Simulation of On-Shore Wind Farm Construction Process in Lebanon

E. Zankoul[a] and H. Khoury[b]
[a b] Faculty of Engineering and Architecture, American University of Beirut, Lebanon
E-mail: efz00@aub.edu.lb, hiam.khoury@aub.edu.lb

Abstract -

For the past thirty years, Lebanon has been experiencing cuts in electricity, thus compelled to import it and use noisy and extremely unhealthy generators. This happened at very high prices with even mediocre quality. Hence, an adequate solution to this shortage in electricity supply can be achieved through the use of renewable energies, in particular wind energy or power produced from wind farm turbines. However, the on-shore wind farm construction process can be a very complicated task due to several reasons such as the challenging topography of the rural areas and the absence of paved roads where they are typically constructed, as well as the impact of wind on the construction process. In order to address these complexities, this paper takes the initial steps and presents work targeted at efficiently designing and planning the construction process of an on-shore wind farm in the region of Falougha, Dahr El Baydar, Lebanon. The solution to the problem is described in detail using a discrete-event simulation model developed in AnyLogic. The developed work illustrates the different construction stages from rough grading, access roads construction, foundation and electrical works, to wind tower assembly and erection. The whole process is then optimized to mainly minimize the project duration. The components of the proposed model have been created and preliminary results highlighted the potential of using AnyLogic for simulating and optimizing complex construction processes offering unique challenges such as those found when constructing on-shore wind farms.

Keywords –
Construction Management, Wind Energy, Wind Farm, Simulation, Optimization, AnyLogic

1. Introduction

Since the 1970s, large interconnected wind-driven turbines and generators have been constructed in many countries in “farms” to generate electricity [1,2]. However, Lebanon is considered behind in terms of wind power energy [3]. Current wind energy sources available in Lebanon constitute mainly of some wind turbines and these are rarely functioning. It is believed that an extensive development of wind energy in Lebanon, i.e. wind farm construction, can play a crucial role towards resolving current electricity supply shortages [3]. While some of the issues associated with other types of construction projects are common to these facilities or plants, large wind farm construction is relatively new in Lebanon and offers unique challenges.

Therefore, this paper takes the initial steps and presents work aiming at efficiently designing and planning the construction process of an on-shore wind farm in Lebanon. This will be mainly achieved through the use of Discrete Event Simulation (DES) techniques. Previous research efforts have focused on simulating typical construction processes using DES tools, in particular Stroboscope [4, 5, 6]. Some have even attempted at simulating wind farm construction operations [7,8]. However, this was done for the case of Egypt presenting different challenges, taking into consideration different parameters and using the Stroboscope software [4].

In this paper, the on-shore wind farm construction process will be modeled as well, but for a specific challenging site in Lebanon, i.e. Falougha, using another simulation software, namely AnyLogic 6.9.0 (Educational Version) [9] and by setting up different conditions and parameters. The overarching goal is to develop a generic and dynamic discrete-event simulation model that can be adopted by contractors in order to plan and optimize the construction process of on-shore wind farms in Lebanon and elsewhere.

2. Methodology

In order to achieve the main objective, the paper addresses issues in two specific task areas. The first task consists of identifying the phases and activities of the whole wind farm construction process and determining the activities' typical required resources and daily outputs. The second task comprises designing the simulation model of the construction process using AnyLogic [9] then optimizing the whole process.

2.1. Construction Process Activities

The construction process of on-shore wind farms can be divided into five main packages. [1,2,8] The first one consists of conducting a topographical survey to the land where the wind farm will be constructed. Next, the internal roads are constructed and prepared so that trucks and cranes can move around the site to complete the other construction steps. The third package consists of constructing the turbines' foundations. The fourth one entails excavating the electrical trenches as well as loading the electrical cables. Finally, the last package involves erecting the wind turbines.

In the next subsections, daily output values and corresponding crews were first extracted from the RS Means Building Construction Cost Data (71th edition) book [10] then adjusted according to construction practices in Lebanon.

2.1.1. Topographical Survey

The resources required for this activity consist of a surveying crew with a laser transit and the daily output is 13,355 m^2/day.

