IPRO 303

Fall 2008

Wind Power Generation

Cost Impact of Equipment Failures

Background

SmartSignal, *our sponsor*

SmartSignal Inc. offers software which models machine and equipment behavior, and can distinguish between normal and abnormal conditions.

This information is used by machine operators to proactively deal with potential problems before they cause faults and unplanned downtime.

Problem Statement

SmartSignal's Objectives:

- Explain faults that are occurring in wind turbines and why
  - Gain a general understanding of how wind turbines work
  - Identify turbine components and major failures
  - Determine turbine faults
  - Determine most costly/most common reasons for turbine downtime
- Provide detailed overview of current maintenance practices and procedures
  - Provide listings of maintenance procedures available
  - The advantages and disadvantages of current maintenance practices
  - Determine who is responsible for maintenance
- Technical Business Case
  - Describe the revenues and cost basis of wind power generation
  - Calculate costs of unplanned downtime due to failures

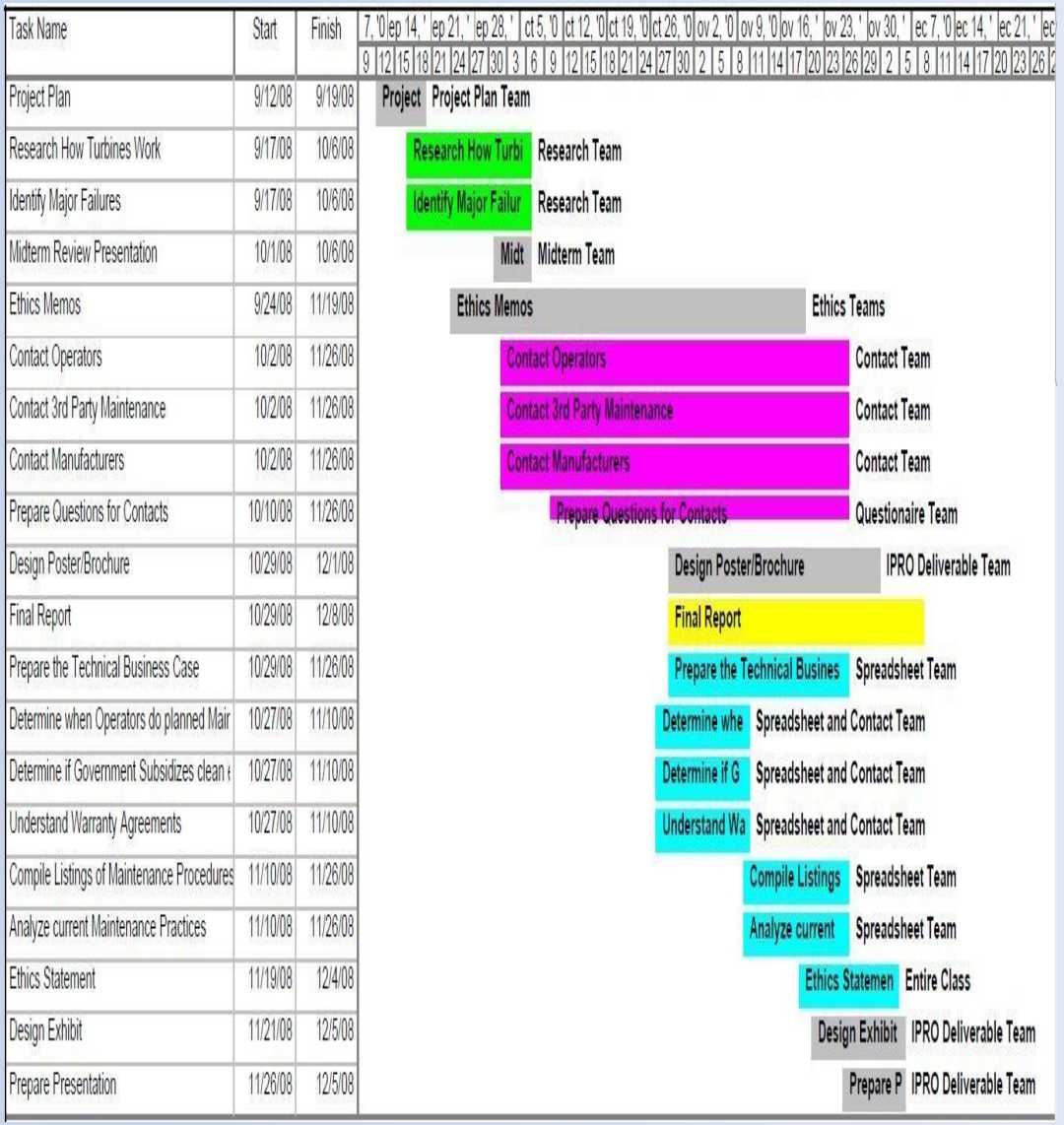
Work Breakdown Structure

Defining the problems: The cost of failures associated with wind turbine operations was determined.

