What Negative Impact does Wind have on the Deadline of a Construction Project? Mathematical Modeling for the Measurement and Optimization of Wind Effects

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Abstract— In regard to economic phenomena such as the expansion of trade, the interactions between markets encouraging companies to cross borders, the research for market in new areas should be accompanied by sufficient knowledge of their own environment and especially the weather conditions. Indeed, the objectives of a construction project (cost, deadline and quality) are affected by a multitude of events, of internal and external origin, such as climate changes when they are severe and abrupt. Certainly, each region is characterized by a specific climate. For some regions, it is rather the wind that remains the most characterizing climate factor. Wind is widely felt in areas exposed to currents such as (trade wind, North wind, *Nordet*, *Harmattan* etc…), in other places we underestimate, see, ignore the effects of wind, particularly on a construction site. Yet, the consequences of ignoring this risk factor can be heavy on a construction company (in terms of late penalty law for example); In fact, if bad weather affects particularly on the initial works: earthworks, foundations, slab; wind effects may proclaim during all the duration of the construction site. The wind affect all project's aspects, quality, cost, safety as well as deadline. Nevertheless there are few studies that were interested in studying relation construction's deadline and wind. Tangier, the city located on the Strait of Gibraltar, where the study was conducted, is exposed to wind whose origin is the Anti cyclone of the Azores, in addition to the local winds that are due to the presence of the two seas and imposing mountains, with a wind that might exceed 220km/h. The equation introduced by this study will allow evaluating (measuring) the impact of wind on the deadline (expressed Δ), it shall encompass all aspects:

- Limiting conditions of equipments existing in construction site (producers' references)

- Recommendations of the standard practice

- Regulation in terms of work's limits conditions in case of wind

The Weibull function that will be used in the study, its formulation will be explained in a simple manner in the heart of the text. The tool introduced at the end, statistically designed in order to manage this risk consists of an iterative system targeting the automation of decision making, searching the minimal of Δ_{Global} and thus creating the optimal planning; it refers to Pareto and MPM management rules.

Construction Site, Risk, Wind, Planning, Assessment, Optimization

I. INTRODUCTION

Every year, several injuries and millions of Euros in terms of damages, are the result of strong winds on construction sites ([4], [5], [8], [12]). These damages and injuries may take place as a result of:

• Using equipments not adapted to the conditions of the wind in the construction site

• Tasks aren't programmed in depending on the state of wind

• Ignorance of the effects of wind on a construction site

• Insufficient information on the state of the wind (incomplete or late) by projects managers.

Should we choose only construction equipments (crane, cherry picker, swing-stages ...) best suited to the wind conditions of a construction site?

However, the security tools to fight against accidents due to the winds do not follow the intensity of the wind, they are standard and limited; Indeed, companies prefer to stop the construction works than expose its staff and equipments to danger, although a construction site insurance is taken out.

Away from risk of damages, the effects of wind impact the partial and overall deadline when a planning does not take it into account [9].

The study will focus on two areas, firstly, confirm the relation Deadline-Wind, by proposing a mathematical model allowing the evaluation, in an advanced stage, of a projected deadline's delay due to strong winds, and secondly to carry out an optimal management for localizing, reducing this construction project external risk's factor.

II. RELATION OF WIND SPEED AND PROBABILITY

A. The Law of Weibull

In different and varied areas such as science, sociology, medicine, humanities..., we are interested in many phenomena which are often the effect of hazard. These phenomena are characterized by the fact that the results of observations vary from one experience to another.

