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Zita Zoltay Paprika

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PREFACE

It is a pleasure to welcome the more than 100 researchers at the 31st European Conference on Modelling and Simulation (ECMS) conference from May 23rd till May 26th 2017, and have their research collected in this proceedings.

The 31st ECMS conference will be hosted by Corvinus University of Budapest and Budapest University of Technology and Economics. Organizing ECMS 2017 is a great opportunity for these two long-established Hungarian universities to give rise to a fruitful cooperation – bringing the two geographically very close institutions even closer. Modelling and simulation are exciting and useful methodologies to study various problems in several research fields.

Besides the disciplines closely related to the two organizing universities (business, economics, finance, engineering, kinematics, mechanisms, mechanical simulations), we are eager to get acquainted with all the fields related to the conference. The main goal of the conference is to share your research questions and expertise with the ECMS community as well. It is always a nice experience to bring inspired researchers together. This conference is a forum to communicate and share new ideas and methods that will foster the development across all aspects of computational methods and their applications in modelling and simulation of different fields of applied science.

We hope you will find your field of interest in our conference tracks which cover exciting topics about intelligent systems, virtual prototyping, operating simulation, applied modelling, simulation and optimization, controlling of technological processes and the modelling and simulation of cases in finance, economics and social sciences.

The high prestige of the ECMS 2017 program is enhanced by our two keynote speakers, one from the field of economics, and the other from the field of engineering. István P. Székely – director of the European Commission, Economic and Financial Affairs, and honorary professor of Corvinus University of Budapest –will talk about the economic modelling and economic policy surveillance in Europe. Jin Ooi – professor of particulate solid mechanics at the University of Edinburgh – will give a lecture on discrete element modelling of granular materials.

The conference will also give you the opportunity to visit Budapest, one of the most exciting cities in Europe. In addition to a decent scientific program, we sincerely hope that you will take a chance to enjoy the culture of Budapest.

We are looking forward to welcoming you in Budapest!

Zita Zoltay Paprika, Péter Horák

Budapest, May 2017

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KEYWORDS

Weibull distribution, approximation, lognormal distribution, gamma distribution, beta distribution, wind speed, statistics

ABSTRACT

Background. This paper study statistical data gathered from wind turbines located on the territory of the Republic of Poland. The research is aimed to construct the stochastic model that predicts the change of wind speed with time. **Purpose.** The purpose of this work is to find the optimal distribution for the approximation of available statistical data on wind speed. **Methods.** We consider four distributions of a random variable: Log-Normal, Weibull, Gamma and Beta. In order to evaluate the parameters of distributions we use method of maximum likelihood. To assess the the results of approximation we use a quantile-quantile plot. **Results.** All the considered distributions properly approximate the available data. The Weibull distribution shows the best results for the extreme values of the wind speed. **Conclusions.** The results of the analysis are consistent with the common practice of using the Weibull distribution for wind speed modeling. In the future we plan to compare the results obtained with a much larger data set as well as to build a stochastic model of the evolution of the wind speed depending on time.

INTRODUCTION

This work is devoted to the problem of stochastic modeling of speed of wind, which is used to generate electrical power in wind plants located on the territory of the Republic of Poland. As a first step several distributions for accuracy of the wind speed approximation will be examined. For this purpose Log-normal, Weibull, Gamma and Beta are chosen. All these distributions have shape-location-scale parametrisation. For statistical data processing the authors used Python 3 with `numpy`, `scipy.stats` (see Jones et al. (2001)) and `matplotlib` (see Droettboom et al. (2017)) libraries and also `Jupyter` (see *Project Jupyter home* (2017))—an interactive shell. We used books (see Norman L. Johnson (1994, 1995); Nelson (1982)) as reference materials for distributions properties. Articles

Proceedings 31st European Conference on Modelling and Simulation ©ECMS Zita Zoltay Paprika, Péter Horák, Kata Váradi, Péter Tamás Zwierczyk, Ágnes Vidovics-Dancs, János Péter Rádics (Editors)
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(see Frchet (1927); Weibull (1951)) are the primary sources in which the Weibull distribution is presented for the first time. Articles (see Lun and Lam (2000); Seguro and Lambert (2000); Bowden et al. (1983); Yeh and Wang (2008); Islam et al. (2011); Garcia et al. (1998)) describe the use of the Weibull distribution in the modeling of wind turbines and wind speed.

