NAU NORTHERN ARIZONA UNIVERSITY
Mechanical Engineering

[Insert Team Number Here]
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Subject: ERs and TPs revamp Memo

This memo covers the revisions made by the Site Team to their engineering requirements to ensure they fulfilled their projects customer requirements and competition requirements. The team's customer requirements has not changed since the Fall of 2019 final report. Collegiate Wind Competition (CWC) committee has set basic standards and rule that are to be met by the teams. In addition, the site team's client has suggested a few requierments as well. This memo also covers the Site Team's testing procedures for their engineering requirements. The Site Team's testing procedures have not been changed since the final report from last semester (Fall 2019). Ultimately, the customer and engineering requirements will be tested by the testing procedures through Openwind.

1 Customer Requirements (CRs)

The CWC Site Team generated the following list of customer requirements based off the CWC 2020 Rule Book and industry standards [1] and speaking with their customer, Professor Willy. The customer requirements were weighted on a scale of 1 to 4. A 1 was used to indicate that the customer requirement was the less relevant and a 4 indicates that the customer requirement is crucial and rewired for the project. Since the final report last semester, no new customer requirements were added or changed.

1. Durable for ~20 years (4) Low Risk [Wind Farm] (2)
2. Accessible (3)
3. Terrain (2)
4. Aesthetics (1)
5. Restoration (1)
6. Cost within budget [$400] (1)
7. Reliable design (3)
8. Safe to operate (3)
9. Less than or equal to 100 MW (4)
10. Wildlife habitat (3)
11. In compliance with local ordinances (4)
12. Location: Eastern Colorado (4)
13. Not placed on a current/planned wind farm (4)
14. Cost Effective [Wind Farm] (2)

Customer requirements received a weighted score of 4 if they were specifically stated in the CWC 2020 Rule Book. Within the competition paper the Site Team is required to produce a cash flow and cost of energy analysis for the proposed wind farm, expecting said wind farm to have a life expectancy of 20 years. The rule book also stated that the proposed wind farms must be located within Eastern Colorado and produce less than or equal too 100 MW to keep all the teams on an even playing field. Additionally, for the proposed plan to be realistically feasible and in line with the CWC 2020 Rule Book the wind farm needs to follow all local and federal rules and regulations.

Accessible received a 3 because large turbines need to be transported to the site location and wind farm needs to connect to transmission lines. If the site location is not accessible additional costs will be added on to the project in the form of having to build roads and/or transmission lines. The wildlife habitat customer requirement received a 3 because no matter where the Site Team places the wind farm in Eastern Colorado the proposed farm will be interacting with a diverse range of wildlife such as bats and eagles. Within the team's competition paper, the team will need to note how they plan on following the U.S. Government Fish and Wildlife Services laws and regulations. Safe to operate, reliable design and low risk all received a 3 because they are important requirements that the Site Team must consider even though the project is theoretical based because these are aspects that would need to be considered if this project were to be done in the real world.

Cost effective got 2 as it's weighted score because the rule book does not impose any limits to the cost of the proposed wind farm plans. Thus, the Site Team must be able to justify all the costs that are reported for the proposed project plan. The proposed plan still needs to be realistic which is why the Site Team still need to make sure that the plan is cost effective. Terrain (elevation, roughness, etc.) scored a 2 because it plays a part in the wind speeds of a site location; therefore, terrain also can affect the overall energy production of the wind farm.

A weighted score of a 1 was given to cost within budget [$400] because the Site Team does not have much to buy since the team received Openwind for free and the budget will be spent on enhancing the team's presentation for U-Grads and CWC. Restoration and aesthetics both also received a weighted score of 1 because they do not play a critical role in the development of the project and are not listed as requirements within the CWC 2020 Rule Book.

2 Engineering Requirements (ERs)

The engineering requirements were derived solely from the rule book and how the team can meet the competitions and customer's requirements. The engineering requirements were geared from how mechanical mechanisms and structures can meet the customer's requirements. Each of the requirements further investigate how the team will propose their project to meet the competition's requirement.