2.1.2. Roads Construction

The roads construction package can be divided into two main parts. The first one consists of cut/fill operations to obtain the required slopes and widths of the roads on which trucks will be operating between turbines. The activities involved are: cutting soil, hauling, filling soil and compaction with typical daily outputs of 92 Bank m^3 (BCM), 240 BCM, 765 Loose m^3 (LCM) and 990 Compacted m^3 (CCM) respectively. A truck is needed for all cut, fill and hauling operations. Besides a truck, a cut operation requires an excavator while a fill operation requires a loader. Compaction's only resource is a compactor. Note that all vehicle-type resources involve an additional resource, i.e. an operator.

The second part consists of constructing the roads once cut and fill is complete. The activities involved in this part are overlaying, grading, watering, aggregate base compaction and testing compaction with daily outputs of 570 m^3, 335 m^2, 2500 m^2, 990 CCM and 32 tests respectively. A road crew is required for the first three activities, in addition to an aggregate truck, a grader and a water truck respectively. Aggregate base compaction requires a compactor which is the same one required for fill compaction.

2.1.3. Foundation Construction

Foundation construction consists of steel reinforcement installation, formwork and pouring concrete and curing. Their respective daily outputs are 3.2 tons, 85 m^3 and 510 m^2. A foundation crew is needed for the first two activities. A concrete truck is additionally needed for the second and two common laborers for curing.

2.1.4. Electrical Works

This package consists mainly of two activities; loading electrical cables with a daily output of 110 m and excavation of electrical trenches with an output of 306 BCM. Loading cables requires a main crane and an electrical cable truck. Electrical trenches excavation requires an electrical crew as well as an excavator.

2.1.5. Turbine Installation

A modern wind turbine is made of three main parts: the tower, the nacelle and the blade hub connecting all three blades as shown in Figure 1.

Figure 1. Wind Turbine Components

The first activity of this package consists of placing the tower at the assigned turbine location according to the as-designed layout. It is worth mentioning that the success of wind farm projects depends on precise turbine placement because meters can mean megawatts.

The second activity consists of tilting the nacelle, lifting, positioning and bolting it. The same series of activities is then repeated for the hub connecting all three blades. Four towers can be loaded and four nacelles can be tilted daily. Lifting and positioning either the nacelle or the blade hub occurs at a daily output of 2, while bolting occurs only at 1. A main crane is required for each of these activities except for bolting which only requires a bolting crew. This crew is also needed for positioning the nacelles and hubs. In addition to those resources, a secondary crane is required for nacelle tilting and a tower truck for tower loading.

2.2. Simulation Model

The construction process was modeled using AnyLogic 6.9.0 (Educational Version) software. It is commonly known for being the only simulation tool that brings together Discrete Event, System Dynamics and Agent Based methods within one model development environment [9].

The five activities or packages previously described in Section 2.1 were modeled using the Discrete Event Simulation component of AnyLogic. Their processes are depicted in Figure 2 and referred to by 1, 2a-2b, 3, 4, and 5 respectively.