THE DESCRIPTION OF THE STATISTICAL DATA STRUCTURE

The set of statistical data is stored in the file `csv` consisting of the following columns:

1) T — time of fixation of wind speed and direction by sensors installed on the wind power turbine (hh:mm format);
2) X_1 — output power of wind turbine [kW] (the negative values mean the power is consumed rather then generated);
3) X_2 — wind speed [m/s] (measured by anemometer installed at the top of wind turbine nacelle);
4) X_3 — wind direction [deg] (measured by anemometer installed at the top of wind turbine nacelle; measured clockwise, the value 0 to the N);
5) X_4 — wind speed 10 m [m/s] obtained at 10 m above the ground m;
6) X_5 — wind direction 10 m [deg] (obtained at 10 m above the ground; measured clockwise, the value from 0 to the N);
7) X_6 — wind speed 50 m [m/s] (obtained at 50 m above the ground);
8) X_7 — wind direction 50 m [deg] (obtained at 50 m above the ground; measured clockwise, the value ftom 0 to the N).

The indicators of wind speed and direction were read out from the sensors every 10 minutes for about 9 months. In total, the table contains 39606 entries.

To make an initial choice of distributions that may be suitable for wind speed approximation, the histograms of wind speed are drawn. Visual assessment of these histograms suggest that the adequate choice will be a “heavy-tailed” distribution. But for the wind direction approximation these distributions are not suitable, as can be seen from the figure 1.

To read out the data we used the function `genfromtxt` from `numpy` (see Jones et al. (2001)) lib:

```
ws1, ws2, ws3 =
    np.genfromtxt('data.csv',
    delimiter=';', skip_header=True,
    usecols=(2, 4, 6), unpack=True)
```

where `'data.csv'` is data file, `delimiter=';'` is columns separator, `skip_header = True` specifies ignoring of the first line as the names of the columns, `usecols=(2, 4, 6)` makes function to use only 2, 4, 6 columns (numbering begins with zero) and `unpack=True` — contents of each column should be written in separate arrays `ws1`, `ws2` and `ws3` for further analysis of the data separately.

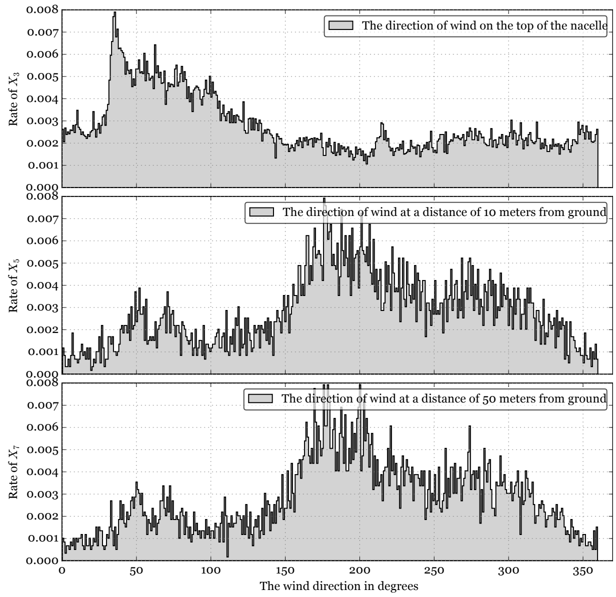

Fig. 1. Histogram of wind direction at three levels of height

PROBABILITY DISTRIBUTIONS

Each of distributions is parameterized by three parameters: α — shape factor, l — location factor and s — scale factor. In the case of the beta distribution the second scale factor is added, denoted by β-letter. All distributions parameters are positive real numbers: $\alpha, \beta, s, l \in \mathbb{R}$, $\alpha, \beta, s > 0$, $l \geqslant 0$.