2.1 ER #1: Blade Span

2.1.1 ER #1: Blade Span Target = 110-meter span

The blade span of the turbine determines the amount of land mass the wind farm will take up. So, the team concluded to keep the turbine span in mind, to make sure they do not overcome the desired land area. In addition, the spacing between each turbine is determined by their rotor diameters which helped in the wake calculations.

2.1.2 ER #1: Blade Space Tolerance = +/-15 meters

The tolerance is designed to work alongside factory specification. In the United States, some models are not locally manufactured. Because of this, the 15-meter tolerance will keep the data and allow the team to better select models.

2.2 ER #2: Cost of Energy

2.2.1 ER #2: Cost of Energy - Target = $0.09 per kilowatt-hour

The overall cost of energy was created as an engineering requirement, because this depends on how efficient the turbines produce energy and the overall construction cost of the wind farm. In order to the find the cost of energy, the team must find sufficient wind turbines that meet the wind characteristics in the area, align them effectively to capture the wind to produce energy, and selected a location with the best wind resources.

2.2.2 ER #2: Cost of Energy- Tolerance = +/- $0.02 per kilowatt-hour

While the $0.09 per kilowatt-hour is acceptable for the common energy market, it will be difficult to maintain this cost if the plant meets unexpected obstacles. This tolerance considers the maximum that will be accepted to stay competitive against gasoline and coal. In addition, federal tax credit will positively affect the cost of energy, making the wind plant more viable and potentially reducing this target value.

2.3 ER #3: Number of Turbines

2.3.1 ER #3: Number of Turbines Target = 45

The site team had initially selected a 2-megawatt turbine which resulted to having 50 turbines in the first simulations of last semester. Now after further research, a turbine of 2.2-kilowatt has been chosen as a better fit which resulted to 35+ turbines, less than the initial. This change in number of turbines resulted to less land coverage of the wind farm, a turbine that best suited the wind characteristics in the area, and decreased the cost of buying more turbines, while still meeting the 100-MW requirement.

2.3.2 ER #3: Number of Turbines - Tolerance = +/- 10 turbines

The changes made positively affect the land use and capital expenses by reducing the number of turbines. Too little, though, and the cost of and reliance on each turbine will hinder the site's overall efficiency. Setting the minimum amount to 35 turbines will ensure that any maintenance will not greatly disturb the overall site productivity.

2.4 ER #4: Energy Production

2.4.1 ER #4: Production - Target = 100-Megawatt

Energy produced by the turbines must be able to produce at least or equal to 100-megawatts for be considered for the competition. This engineering requirement did not undergo any changes, as this requirement is set in place and the team's simulations ensure the turbines meet and does not exceed 100-megawatts.

2.4.2 ER #4: Production - Tolerance = +/- 1 Megawatt

The team is working to prioritize the requirement of 100 Megawatts by balancing the number of turbines and rated power. This will help in meeting the competition's requirement.

2.5 ER #5: Land Occupation

2.5.1 ER #5: Land Target = 4500 acres

The wind farm does not have a specific land area that it can occupy, but the team will take keep consideration of not taking too much land as it may result to wildlife habitat destruction. So, in order to fulfill this requirement, the team will construct the wind farm with little disturbance of the land and use it conservatively.

2.5.2 ER #5: Land Target - Tolerance = +/- 500 acres

Spacing the wind turbines through manual optimization has created a need to exceed or shrink the site area. With a better-spaced layout, the array efficiency will increase. However, the team must balance the distance between turbines and the amount of effective land used.

2.6 ER #6: Turbine Overall Height

2.6.1 ER #6: Height - Target = 175 meters

The wind characteristics and Federal Aviation Administration's regulations will further determine the turbine's height in the end, with the simulations results at hub height of 80m, the turbine overall height must follow FAA's height requirement in order to operate.