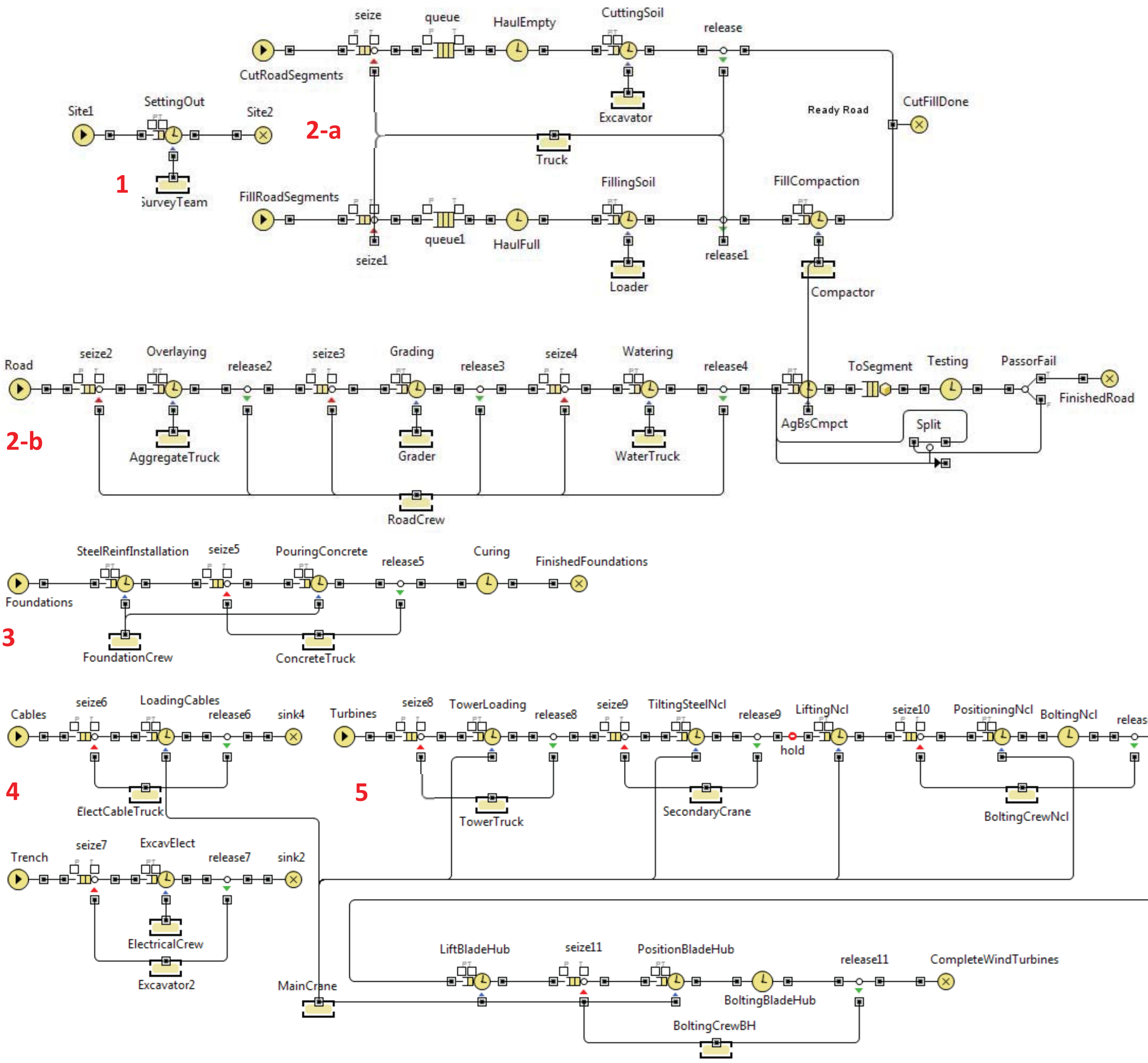

Figure 2. AnyLogic Model of the Construction Process

The main elements used to model the wind farm construction process are the following: *Source*, *Sink*, *Service*, *Delay*, *Resource Pool*, *Seize*, *Release*, *Select Output*, *Batch* and *Copy*.

The *Source* generates resources (entities) and is used in our model to represent the main resource(s) for each phase, e.g. site, road, soil, foundations, cables, turbines, etc. The most important property of the *Source* element is the arrival rate. The software offers an option to inject entities to that source when a certain condition occurs. In the case of this model, the conditions depend on the activities' sequencing.

The *Sink* is used as a discharge point for the entities generated by the *Source*. In this model, sinks are found at the end of each phase. These elements do not have any specific property. However, they are important to place a condition on when the run should end. This is defined in the model as follows:

```
CompleteWindTurbines.count() == TurbinesEa
&& sink4.count() == CablesLM
&& sink2.count() == TrenchCM;

stopSimulation();
```

The *Service* and *Delay* elements are used to represent construction activities. The difference between the two in modeling is that in the first one, resources are required for the activity to take place, while the second does not require any resource to be performed. Their most important property is the delay time per entity which is the inverse of the daily output. An additional property specific to the *Service* is the amount of each resource required for the activity to take place. In most cases, this number is equal to one. A *Resource Pool* is connected to a *Service* and represents the resource that the activity needs to get executed. In this model, it represents equipment (paver, truck, loader, etc.) and labor (foundation crew, bolting crew, etc.). In case a *Service* requires more than one resource, a *Seize* and *Release* elements are added before and after the *Service* respectively to seize a resource from the *Resource Pool* and release it after the service is complete.