The probability density function (PDF) of a Log-Normal random variable X is:

$$f_{LN}(x; \alpha, l, s) = \\ = \begin{cases} \dfrac{1}{(x-l)\alpha\sqrt{2\pi}} \cdot \\ \quad \cdot \exp\left(-\dfrac{1}{2}\left(\dfrac{\ln(x-l) - \ln s}{\alpha}\right)^2\right), & x \geqslant l. \\ 0, & x < l. \end{cases}$$

The probability density function of a Weibull (see Frchet (1927); Weibull (1951)) random variable X is:

$$f_W(x; \alpha, l, s) = \\ = \begin{cases} \dfrac{\alpha}{s}\left(\dfrac{x-l}{s}\right)^{\alpha-1} \exp\left[-\left(\dfrac{x-l}{s}\right)^{\alpha}\right], & x \geqslant l, \\ 0, & x < l. \end{cases}$$

The probability density function of a Gamma random variable X is:

$$f_\Gamma(x; \alpha, l, s) = \begin{cases} \dfrac{(x-l)^{\alpha-1} \exp\left(-\frac{(x-l)}{s}\right)}{s^\alpha \Gamma(\alpha)}, & x \geqslant l, \\ 0, & x < l. \end{cases}$$

where $\Gamma(\alpha)$ is gamma-function.

The probability density function of a Beta random variable X is:

$$f_{\mathcal{B}}(x;\alpha,\beta,l,s) = \\ = \begin{cases} \dfrac{\Gamma(\alpha+\beta)}{s\Gamma(\alpha)\Gamma(\beta)}\left(\dfrac{x-l}{s}\right)^{\alpha-1}\left(1-\dfrac{x-l}{s}\right)^{\beta-1}, & x \geqslant l, \\ 0, & x < l. \end{cases}$$

If in PDF formulas of Log-Normal, Weibull and Gamma distributions let $l = 0$, and for Beta distribution let $s = 1$, we get the formulas of distributions most frequently used in Norman L. Johnson (1994); Nelson (1982).

DETERMINATION OF DISTRIBUTIONS PARAMETERS

In `scipy.stats` (see Jones et al. (2001)) following objects are defined: `lognorm`, `weibull_min`, `gamma` and `beta`. These objects implement distributions we work with. Every one of these objects has PDF function `pdf(x, a, [b,] loc, scale)` and CDF (cumulative distribution) function `cdf(x, a, [b,] loc, scale)`, where `x` — function argument, `a`, `b` — shape parameters α, (and β for Beta-distribution), `loc` and `scale` are location and scale parameters.

For parameters estimation of our distributions the library `scipy.stats` provides the function `fit(data)`, which calculates the parameters of distributions by maximum likelihood method and the empirical data. We used this function to calculate parameters of the considered distributions. Then we used `pdf` and `cdf` functions to compute values of the probability density function and cumulative distribution function.

There is the example of the code for the case of Log-Normal distribution:

```
s, loc, scale =
    scipy.stats.lognorm.fit(ws1)
xs = np.linspace(np.min(ws1),
    np.max(ws1), 1000)
logN_PDF =
    scipy.stats.lognorm.pdf(xs, s,
    loc, scale)
logN_CDF =
    scipy.stats.lognorm.cdf(xs, s,
    loc, scale)
```

The results are presented graphically on figures 2–9.

The figures were plotted for theoretical distributions, the parameters of which have been determined on the basis of the entire dataset. From the analysis of the quantile-quantile plots (Q-Q plots) we can conclude that the Weibull distribution is best suited for approximation of available data (although only slightly), outmatching them only in the approximation of extreme values of a random variable.