Gathering research: Research and background information on turbine failures was gathered

Initial data compilation: Compilation of results gathered from research over the semester:

Prepare Technical Business Case: Compiled data was used to prepare a technical business case in the form of a MS Excel spreadsheet



Task Name	Start	Finish
Project Plan	9/12/08	9/19/08
Research How Turbines Work	9/17/08	10/6/08
Identify Major Failures	9/17/08	10/6/08
Midterm Review Presentation	10/1/08	10/6/08
Ethics Memos	9/24/08	11/19/08
Contact Operators	10/2/08	11/26/08
Contact 3rd Party Maintenance	10/2/08	11/26/08
Contact Manufacturers	10/2/08	11/26/08
Prepare Questions for Contacts	10/10/08	11/26/08
Design Poster/Brochure	10/29/08	12/1/08
Final Report	10/29/08	12/8/08
Prepare the Technical Business Case	10/29/08	11/26/08
Determine when Operators do planned Mair	10/27/08	11/10/08
Determine if Government Subsidizes clean	10/27/08	11/10/08
Understand Warranty Agreements	10/27/08	11/10/08
Compile Listings of Maintenance Procedures	11/10/08	11/26/08
Analyze current Maintenance Practices	11/10/08	11/26/08
Ethics Statement	11/19/08	12/4/08
Design Exhibit	11/21/08	12/5/08
Prepare Presentation	11/26/08	12/5/08

The Team Structure

Pre-Midterm Teams

- **Team Leaders**
  - Led the meetings and also helped the teams complete their tasks
- **Research Team**
  - Researched how wind turbines work and identifying the major failures
- **Spreadsheet Team**
  - Compiled wind turbine failure data and costs into an interactive spreadsheet
- **Questionnaire Team**
  - Prepared questionnaires for the contact team
- **Contact Team**
  - Contacted people in the wind power industry to schedule interviews
- **Deliverable Team**
  - Handled IPRO requirements

Wind Turbine Function

- Basic Components of a Wind Turbine
- Wind Turbine Classification
  - Small (20- kW)
    - Rotor
    - Gearbox
  - Medium (20 – 300 kW)
    - Nacelle
    - Break
  - Large (300+ kW)
    - Generator
    - Tower

Source: Alliant Energy Kids
http://www.alliantenergykids.com

Wind Turbine Faults

- Regularly occurring faults and not the same as the most costly faults
- Fault data tends to be inconsistent

Most Common/Regularly Occurring	
Electrical System	17.5%
Sensors	14.1%
Control System	12.9%
Blade Pitch	13.4%
Contribution ~ 60%	

Most Downtime/Most Costly	
Gears	19.4%
Control System	18.3%
Electric System	14.3%
Yaw System	13.3%
Contribution ~ 65%	

This information is taken from a case study on wind turbine component failures conducted in Sweden. Study includes wind farms in Germany and Sweden

Most Costly Reasons for Turbine Downtime

- Gearbox failures are the most costly component that affects turbine downtime
  - Bearings and gears are the main reason it fails
  - Caused by contamination and lack of maintenance

- The typical costs associated with gearbox repair
  - Replacing a gearbox can cost around $120,000 for a 660 kW turbine
  - A rebuild can cost around $40,000-$50,000
  - Higher producing power wind turbines are more expensive
  - Total crane costs can reach $50,000-70,000
  - Other data has shown that a crane can cost up to $300,000

Source: http://www.clowd.org.uk/Images/turbine_head_20080103_470x314.jpg

This information is taken from a case study on wind turbine component failures conducted in Sweden. Study includes wind farms in Germany and Sweden

Current Maintenance Practices

- **Maintenance Contract Options**
  - Most repairs do not require a lot of specialty tools
  - **Manufacturer Warranty:**
    - Most repairs are either trivial repairs or extremely costly
      - Components to complete coverage
  - **3rd Party Maintenance Crews:**
    - Crews can be hired to repair faults as they occur, or they can be contracted to particular wind farms.
    - Operator can choose to have on-staff maintenance crews rather than hire a third-party company to handle repairs