The *Resource Pool* sizes are the most important parameters for optimization. They are the ones that can be monitored and varied to find the optimum number of resources leading to the shortest execution time with the lowest cost.

The *Select Output* element is used when there are two possible alternatives an entity can take. In our model, it was used to check whether a certain road segment passed or failed the compaction test (i.e. last part of 2-b process in Figure 2). In case of failure (e.g. 20% chance), the compaction process is repeated. It can also be used to stop the installation of turbines when the wind speed exceeds a pre-set required threshold until the wind speed goes down to the required value. This pause/ stop action can be modeled using the *Hold* element as shown below:

```
WindSpeed = random()*18;
if(WindSpeed > 14)
hold.setBlocked(true);

if(WindSpeed <= 14)
hold.setBlocked(false);
```

The *Batch* and *Copy* work in an opposite way. *Batch* converts a certain number of entities into one, while *Copy* is used to turn one entity into several. In our model, it is used at only one point, to convert m^3 into road segments which is required because compaction output is defined in m^3 while testing output is defined per road segment. Therefore, each 100 m road segment is tested only once.

Finally, the time of each phase needs to be recorded. Therefore, each time a *Sink* reaches the number of resources initially injected in the *Source*, the time is recorded as follows:

```
if(CutFillDone.count() = CutCM+FillCM)
phase2 = time();
```

Regarding sequencing, the model contains eight *Sources*. In order to know when to inject the required quantities in each *Source*, sequencing the activities is required. In fact, as mentioned above, a *Source* has a property called arrival rate and in this case it will be defined manually, i.e. conditions were put on how many resources are available and at what times. For instance, at time 0, the whole site area is injected into "*Site1*" (Part 1 in Figure 2). Once surveying is done, all cut and fill material is injected in "*CutRoadSegments*" and "*FillRoadSegments*" (Part 2-a in Figure 2) as follows:

```
Site2.count() == SiteAcres;

CutRoadSegments.inject(CutCM);
FillRoadSegments.inject(FillCM);
```

Using a similar syntax, the rest of the activities were sequenced by setting, for each, different conditions. When all the soil is cut and/or filled as required

(“*CutFillDone”*, Part 2-a in Figure 2), the road construction begins (Part 2-b in Figure 2). On the other hand, foundation construction (Part 3), cables loading and excavation for electrical trenches (Part 4) can begin simultaneously when the roads are ready signaled by “*FinishedRoad*”. Each time a foundation is complete, i.e. “*FinishedFoundations”,* the installation of one wind turbine begins and proceeds with all aforementioned stages in Subsection 2.1.5 (Part 5).

3. Case Study and Results

3.1. Falougha Case Study

The site selected for the case study is located in the region of Dahr El Baydar, Lebanon, precisely in Falougha. The choice of this particular site at the coordinates 33°49'4.36", 35°45'41.20" was made due to several reasons, mainly because it is a public property and it is isolated thereby preventing the high voltage effects from harming people. It is also a non-vegetated open space with neither dwellings nor infrastructure. Above all, the wind power in the area is great.

As a first approach to the site investigation process, an examination of the geological map and the Google Earth view of the site were done. From the geologic maps of Lebanon and the geologic study done by the American University of Beirut on Lebanon [11], it was found that the site is located above lower-mid cretaceous formation which is mainly composed of a thick layer of limestone. The water table is at a depth greater than 200 meters [11]. It was thus decided that the site is adequate for wind turbine construction.

In order to determine the total site surveying area, the Falougha region was located on Google Earth then loaded into AutoCAD. The area was found to be 429 acres. Given an uninhabited and relatively large site, large turbines were selected namely Vestas V80 with a power of 2 Megawatts (MW) [12]. Each of its 3 blades is 39 meters long with an 80 meters rotor diameter. The tower is 65 meters high and the total weight of the turbine is 230 tons [12]. In this case study, 30 V80 turbines were distributed over the area in question and arranged according to the layout in Figure 3. The detailed analysis regarding the choice of turbines type, their number and their layout was carried out separately and is, however, not included in this paper.