We also performed computations with the considered distributions parameterized by only two parameters

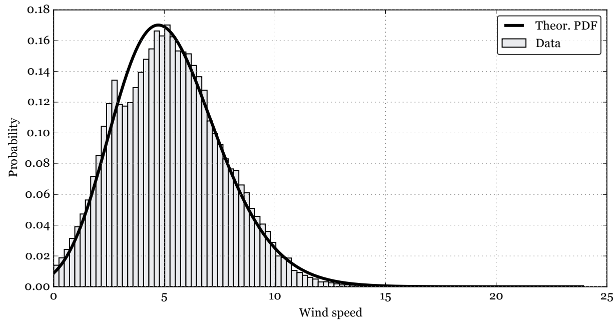

Fig. 2. PDF of **Log-Normal** distribution compared with data histogram

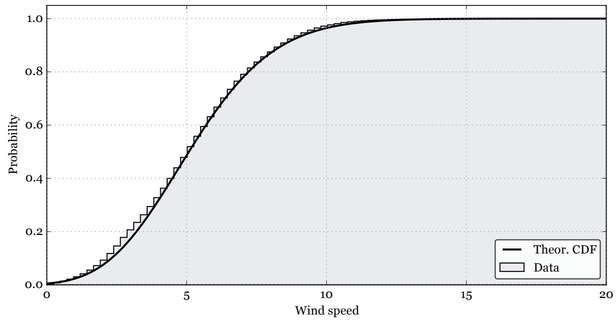

Fig. 3. CDF of **Log-Normal** distribution compared with empirical distribution function

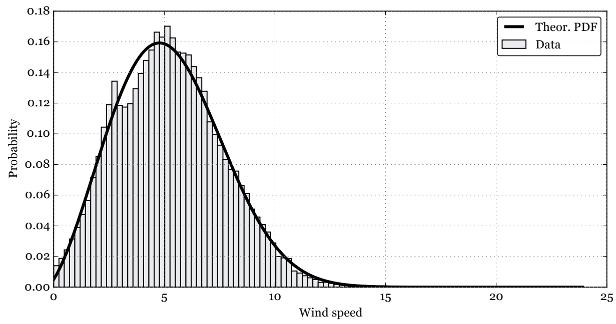

Fig. 4. PDF of **Weibull** distribution compared with data histogram

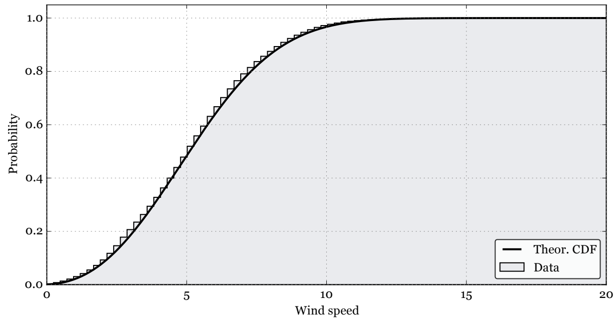

Fig. 5. CDF of **Weibull** distribution compared with empirical distribution function

(let $l = 0$, and for Beta distribution an addition let $s = 1$). After plotting the results of calculations we found out that the two-parameter Weibull distribution has superiority over other two-parameters distributions (Log-Normal, Gamma and Beta), which is not true for

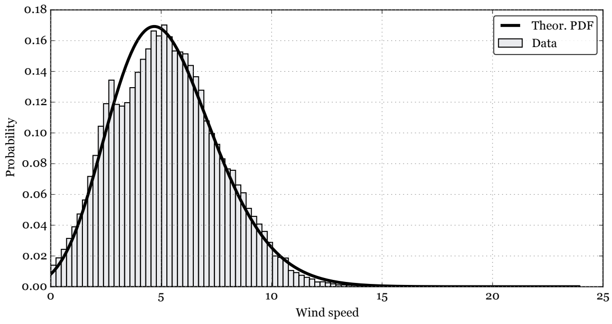

Fig. 6. PDF of **Gamma** distribution compared with data histogram

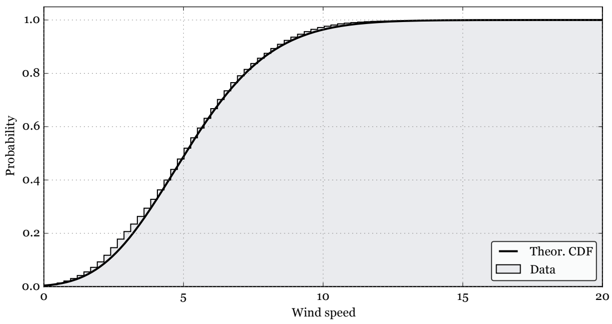

Fig. 7. CDF of **Gamma** distribution compared with empirical distribution function