2.6.2 ER #6: Height - Tolerance = +/- 25 meters

Overall heights that are far too high or far too low will cause distinct problems. Any heights that range too far in magnitude will reduce the accuracy of the data created in conjunction with wind speeds at 100 meters. Increased regulations will apply to a higher turbine, and a lower turbine will not harvest the wind energy as efficiently.

2.7 ER #7: Land Elevation

2.7.1 ER #7: Elevation - Target = 6800 meters

Considering eastern Colorado is filled with plain areas, there is still gradient to the land. This change in elevations can affect the air density, but being at just above ~1000m, the team has been using sea level density for the simulation runs. Terrain in the area is generally filled with rolling hills, so the team does not have to account for major drops in terrain.

2.7.2 ER #7: Elevation - Tolerance = +/- 600 meters

At maximum, these rolling hill elevations will alter the efficiency of the turbine on a negligible scale. This tolerance represents the greatest magnitude in which the turbine's elevation will change on the selected site.

2.8 ER #8: Noise Pollution

2.8.1 ER #8: Noise Measurement- Target = 40 decibels

Noise in the area can affect the community and wildlife with the turbines being huge structures as well. In order to meet this requirement, the team can configure the noise pollution so that it is not placed in certain areas close to residential areas and wildlife habitats. The noise can be kept to minimum by adding the feature into Openwind.

2.8.2 ER #8: Noise Measurement- - Tolerance = +/- 10 decibels

While 40 decibels are the preferred target, spacing will increase the turbines proximity to homes and roadways. However, these paths are useful in transporting the turbine components and moving maintenance crews between the structures. This requires a balance of distance from roadways and a tolerance of the sound of wind turbines.

2.9 ER #9: Wind Farm Lifespan

2.9.1 ER #9: Wind Farm Lifespan - Target = 20 years

The wind farm must be able to survive for 20 years, meaning on top of meeting numerous requirements, the team will select an efficient turbine that is made with durable material and constructed well for a long lifespan. With this in mind, operation and maintenance of the turbines must be considered in order for the farm to continue function after 20 years.

2.9.2 ER #9: Wind Farm Lifespan - Tolerance = +/- 1 year

Luckily, many turbine manufacturers today strive to ensure that their turbines last longer than 20 years with the proper maintenance. An issue that arises, though, is the time required for an individual turbine to break even. Therefore, any turbines that need replacement may increase the lifespan of the project in order to pay back the capital expense. There is another possibility where the number of failing turbines will force the project to close early out of necessity or unprofitable practice.

2.10 ER #10: Turbine Hub Height

2.10.1 ER #10: Hub height- Target = 80 meters

Depending on the data collected from National Renewable Energy Laboratory (NREL)'s Wind Prospector, the team can analyze turbine hub height in various measurements which are 40m, 80m and 100m. Thus far, the team has been conducting simulations at 80m.

2.10.2 ER #10: Hub height - Tolerance = +/- 20 meters

While the 80-meter turbines have been the most commonly used during this project, new information recommends that a higher hub height will yield more accurate results. This tolerance is designed for a higher hub height that does not exceed the maximum overall height when in conjunction with the blade span.

2.11 ER #11: Rotor Diameter

2.11.1 ER #11: Rotor Diameter - Target = 110 meters

The rotor diameter is the main feature of the wind farm that will determine the land coverage and how the land is going to be affected. For this reason, the rotor diameter is significant because it is also connected to the wake calculations which is used in optimizing the wind farm in general. Each of the turbines can be measured 7 to 10 rotor diameters apart from one another so that the wind resources in distributed evenly to produce as much energy as possible.

2.11.2 ER #11: Rotor Diameter - Tolerance = 15 meters

The rotor diameter is relative to the model and is typically paired with a few different hub heights. Selecting models within this tolerance have a relative number of hub heights that, when constructed, will meet the specifications of the overall turbine height.