Based on this turbine layout, road paths were then designed (Figure 3). For the roads, it is essential to start by drawing the horizontal and vertical alignments. In order to achieve that, certain specifications were followed. For instance, the maximum allowable longitudinal slope for such a project is 10%. [13].

Figure 3. Aerial View of the Site (Turbine locations and horizontal alignment are shown)

The turning and longitudinal radii should not be less than 32 m and 200 m respectively [13] and the road width for wind farms is around 10 m. [13]. Based on these specifications and using AutoCAD, the horizontal alignment was traced and then imported to Google Earth as shown in Figure 3.

The next step involved acquiring the elevation profiles of the road segments’ horizontal alignment from Google Earth. These elevation profiles were imported back to AutoCAD where the vertical alignments were traced according to known specifications as shown in Figure 4. Using the correct scale, the cut and fill areas were calculated then multiplied by 10 m, the required road width for wind farms. The cut and fill quantities were found to be 78, 208 m^3 and 73,450 m^3 respectively.

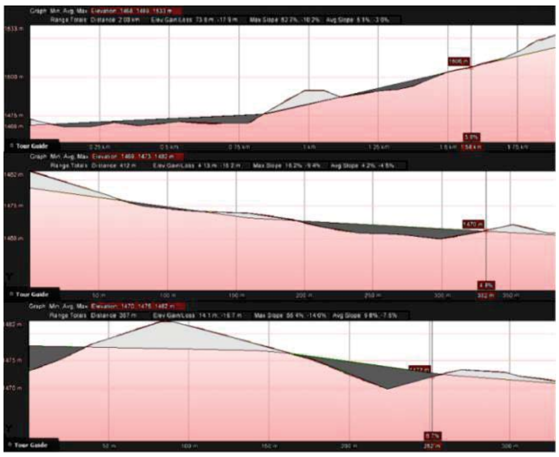

Figure 4. Three Road Segments Elevation Profiles and Vertical Alignments

The road length determined using Google Earth is 6.6 km. The roads’ total area is thus 66,000 m^2, a data required for grading and watering. Assuming a sub-base of 30 cm, the volume for overlaying and compaction was computed to be 19,800 m^3.

As for foundations works, a typical foundation design for Vestas V80 wind turbines [14] was adopted and is shown in Figure 5. Using these dimensions, the volume of concrete and area of curing for each of the 30 foundations were calculated, 320 m^3 and 256 m^2 respectively. To find the quantity of steel needed, a unit weight value of 130 kg/m^3 (typical for heavy industrial projects [15]) was adopted. It was found that the weight of steel needed for each foundation is around 42 tons.

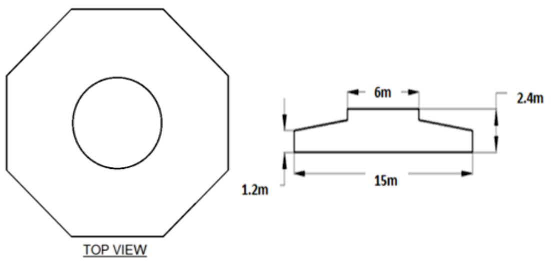

Figure 5. Turbine Foundation Dimensions

According to the total road length computed earlier, the length of electrical cables should be 6.6 km. Assuming that the trench is 2 m wide and around 2 m deep, the total quantity to be excavated is 28,165 m^3.

3.2. Results and Evaluation

Based on computed daily outputs (Subsection 2.1) and Falougha's specific construction works quantities (Subsection 3.1), the generic simulation model (Figure 2) was run, with only one resource of each type, and preliminary scheduling information (Figure 6) together with resources' utilization rates (Figure 7) were obtained.

At a first glance, it is apparent that the total project duration (2,228 working days) is unreasonable and utilization rates of the different resources are very unbalanced. In fact, eight resources have a utilization rate equal or very close to 1 while, seven other resources have a utilization rate ranging between 0.019 and 0.109. This implies that some resources are idle most of the time while others are fully active. Therefore, the number of resources needs to be efficiently chosen according to site and operations requirements. For instance, the resources "Excavator" and "Loader", with a relatively low utilization rate, depend on the resource "Truck" (utilization rate>0.92). In other words, these resources are idle for long periods of time due to the lack of trucks. Increasing the number of trucks will thereby increase the utilization rate of "Excavator" and "Loader".