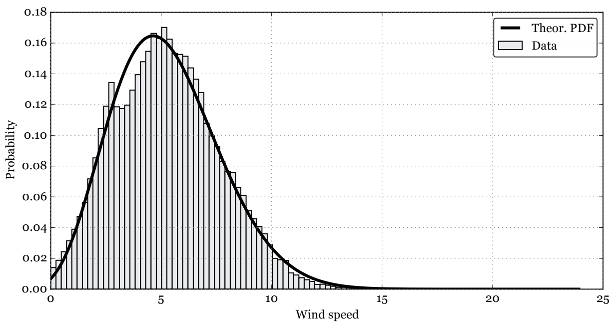

Fig. 8. PDF of **Beta** distribution compared with data histograms

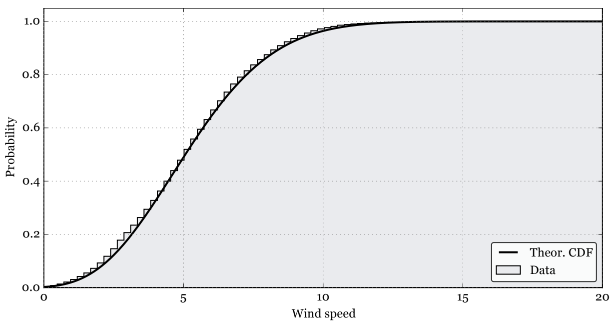

Fig. 9. CDF of **Beta** distribution compared with empirical distribution function

three-parameter case (Fig. 10–13).

CONCLUSIONS

The results of statistical data processing correspond to the results presented in the literature, where Weibull distribution is the most often used distribution for the