2.12 ER #12: Shadow Flicker

2.12.1 ER #12: Shadow Flicker - Target = 3 Hours per Day

Shadow flicker is an illusion created by the turbines' rotation angled in front of the sun. It becomes a prominent issue for nearby households and roads at sunrise and sunset. The time it lasts is affected by the distance of the shadow cast and the size of the turbine model. The visual effect of shadow flicker is as significant of a disturbance as the sound produced. Regulations intend to minimize this time of disturbance as much as possible.

2.12.2 ER #12: Shadow Flicker - Tolerance = 1 Hour per Day

A lower shadow flicker is preferred by the team as well. The possibility of no shadow flicker, though, will poorly affect the transport of turbine components and maintenance crews between the turbines. The team will also look for lower blade spans and hub heights in order to reduce the area affected by shadow flicker.

3 Testing Procedures (TPs)

[Use this section to discuss the testing procedure developed by the team for each Engineering Requirement. Testing procedures MUST be detailed enough to completely describe how each Engineering Requirement will be tested to prove it has been satisfied (including what the testing equipment is, where the team will acquire the equipment, how the test will be performed, etc.). Each team must include testing procedures that verify the system in reliable and robust (i.e. can withstand numerous tests, withstand external forces such as drops or impacts, etc.).]

[Include a brief introduction to this section here before moving on.]

The testing procedures within Openwind will verify that wind farm is sufficient for the competition. Openwind can use numbers the team inputted to run through simulations and legality, so the wind farm works effectively as possible. There are numerous features that can be tested and proved insufficient or not, so the team will be conducting more simulations to gather and analyze each result to come to conclusion what setup will fulfill all the requirements listed above.

3.1 Testing Procedure 1: Polygon Boundary

3.1.1 Testing Procedure 1: Objective

The use of the polygon boundary layer will satisfy the land area engineering requirement. In Openwind, the team sets the polygon boundary layer properties to a desired area location and manipulates the size. Then, the team can create a buffer that will fixes the turbines within the set polygon boundary area. Setting up these parameters creates a foundation to use once the final site location is selected and in-depth testing begins.

3.1.2 Testing Procedure 1: Resources Required

After the final site location is confirmed, the site team could add the official polygon boundary layer within Openwind. To accomplish this in detail, select within an open area of the left-hand panel where the tree structure is located and choose “New Layer,” then “Polygon.” To create a free-hand polygon, use the edit tool on the site and select the pre-loaded map. Then, the team will choose the polygon layer in the tree structure and input the coordinates for each polygon node that was made during the free-hand section. This will transform the polygon's location and desired land size that satisfies the engineering requirements. Overall, the land area’s importance by staying within a predetermined set of boundaries great determines the cost efficiency. This will also restrict where the team can place the wind farm regarding roadways and structures.

3.2 Testing Procedure 2: Energy Capture

3.2.1 Testing Procedure 2: Objective

The number of turbines and energy production can be proven to be satisfied through the use of Openwind's energy capture calculation. Once the appropriate data layers (elevation, land cover, wind maps, buildings, roads, new polygon, turbines, etc.) are added into Openwind's tree structure an energy capture report can be calculated. With every new micro-sitting iteration conducted by the team, a new energy capture will be ran to produced data that the team can use for comparison purposes to determine the best micro-sitting setup.

3.2.2 Testing Procedure 2: Resources Required

Commented [RW1]: Who's doing this section?

After turbines are manually placed within the polygon boundary layer ea the Site Team will have the ability to run an energy capture by selecting said calculation within the calculations tab at the top of the Openwind software. Openwind generates a .csv file that can be converted into an Excel spreadsheet. The .csv file contains information about each turbine including the location (X and Y), type of turbine, losses, amount of energy they are producing, etc. The overall site summary data is also included within the spreadsheet; for example, the total energy production. With the CWC Rule Book stating that the proposed plan must be less than or equal to 100MW; thus, making the energy capture spreadsheet is very important. The energy capture report lets the team known whether adjustments need to be made to the number of turbines and/or the micro-siting layout to achieve the best production of energy.