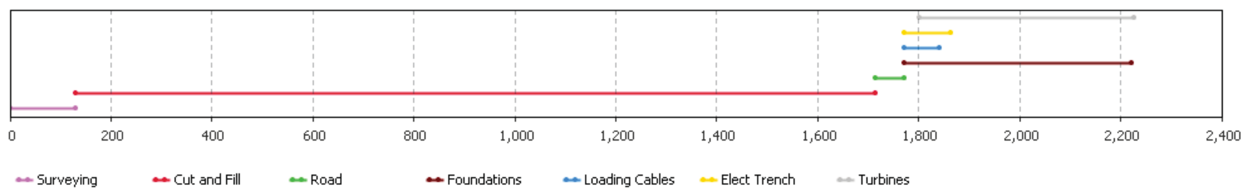

Figure 6. Gantt chart of the Falougha's Wind Farm Construction Process (in working days)

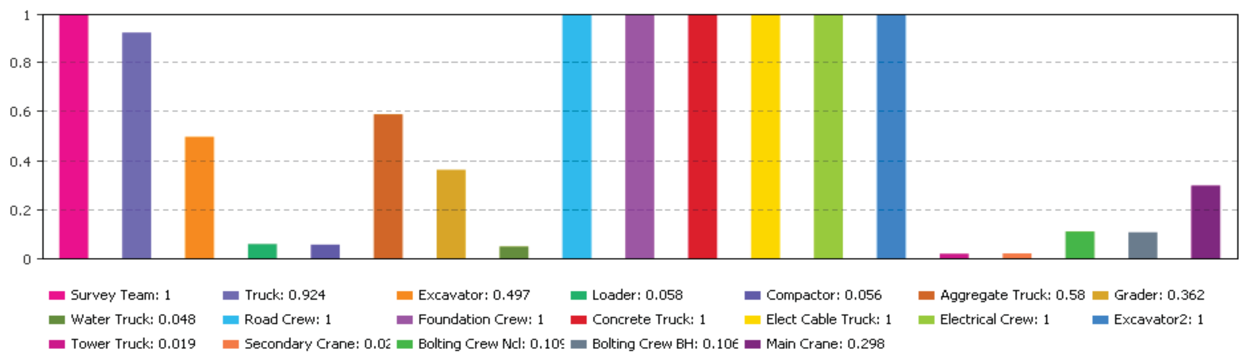

Figure 7. Resource Utilization Rates of the Falougha Wind Farm Project

It was thereby imperative to optimize the process by minimizing time while keeping the utilization rate of all resources as high as possible. For instance, optimizing the number of resources used on more than one activity, such as "Main Crane", is of paramount importance.

Using trial and error, the model was rerun to find ranges of optimum number of resources. AnyLogic 6.9.0 (Educational Version) offers a type of experiment called

"Parameters Variation". It allows the user to select ranges and a step for different parameters and get results for all possible combinations falling under these ranges. Independent phases were optimized separately by varying only their related resources while dependent phases or activities were optimized together, each time refining the ranges based on the results. For each variation, the duration and utilization rates were monitored. After several runs, the combination of resources leading to an optimal scenario was found to be as follows: six survey teams, 10 excavators, two loaders, 19 trucks, two compactors, nine aggregate base trucks, seven graders, one water truck, 16 road crews, 16 foundation crews, four concrete trucks, three electrical crews, three excavators for trenches, two electrical cable trucks, one secondary crane, five main cranes, two bolting crews for nacelles, two bolting crews for blade hubs, and one tower truck. This combination of resources led to the following Gantt chart (Figure 8) and utilization rates diagrams (Figure 9). The results have greatly improved; the duration has significantly decreased while the utilization rates have increased and become more leveled.