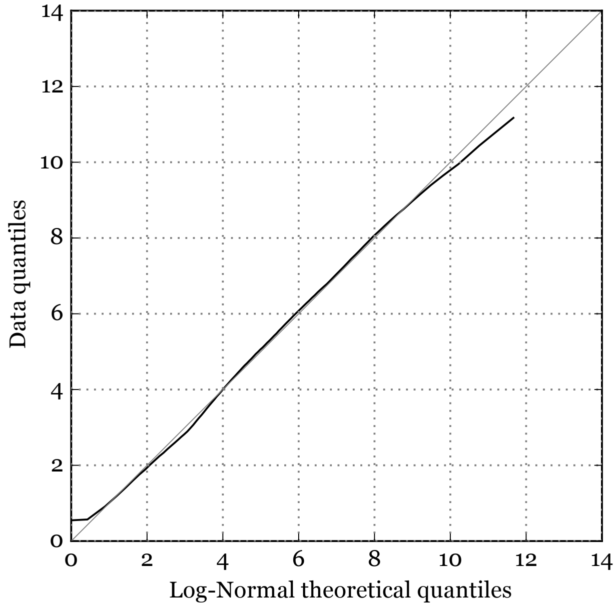

Fig. 10. Q-Q plot for LogNormal distribution

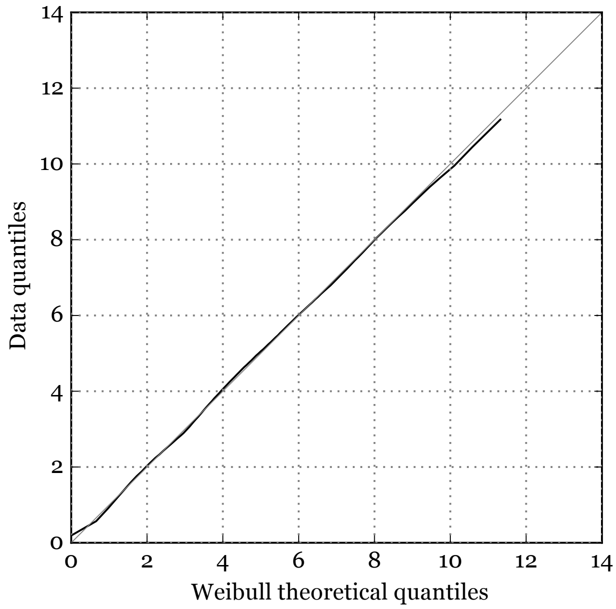

Fig. 11. Q-Q plot for Weibull distribution

wind speed approximation (see Lun and Lam (2000); Seguro and Lambert (2000); Bowden et al. (1983); Yeh and Wang (2008); Islam et al. (2011); Garcia et al. (1998)).

Our future work will be aimed at the construction of stochastic models that can approximate the wind speed depending on time (see Miano and Milano (2015)). On the other hand, we expect to verify the results of this work by using more dilated and large data array.

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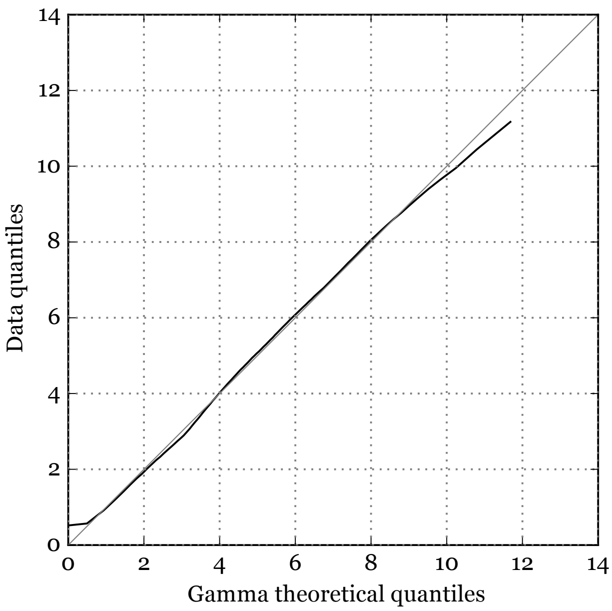

Fig. 12. Q-Q plot for Gamma distribution

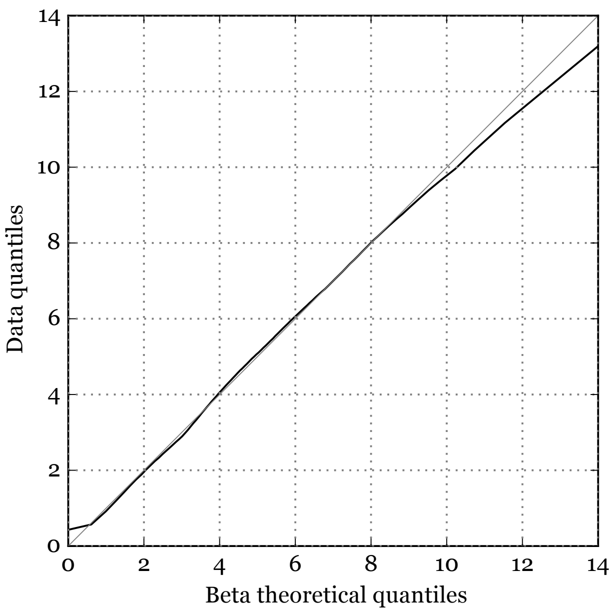

Fig. 13. Q-Q plot for Beta distribution

and Science of the Russian Federation (the Agreement No 02.a03.21.0008). The computations were carried out on the Felix computational cluster (RUDN University, Moscow, Russia) and on the HybriLIT heterogeneous cluster (Multifunctional center for data storage, processing, and analysis at the Joint Institute for Nuclear Research, Dubna, Russia).

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