Fault Cost Analysis Spreadsheet - Main Worksheet

- User Input of Turbine Parameters, Electricity Rates and Component Faults
- Outputs Economic Effects of Faults with Baseline (no faults) for Comparison
- All Input Values from Drop-Down Lists – (user editable)

IPRO 303 Wind Turbine Component Failure Economic Impact Calculator

This spreadsheet calculates the economic costs of specific faults on a single wind turbine. Inputs are in BLUE, and are found in Tables 1 , 2 & 3. Tables 4 & 5 contain calculated output values, which are plotted in the bar graphs. Instructions: *Place the mouse over the TITLE BAR on any table to view the help comments for that table. To add or edit component faults, go to the Faults worksheet, either by clicking the TAB at the bottom, or clicking the View/Edit Faults button. Buttons require macros to be enabled. See Excel help to enable macros.*

Table 1

Turbine Data & Energy Produced			
Input	Baseline	W/Faults	Units
Turbine Rated Size	2.00	2.00	*MW*
Capacity Factor	0.320	0.301	
Annual Energy Produced	5,548,800	5,277,440	*kWh*
Turbine Expenses			
Turbine	$ 235,815	$ 235,815	
LRC	$ 21,400	$ 21,400	
Baseline O&M	$ 40,000	$ 40,000	
Land Lease	$ 5,000	$ 5,000	
Repair Costs	0	$38,540	
Total Annual Costs	$ 302,215	$ 340,755	

Table 2

Z	Component Faults		
#	Component	Cost to Repair ($)	Downtime (Hours)
0	Gearbox	448,000	900
0	Generator	325,450	875
0	Rotor	287,400	850
2	Hydraulic System	5,470	72
1	Electrical System	27600	280
0	Control Electronics	2,110	8
	Totals ==>	$38,540	424

Table 3

Income *Rate* for Produced Electricity		
Utility Rate Paid	0.040	*$ per kWh*
Federal Incentive	0.018	*per kWh*
State Incentive		*per kWh*
Total Income Rate		*per kWh*

0.017
0.018
0.019
0.020
0.021
0.022
0.023
0.024

All Value

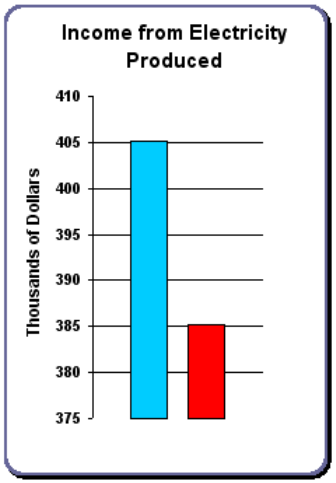
Table 4

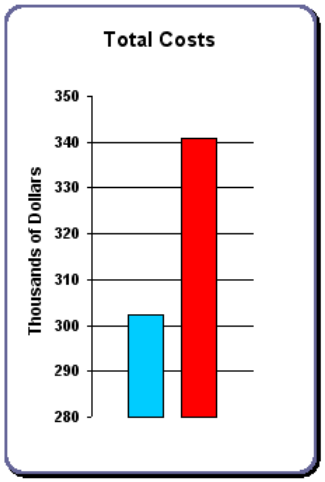
Income or Loss (Baseline)		
Gross Income	$	405,062
Total Costs	$	302,215
Net Income	$	102,847

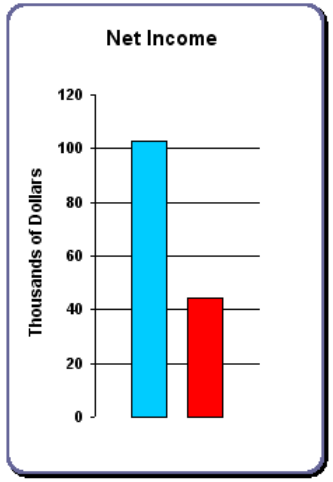
Table 5

Income or Loss (with Faults)		
Gross Income	$	385,253
Total Costs	$	340,755
Net Income	$	44,498