3.3 Testing Procedure 3: Cost of Energy

3.3.1 Testing Procedure 3: Objective

The cost per kilowatt-hour engineering requirement is determined using the cost of energy calculations. The calculations found in Openwind makes an analysis on the wind farm's entirety, simulating how much energy the wind farm will produce on an annual basis. It also finds the overall total costs. These costs include the construction of roadways, installing new transmission lines, and the initial startup costs for the turbines. Upon site selection, the team will run a unique set of micro-siting layouts and energy capture reports produced by the software. This will be used to critic and, eventually, determine a micro-siting layout.

3.3.2 Testing Procedure 2: Resources Required

Commented [RW2]: Who's doing this section?

With each iteration of the micro-siting process, the team will need to discuss the placement of sub-stations. Then, the transmission lines must be adjusted to sync with the new placement. With the adjustments finalized, the team could run an effective cost of energy analysis within Openwind. In detail, this is done by selecting the calculations tab and choosing cost of energy. Openwind will output a list of data on each individual turbine, the overall wind farm, which includes, and the cost per kilowatt-hour. Knowing this information and matching the target value is important because it verifies the feasibility of the proposed plan. This will make this project competitive within Colorado's energy market.

3.4 Testing Procedure 4: Noise Pollution

3.4.1 Testing Procedure 4: Objective

The engineering requirement, noise pollution, can be calculated and accounted for within Openwind. To gain favor with the surrounding community and to comply with local ordinances, noise pollution must be considered when conducting micro-siting layouts and picking a specific site location. The noise pollution test within Openwind is done on each of the nearby receptors (buildings).

3.4.2 Testing Procedure 2: Resources Required

Commented [RW3]: Who's doing this section?

Noise pollution is considered to be an environmental sensor within Openwind. Therefore, a noise pollution buffer layer can be created after right clicking on a blank spot of the tree-structure and selecting "New Layer" and then "Environmental Sensor". Within the properties of the new layer said layer can be edited to focus on noise pollution and the Site Team can indicate the max amount of noise pollution each receptor may receive. Then within the Openwind map a receptor can be selected and the noise pollution for the selected receptor can be calculated. The Openwind then creates a .csv spreadsheet file that contains information such as the amount of noise pollution the selected receptor is receiving. Noise pollution analysis is important because minor changes done to the micro-siting layout can increases the amount of noise pollution a receptor receives; thus, different micro-sitting layouts will have to be considered and in the worst case a new location would have to be selected.

3.5 Testing Procedure 5: Environmental Sensors

3.5.1 Testing Procedure 5: Objective

Shadow flicker is the creating of flickering shadows caused by the rotating blades. The stropelight effect can cause irritation in any surrounding communities. This engineering requirement is tested though an environmental sensors layer and calculates the duration of the shadow flicker. Much like noise pollution, there is no data found for the combined receptors. Data is only produced for individually receptors.

3.5.2 Testing Procedure 2: Resources Required

Commented [RW4]: Who's doing this section?

The shadow flicker buffer works much like noise pollution. The key difference is found in layer properties. It is important to point out that the workbook should also have the proper time zone. However, the team will be using the Openwind file from preliminary testing. Therefore, is not a necessary. These calculations will plot a graph showing the amount of shadow flicker received during the year. It is important to know if minor changes to the micro-siting layout decrease the receptor's amount of shadow flicker. Then the team must consider relocation.

References

[1] U.S. Department of Energy Collegiate Wind Competition. 2019. [pdf] National Renewable Energy Laboratory. Available: https://www.energy.gov/sites/prod/files/2019/01/f58/CWC%202019%20Rules%20and%20Requirements%20Manual_20190104_0.pdf [Accessed: 13-Sep-2019].