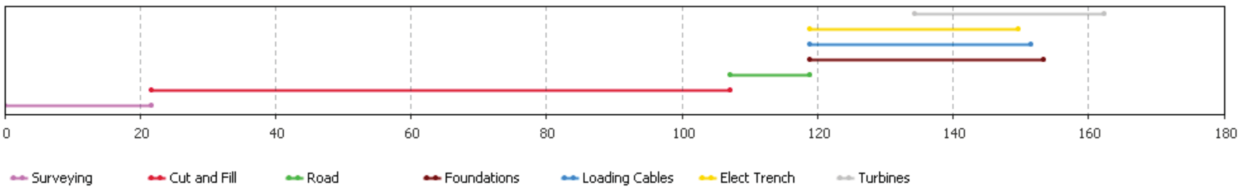

Figure 8. Optimized Gantt chart of the Falougha's Wind Farm Construction Process (in working days)

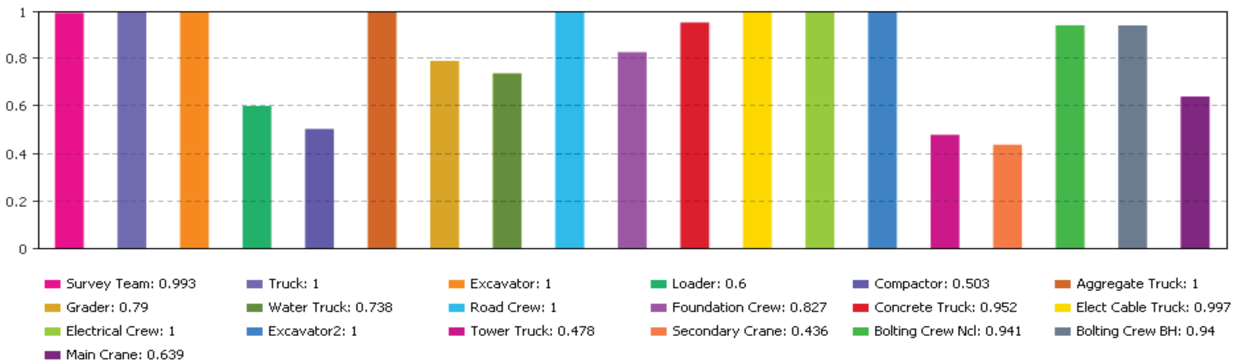

Figure 9. Optimized Resource Utilization Rates of the Falougha Wind Farm Project

Table 1. Comparison between Initial and Optimized Duration Results (in working days)

	Surveying	Cut & Fill	Road	Foundation	Loading Cables	Electrical Trenches	Turbine Installation	**Total**
Initial	130	1,584.28	58.27	450.5	67.78	92.1	427	**2,228**
Optimized	21.82	85.26	11.88	34.5	32.61	30.7	27.83	**162.3**
Ratio (I/O)	6	18.6	4.9	13.1	2.1	3	15.3	**13.7**

Table 1 depicts the initial scenario where only one resource of each type was applied in comparison to the optimized scenario. In this case, all activities durations are shorter and the resulting project duration is around 163 working days (7.5 months assuming 5 working days per week) compared to 2,228 working days (equivalent to approximately 8.5 years). It is important to note that the construction of the electrical substation and other related electrical activities were not included in this study and did thereby not contribute to the project duration.

On the other hand, project duration is not enough to assess and evaluate whether the performance was optimized. The utilization rate needs to be evaluated as well. According to Figure 9, the majority of resources (11 out of 19) have a utilization rate greater than 0.9. The mean utilization rate in the initial scenario was equal to 0.53 and it increased to 0.83 after optimization. The standard deviation was 0.419 and it decreased to 0.198 which means that the use of the different resources has become quite more balanced.

Based on the aforementioned results, AnyLogic, when compared to other software, proved to be very effective in simulating construction operations using one of its modeling paradigms, DES. It does not require advanced skills in programming, is very flexible and can easily incorporate changes and updates, while allowing modeling of any desired situation with any level of details. It can display results in different formats (e.g. graphs, histograms, etc.) at runtime and can easily be linked to other software (e.g. MS Excel, GIS, etc.) for data collection and analysis purposes. Most importantly, it includes optimization tools and allows the user to validate simulation results using built-in 2D and 3D animation features. This latter attribute led the authors to take unprecedented steps attempting at animating and visualizing in 3D the whole wind farm construction process for validation purposes. Preliminary results are depicted in Figure 10.