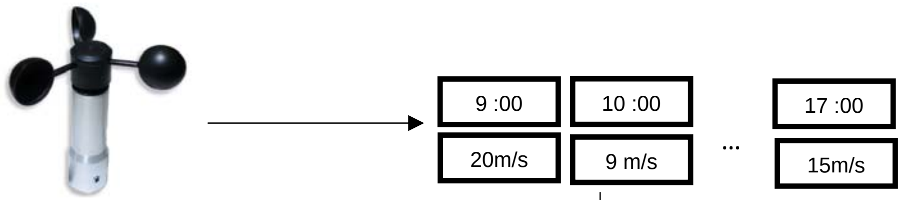
An experience is called random if it is impossible to predict its outcome and if it is repeated under identical conditions, it may give, if the experience is unique, different results. In general, the results obtained vary in a certain area; some results appear more frequent than others. They can be viewed by diagrams, histograms, cumulative frequencies curves, etc., and be characterized by some numerical values such as the arithmetic average. ([1], [6], [13], [14]).

Random experience for our case is the wind speed, the measurement is made using a measuring device such as the anemometer. ([1], [6], [7])

The probability of repetitive events is defined on the basis of the frequency of occurrences of these events. It is based on the notion of repeated and independent tests. The probability is defined as the limit of the relative frequency of observations.

This frequency, expressed as the relation $\frac{n_a}{n}$ (n_a being the number of trials in which the event "a" has been carried out during n independent tests, repeated under identical conditions), knows fluctuations around a limit value which is the probability of the event "a". [1].

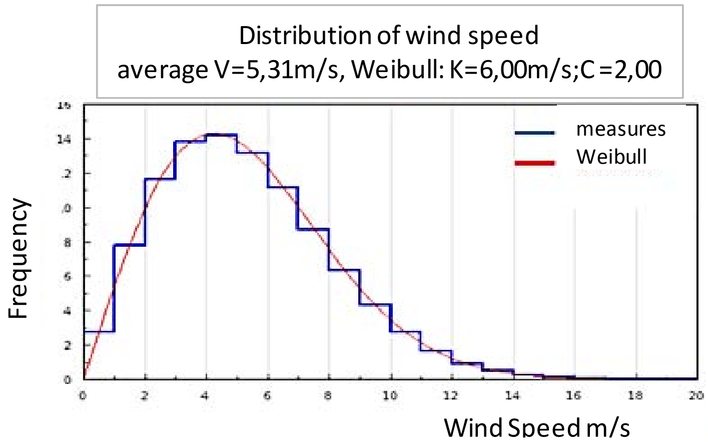
To better understand these concepts of probability, we will project them on the studied case. The following diagram (Figure 1) represents the steps needed to achieve the definition of wind speed probability of a given construction site (Weibull formula).



The anemometer measures wind speed

Wind Speed V(m/s)	0≤V<1	1≤V<2	……	13≤V<14	V≥20
Effective	2	8		2	0

The collected data is grouped by class and gather as a staffing table



The representation of the histogram that can approach the probability law

Fig.1. The necessary steps for the definition of the of the function of probability density

The probability, being the limit of relative frequencies. The blue curve indicates the relative frequencies and the one in red is the probability by reducing the extent of classes, the blue and the red curves become mixed up.

The density of probability of the random variable V (Weibull law) is the mathematical function, approached and expressed as follows:

$$f(v) = \frac{k}{c}\left(\frac{v}{c}\right)^{k-1} exp\left[-\left(\frac{v}{c}\right)^{k}\right] \quad ,v > 0, c > 0 \ ,k > 0$$

And its repartition function:

$$F(x) = 1 - exp\left[-\left(\frac{v}{c}\right)^{k}\right], \quad v > 0$$

With,

p(V) : density of wind speed probability V in m/s

k : form factor of the curve (without dimension)

c : scale factor of the curve (m/s)

B. Modeling of frequencies of wind speeds for each month

Based on existing studies on the wind speed in Tangier (as an example), [3], we note that the distribution of frequencies of wind speed is modeled by the Weibull distribution parameters k and c. This law models the probability that the wind blows so fast on this site. The following figure shows the graphical representation of the probability densities of the first three months.