View/Edit Faults | Help | Gridlines

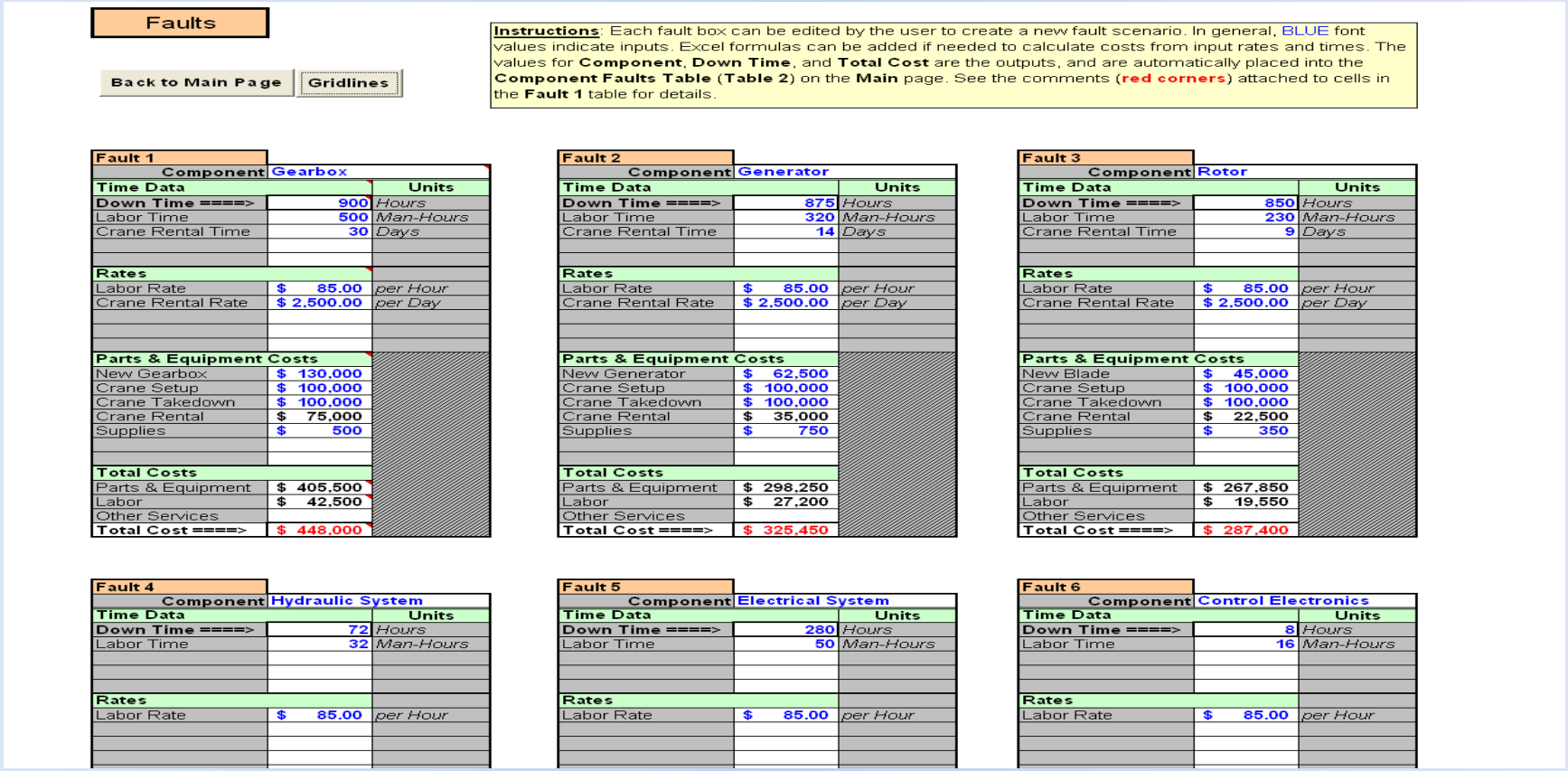






Fault Cost Analysis Spreadsheet - Faults Worksheet

- Six Fault Data boxes
- Times, Rates and Costs entered by user
- Cost calculations (e.g. labor cost)
- **Total Costs** and **Down Time** ➔ **Main Worksheet**



Faults

Back to Main Page | Gridlines

Instructions: Each fault box can be edited by the user to create a new fault scenario. In general, BLUE font values indicate inputs. Excel formulas can be added if needed to calculate costs from input rates and times. The values for **Component**, **Down Time**, and **Total Cost** are the outputs, and are automatically placed into the **Component Faults Table** (**Table 2**) on the **Main** page. See the comments (**red corners**) attached to cells in the **Fault 1** table for details.

