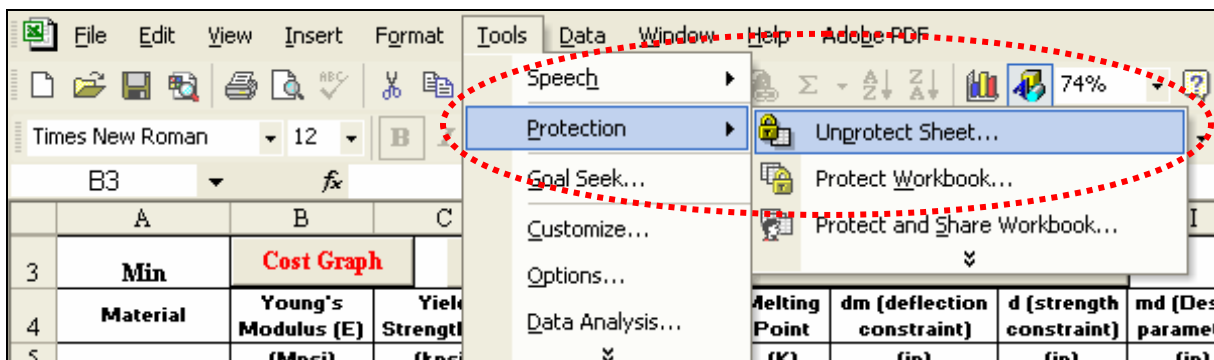


Figure 27: Unprotect a Sheet in Microsoft Excel®

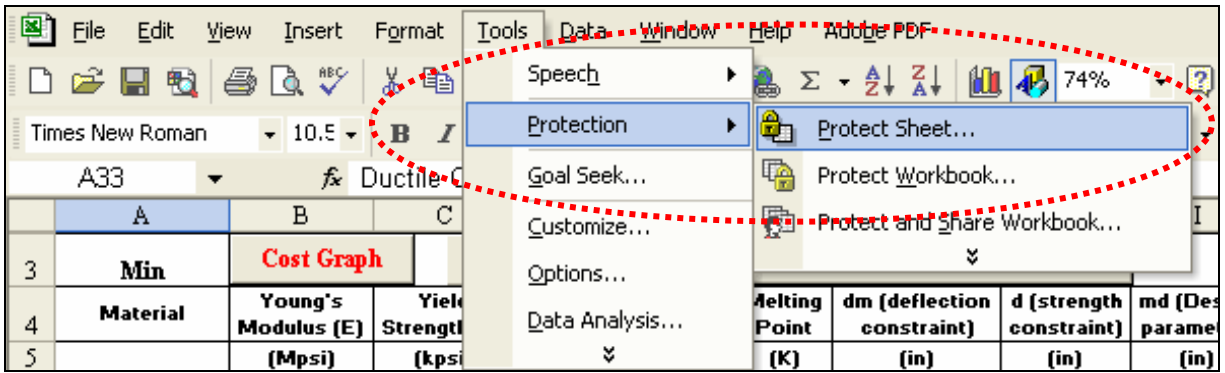


Figure 28: Protect a Sheet in Microsoft Excel®

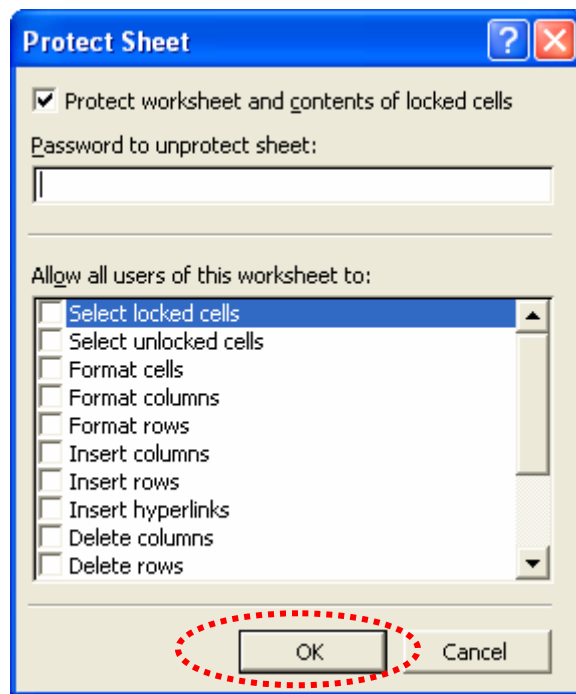


Figure 29: Options to Protect a Sheet in Microsoft Excel®

End of Instructions