Fig.2. Aerial view

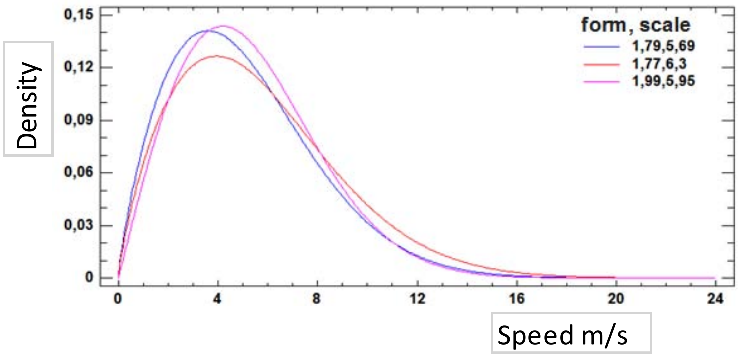


Fig.3. Representation of probability average's densities for the months of Jan., Feb. & Mar., Tangier

The monthly assessment of parameters **K** and **C** of Weibull law on the site of Tangier [3] are shown in the following table:

TABLE 1: Monthly average of factors K and C (estimated shape and scale, Tangier)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
K	1.79	1.77	1.99	2.05	2.21	1.82	1.70	1.77	1.97	2.21	2.15	1.71
C (m/s)	5.69	6.30	5.95	6.11	6.45	6.15	7.14	6.95	7.39	6.67	7.39	6.18

III. DESIGN OF A RISK DELAY MEASURING ON A PROJECT IN RELATION TO A GIVEN SCHEDULE

We will, therefore, define the mathematical function that will allow measuring the delay time expected within a given interval of the wind speed.

Let's consider V to be the random variable for our study of the wind speed at a given moment. The function $Weibull(k_i; c_i)$ in a given period$[t_1; t_2]$, where i means the month concerned.

In this note, the period $[t_1; t_2]$ shall be determined by the duration of each task, likewise we must specify the nature between two tasks, are they dependent or not?

The answer to this question is crucial, because it highlights the most influential tasks on the taking place of the project on the one hand, and on the other hand it gives us a decisive indication concerning the perfect formula of probability to use.

A. Case of non-related tasks:

A first example which shows only one task in order to explain the various stages to detect the level of risk,

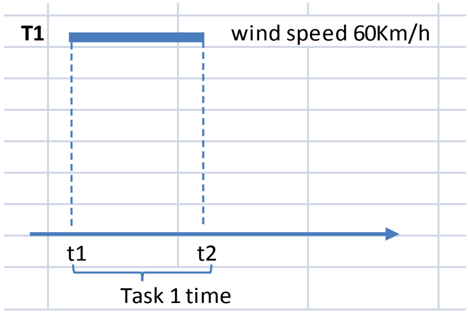


Fig.4. Planning for one task

$$Risk_1 = P\,(V > z),\ z \text{ speed threshold (60 km/h)}$$

$$= \int_z^{+\infty} f(v, k_i, c_i)\,dv$$

$$= \int_z^{+\infty} \left(\frac{k_i}{c_i}\right)\left(\frac{v}{c_i}\right)^{k_i-1} \exp\left[-\left(\frac{v}{c_i}\right)^{k_i}\right] dv$$

$$f(v, k_i, c_i) = \begin{cases} f(v, k_1, c_1) & for\ [t_1; t_2] \subset January \\ \vdots & \\ f(v, k_{12}, c_{12}) & for\ [t_1; t_2] \subset December \end{cases}$$

$Risk_1$ will represent the estimated difference between t_2 scheduled and t_2 real.

On the other hand, if the period $[t_1; t_2]$ was spread on several months, parameters of Weibull law will be assessed by weighted average.