Fault 1

Component	Gearbox	
Time Data		**Units**
Down Time ====>	900	*Hours*
Labor Time	500	*Man-Hours*
Crane Rental Time	30	*Days*
Rates		
Labor Rate	$ 85.00	*per Hour*
Crane Rental Rate	$ 2,500.00	*per Day*
Parts & Equipment Costs		
New Gearbox	$ 130,000	
Crane Setup	$ 100,000	
Crane Takedown	$ 100,000	
Crane Rental	$ 75,000	
Supplies	$ 500	
Total Costs		
Parts & Equipment	$ 405,500	
Labor	$ 42,500	
Other Services		
Total Cost =====>	$ 448,000	

Fault 2

Component	Generator	
Time Data		**Units**
Down Time ====>	875	*Hours*
Labor Time	320	*Man-Hours*
Crane Rental Time	14	*Days*
Rates		
Labor Rate	$ 85.00	*per Hour*
Crane Rental Rate	$ 2,500.00	*per Day*
Parts & Equipment Costs		
New Generator	$ 62,500	
Crane Setup	$ 100,000	
Crane Takedown	$ 100,000	
Crane Rental	$ 35,000	
Supplies	$ 750	
Total Costs		
Parts & Equipment	$ 298,250	
Labor	$ 27,200	
Other Services		
Total Cost =====>	$ 325,450	

Fault 3

Component	Rotor	
Time Data		**Units**
Down Time ====>	850	*Hours*
Labor Time	230	*Man-Hours*
Crane Rental Time	9	*Days*
Rates		
Labor Rate	$ 85.00	*per Hour*
Crane Rental Rate	$ 2,500.00	*per Day*
Parts & Equipment Costs		
New Blade	$ 45,000	
Crane Setup	$ 100,000	
Crane Takedown	$ 100,000	
Crane Rental	$ 22,500	
Supplies	$ 350	
Total Costs		
Parts & Equipment	$ 267,850	
Labor	$ 19,550	
Other Services		
Total Cost =====>	$ 287,400	

Fault 4

Component	Hydraulic System	
Time Data		**Units**
Down Time ====>	72	*Hours*
Labor Time	32	*Man-Hours*
Rates		
Labor Rate	$ 85.00	*per Hour*

Fault 5

Component	Electrical System	
Time Data		**Units**
Down Time ====>	280	*Hours*
Labor Time	50	*Man-Hours*
Rates		
Labor Rate	$ 85.00	*per Hour*

Fault 6

Component	Control Electronics	
Time Data		**Units**
Down Time ====>	8	*Hours*
Labor Time	16	*Man-Hours*
Rates		
Labor Rate	$ 85.00	*per Hour*

Fault Cost Analysis Spreadsheet - Component Faults

Fault 1		
Component	Gearbox	
Time Data		**Units**
Down Time ====>	900	*Hours*
Labor Time	500	*Man-Hours*
Crane Rental Time	30	*Days*
Rates		
Labor Rate	$ 85.00	*per Hour*
Crane Rental Rate	$ 2,500.00	*per Day*
Parts & Equipment Costs		
New Gearbox	$ 130,000	
Crane Setup	$ 100,000	
Crane Takedown	$ 100,000	
Crane Rental	$ 75,000	
Supplies	$ 500	
Total Costs		
Parts & Equipment	$ 405,500	
Labor	$ 42,500	
Other Services		
Total Cost ====>	$ 448,000	

Faults Worksheet

- Blue text inputs edited by user
- Editing enables user-defined scenarios
- Figures of merit are automatically displayed on Main worksheet
  - Component Name
  - Total Cost to Repair
  - Down Time

Z	Component Faults		
#	Component	Cost to Repair ($)	Downtime (Hours)
0	Gearbox	448,000	900
0	Generator	325,450	875
0	Rotor	287,400	850
0	Hydraulic System	5,470	72
0	Electrical System	27600	280
0	Control Electronics	2,110	8
	Totals ==>	$0	0