Figure 10. AnyLogic Animation Snaphots

4. Summary and Conclusions

This study modeled on-shore wind farm construction processes using a general purpose simulation tool, AnyLogic. A generic simulation model, based on construction activities' typical daily outputs and crews in Lebanon, was created then was tested by adopting the site of Falougha, Dahr El Baydar, Lebanon. Initial results displayed a long project duration coupled with uneven resource utilization rates. Those were greatly enhanced and improved after optimization in AnyLogic was carried out.

Future work will include cost information and consequently will optimize both project cost and time. A time-cost tradeoff analysis is deemed necessary to reach the most optimal results. Additionally, more efforts will be channeled into 3D animation to further ensure the credibility and validation of the proposed simulation model.

Acknowledgments

The presented work has been supported by Munib and Angela Masri Institute of Energy and Natural Resources. The authors gratefully acknowledge Masri Institute support.

References

[1] Burger, M., Colella, S., Quinlivan, S., and Rousseau, J. Construction of a Wind Turbine Project in the Town of Florida, MA, a Major Qualifying Project submitted to the faculty of Worcester Polytechnic Institute (WPI), 2007.

[2] Carns, D., and Bender, W. Construction of a Wind Farm and Case Study. Central Washington University, Ellensburg, Washington. Online: ascpro0.ascweb.org/archives/cd/2008/paper/CPGT184002008.pdf, Accessed: 18/10/2012.

[3] Hassan, G. The National Wind Atlas of Lebanon, UNDP/CEDRO project. Online: http://www.undp.org.lb/communication/publications/downloads/National_Wind_Atlas_report.pdf , Accessed 10/1/2012.

[4] Martínez, J.C. *STROBOSCOPE: State and Resource Based Simulation of Construction Processes*. Doctoral Dissertation, University of Michigan, 1996.

[5] Kamat, V. R., and Martinez, J. C. Validating Complex Construction Simulation Models Using 3D Visualization. *Systems Analysis Modelling Simulation*, 43(4): 455-467, 2003.

[6] Khoury, H. M., Kamat, V. R., and Ioannou, P. G. (2007). Evaluation of General-Purpose Construction Simulation and Visualization Tools for Modeling and Animating Airside Airport Operations. *Simulation: Transactions of the*

Society for Modeling and Simulation International, 83 (9): 663-679, 2007.

[7] Nassar, K., El Masry, M., and Osman, H. Simulating the Effect of Access Road Route Selection on Wind Farm Construction. In *Proceedings of the 2010 Winter Simulation Conference (WSC)*, pages 3272 - 3282, Baltimore, MD, 2010.

[8] Atef, D., Osman, H., Ibrahim, M. , and Nassar, K. A Simulation-based Planning system for Wind Turbine Construction. In *Proceedings of the 2010 Winter Simulation Conference (WSC)*, pages 3283 – 3294, Baltimore, MD, 2010.

[9] The AnyLogic company. About the AnyLogic Company. Online: http://www.anylogic.com, Accessed: 10/01/2014.

[10] Waier, P., Charest, A., RSMeans Eng Dept, and RSMeans Inc. *RSMeans Building Construction Cost Data*, 71th edition. R.S. Means Company, United States of America, 2013.

[11] Walley, C. D. Some Outstanding Issues in the Geology of Lebanon and their Importance in the Tectonic Evolution of the Levantine Region, *Tectonophysics*, 298, 1-3, 37-62, 1988.

[12] Coleman, D. Transporting Wind Turbines. White Paper, Canada, 2009.

[13] Technology R&D. Road, Crane Pad and Hardstand Specifications for Vestas Turbines. 2010.

[14] YourSpreadsheets Inc. Reinforcement Estimates Online: http://www.yourspreadsheets.co.uk/reinforcement-estimates.html, Accessed: 8/8/2013

[15] Bentley-RAM/STAAD Solution Center. Design of Wind Turbine Foundations. Online: ftp://ftp2.bentley.com/dist/collateral/Web/Building/STAADPro/Wind_Turbine_Footing_Design.pdf, Accessed: 8/10/2011