Example:

If, $t_1 = 10$ January, and $t_2 =$ end of February

$$k'_1 = \frac{n_1 * k_1 + n_2 * k_2}{n_1 + n_2}$$

$$c'_1 = \frac{n_1 * c_1 + n_2 * c_2}{n_1 + n_2}$$

n_1 : Number of days included in the month of January

n_2 : Number of days included in the month of February

The case of a schedule of two unrelated tasks:

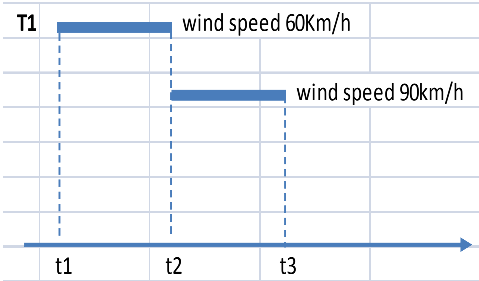


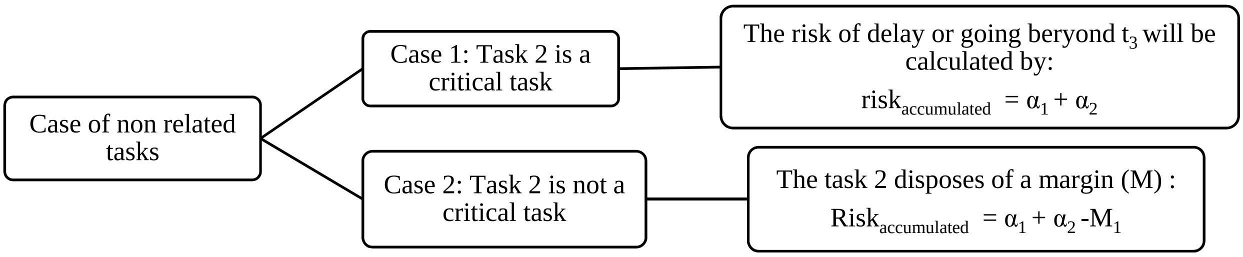
Fig.5. Planning of two unrelated tasks

The risk of task 1 is calculated following the method illustrated in case 1.

Supposing that this risk is worth:

$Risk1 = \alpha_1\%$;

$$Risk2 = \int_{z}^{+\infty} f(v, k_i, c_i)\, dv = \alpha_2\%$$



B. Case of related tasks

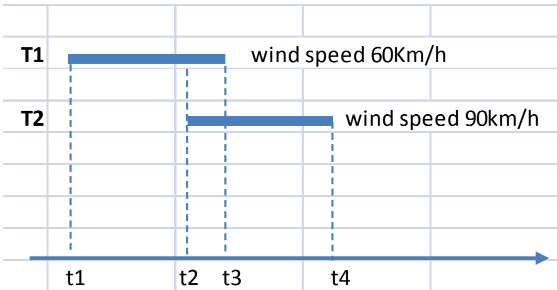


Fig.6. Planning of two related tasks

$R_1 = \int_{z}^{+\infty} f(v, k_i, c_i)\, dv = \alpha_1$, if $t_1 < t < t_2$;

Calculated according to the method detailed in the first case.

$R_2 = P[(V > z1) \cup (V > z2)] = \alpha_2$, if $t_2 < t < t_3$;

R_2 is calculated taking into account the minimal of the two threshold z1 and z2.

$R_3 = \int_{z}^{+\infty} f(v, k_i, c_i)\, dv = \alpha_3$, if $t_3 < t < t_4$

C. General case: related and non-related tasks

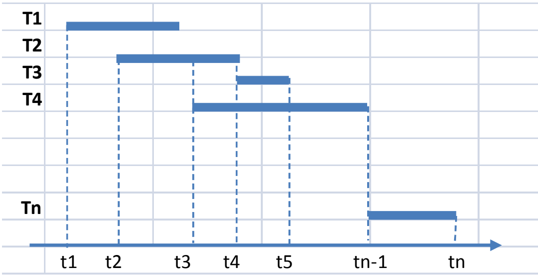


Fig.7. General case

The transformation of the schedule in the form of intervals allows us to determine the risk associated with tasks and to take into consideration the overlaps between tasks in the calculation.