Main Worksheet

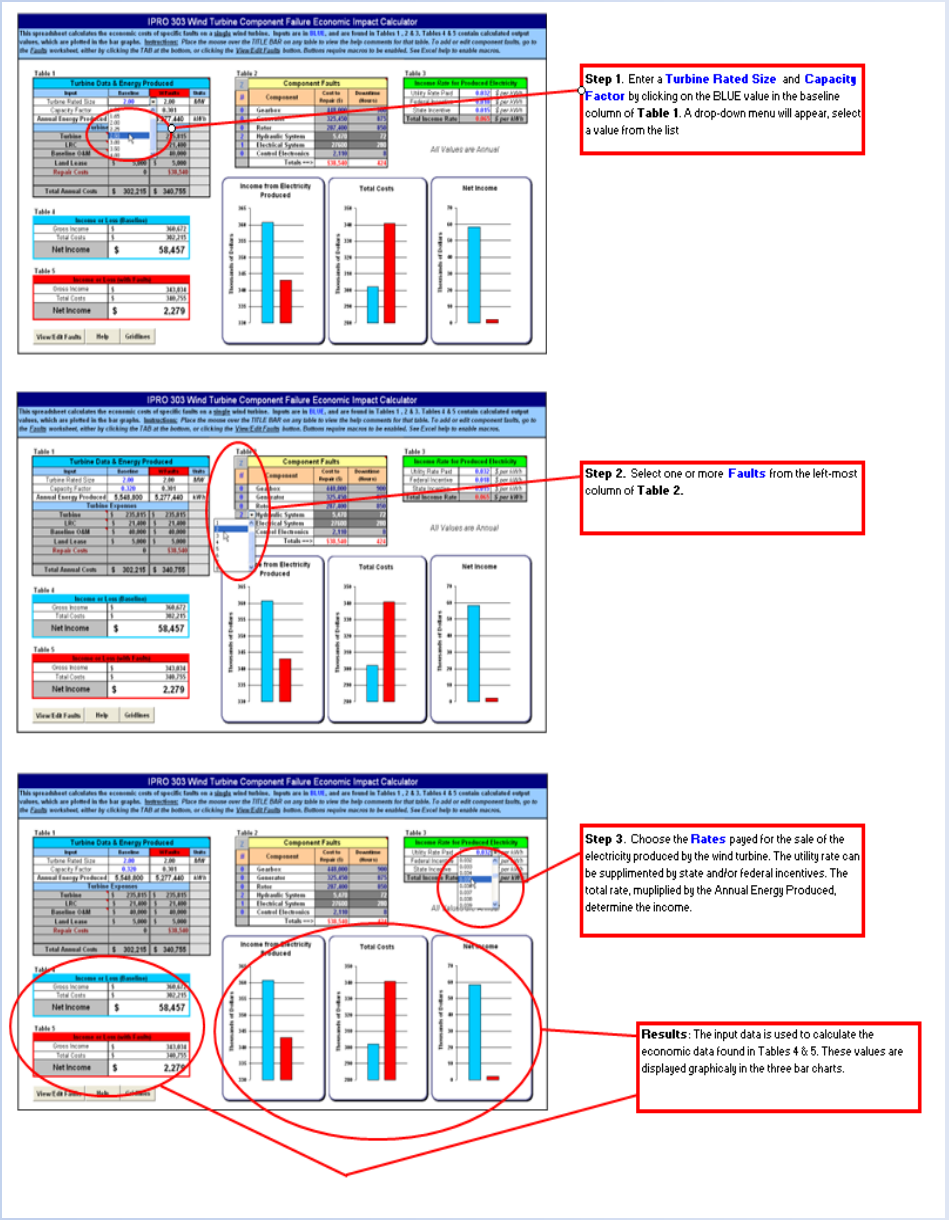
Fault Cost Analysis Spreadsheet - User Help

Help Worksheet

Extensive Balloon Comments

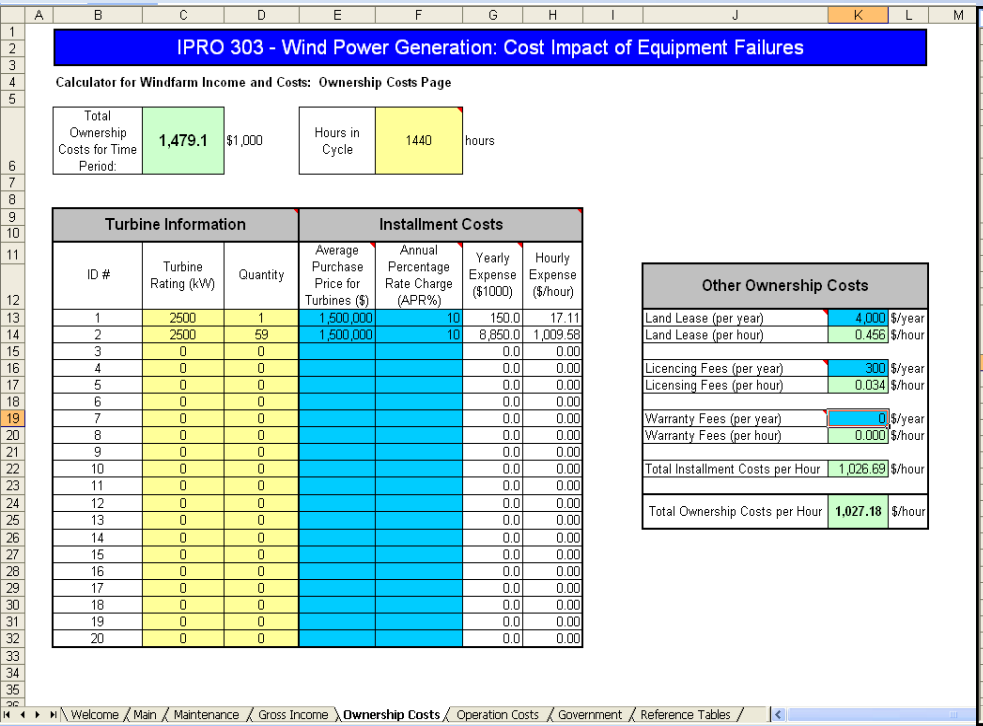
Rates		
Labor Rate	$ 85.00	per Hour
Crane Rental Rate	$2,500.00	per Day
Parts & Equipment Costs		
New Gearbox	$ 130,000	
Crane Setup	$ 100,000	
Crane Takedown	$ 100,000	
Crane Rental	$ 75,000	
Supplies	$ 500	
Total Costs		
Parts & Equipment	$ 405,500	
Labor	$ 42,500	
Other Services		
Total Cost ====>	$ 448,000	

Enter induvidual costs here, or add an Excel formula to calculate a cost from **Time** and **Rate** values entered above.



Wind Farm Spreadsheet

- Focuses on Wind Farms
- Calculates economic costs
- User chooses turbine sizes/numbers



IPRO 303 - Wind Power Generation: Cost Impact of Equipment Failures

Calculator for Windfarm Income and Costs: Ownership Costs Page

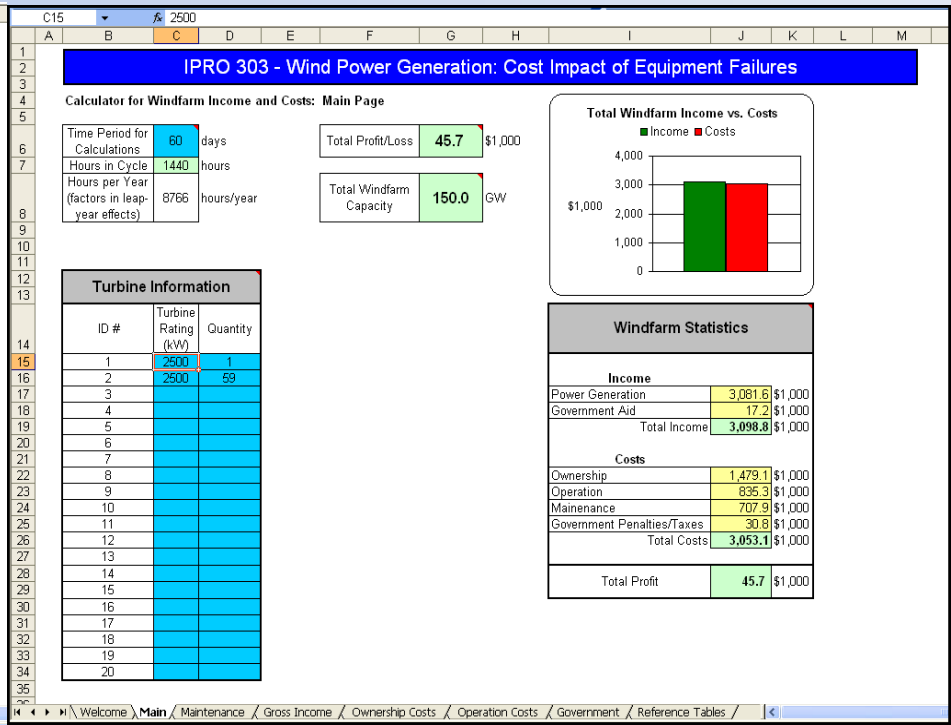
Total Ownership Costs for Time Period:	1,479.1	$1,000