$$I_1 = [t_1, t_2], I_2 = [t_2, t_3], \ldots\ldots, I_{n-1} = [t_{n-1}, t_n]$$

$$R_1 corresponds\ to \rightarrow [t_1, t_2]$$

$$R_2 corresponds\ to \rightarrow [t_2, t_3]$$

$$\ldots\ldots..$$

$$R_n corresponds\ to \rightarrow [t_{n-1}, t_n]$$

In each interval I_i we have a Weibull parameter (c_i, k_i)

Calculation method

The proposed method of calculation allows taking into account the overlaps and the change of parameters (c_i, k_i)

$$R(i) = \int_{\min(z_j)}^{+\infty} f(v, k_i, c_i) dv$$

With, $f(V, K_i, c_i): density\ of\ wibull = \frac{K_i}{c_i}(\frac{V}{c_i})^{K_i - 1} exp^{-(\frac{v}{c_i})^{K_i}}$

$$\Omega = \{[t_1, t_2], [t_2, t_3], \ldots \ldots \ldots, [t_{n-1}, t_n]\}$$

Each period of time will have a number of thresholds which will be determined based on the input task data (starting date, ending date,…), and determined by computer:

$[t_1, t_2]$	z_1
$[t_2, t_3]$	z_1, z_2
…….	……….
$[t_{n-1}, t_n]$	z_{n-2}, z_{n-1}, z_n

The thresholds are set by:

- Manufacturer instructions, the code of practice (impracticability of the construction site …) regulation fixing the work conditions in case of wind, etc.

The global risk of the project

$$R_{total} = \sum_{i=1}^{n-1} R(i) = \sum_{i=1}^{n-1} \int_{\min(z_j)}^{+\infty} f(v, k_i, c_i) dv$$

D. Application on an example

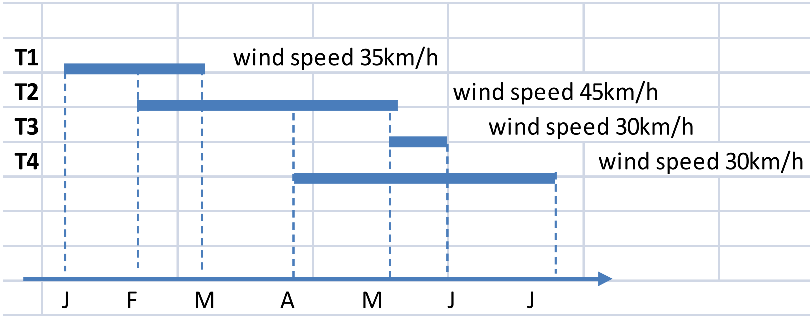


Fig.8. Planning example

<u>Calculation of risk:</u>

Risk task 1:

$$R_{T_1} = P(V \geq 35) + P(V \geq 35 \; ou \; V \geq 45) \;\; = \int_{35}^{+\infty} f(V, K_1, c_1) dv + \int_{35}^{+\infty} f(V, K_2, c_2) dv$$

The distance marker of the integral is in km/h, in our calculations we will convert it to m/s : 35km/h = 9,72m/s

$$R_{T_1} = \int_{9,72}^{+\infty} \frac{K_1}{c_1} (\frac{v}{c_1})^{K_1 - 1} exp^{-(\frac{v}{c_1})^{K_1}} dv + \int_{9,72}^{+\infty} \frac{K_2}{c_2} (\frac{v}{c_2})^{K_2 - 1} exp^{-(\frac{v}{c_2})^{K_2}} dv$$

$$R_{T_1} = 0{,}0736977 + 0{,}115967$$

Interpretation:

We will interpret the risk for the two months January and February

$$\text{January: } P(V \geq 35) = 0{,}07369770{,}0736977 = \frac{x}{31}$$

$$x = 2{,}28 \text{ DAY} \sim \; 2D$$

And so forth, being that in total the delay risk on the project deadline is 21 days within a deadline of 6 months. This is translated by an interval risk of $\Delta \; = \; 12\%$

IV. PLANNING TAKING INTO ACCOUNT TO THE OPTIMIZATION OF THE EFFECTS OF WIND

The algorithm (Fig.9.), as an iterative system, presented below, will reduce Δ from Pareto and MPM management rules, and decision making.