Hours in Cycle	1440	hours

Turbine Information			Installment Costs			
ID #	Turbine Rating (kW)	Quantity	Average Purchase Price for Turbines ($)	Annual Percentage Rate Charge (APR%)	Yearly Expense ($1000)	Hourly Expense ($/hour)
1	2500	1	1,500,000	10	150.0	17.11
2	2500	59	1,500,000	10	8,850.0	1,009.58
3	0	0			0.0	0.00
4	0	0			0.0	0.00
5	0	0			0.0	0.00
6	0	0			0.0	0.00
7	0	0			0.0	0.00
8	0	0			0.0	0.00
9	0	0			0.0	0.00
10	0	0			0.0	0.00
11	0	0			0.0	0.00
12	0	0			0.0	0.00
13	0	0			0.0	0.00
14	0	0			0.0	0.00
15	0	0			0.0	0.00
16	0	0			0.0	0.00
17	0	0			0.0	0.00
18	0	0			0.0	0.00
19	0	0			0.0	0.00
20	0	0			0.0	0.00

Other Ownership Costs		
Land Lease (per year)	4,000	$/year
Land Lease (per hour)	0.456	$/hour
Licencing Fees (per year)	300	$/year
Licensing Fees (per hour)	0.034	$/hour
Warranty Fees (per year)	0	$/year
Warranty Fees (per hour)	0.000	$/hour
Total Installment Costs per Hour	1,026.69	$/hour
Total Ownership Costs per Hour	1,027.18	$/hour

Welcome | Main | Maintenance | Gross Income | Ownership Costs | Operation Costs | Government | Reference Tables



IPRO 303 - Wind Power Generation: Cost Impact of Equipment Failures

Calculator for Windfarm Income and Costs: Main Page

Time Period for Calculations	60	days
Hours in Cycle	1440	hours
Hours per Year (factors in leap-year effects)	8766	hours/year

Total Profit/Loss	45.7	$1,000
Total Windfarm Capacity	150.0	GW

Total Windfarm Income vs. Costs

Turbine Information		
ID #	Turbine Rating (kW)	Quantity
1	2500	1
2	2500	59
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		
15		
16		
17		
18		
19		
20		

Windfarm Statistics		
Income		
Power Generation	3,081.6	$1,000
Government Aid	17.2	$1,000
Total Income	3,098.8	$1,000
Costs		
Ownership	1,479.1	$1,000
Operation	835.3	$1,000
Mainenance	707.9	$1,000
Government Penalties/Taxes	30.8	$1,000
Total Costs	3,053.1	$1,000
Total Profit	45.7	$1,000

Welcome | Main | Maintenance | Gross Income | Ownership Costs | Operation Costs | Government | Reference Tables

Obstacles

- Understanding the goals
- Establishing contacts in industry
- Establishing a team leader
- Technical background of team members
- Documents and Formatting
- Ethical issues

Ethics

The IPRO team is to consider these issues.

Three Perspectives:

- The Seven Layers of Integrity by Dr. June Ferrill
- It's Good Business by Kristine R. Hanson, Robert C. Solomon
- Professional Engineering Code of Ethics by the American Society of Mechanical Engineers

1. Honoring the confidentiality agreement with our sponsor, SmartSignal, when dealing with our contacts.
2. Actions to be taken should unequal contributions amongst team members occur.
3. Address how communication among IPRO team members may be impacted by our cultural diversity

Ethics Conclusions

- Will not disclose SmartSignal's name to our contacts, and we will also not disclose our contacts' names to SmartSignal
- When we have a team member who is contributing equally, they should be contacted to improve the situation
- Cultural differences may affect our communication, and we need to be aware of this

Recommendations

- **General**
  - Establish leadership early in the semester
  - Define a well thought out set of goals

- **Contact Team**
  - Reference contact list and keep communication open with previous contacts
  - Favor live phone interviews

- **Research Team**
  - Become familiar with the research done this semester and expand on it
  - Find more information on the actual “cost of maintenance”

- **Spreadsheet Team**
  - Enhance the previous spread sheets
  - Combine them into one comprehensive version
  - Apply more research data to the inputs

Thank you for listening!

QUESTIONS?

Cover page: http://www.ecofuss.com/wp-content/uploads/2008/04/offshore-wind-turbines.jpg
Animation: http://www.originenergy.com.au/2039/files/renew_wind.gif