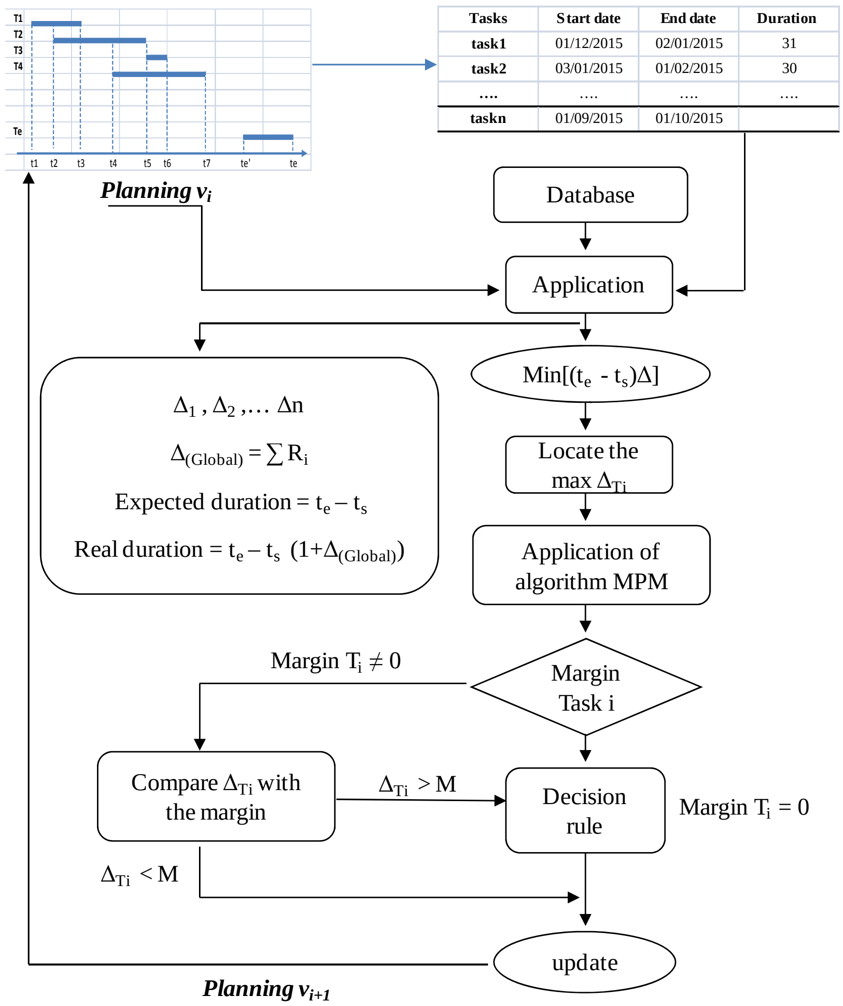


Fig.9. Algorithm of optimal schedule

The application will receive as input data:

• Table presenting the project tasks, start date, end date and duration of each task.

• A database containing the parameters of the Weibull law (for year of reference) which will serve us for the definition and application of the statistical decision rule.

Thereafter, we will be able to determine $\Delta_i$and global risk.

We will have as an aim, the minimizing of the global risk by:

1. Localization of the most influential tasks on the global risk (Pareto)

2. Determination of margins presented by each task via the MPM method

The decision rule will integrate the iterative system, from entry to exit, it will especially take on the organization of tasks in such a way to avoid periods where wind speeds exceed critical thresholds achievements of these last ones.

The overall application seeks the minimum Δ_{Global} will give way to the optimal schedule. Research studies are underway concerning the automation of decision making in the studied context.

V. GENERATION OF RANDOM SAMPLES BY THE MONTE CARLO SIMULATION

The assessment of an interval percentage for a task T which can translated as explained in the example to a number of days is not enough to make correctly a project's plan, a vision on the position of these days within the specified period should be known.

The chart (Fig.10.) is the graphic representation of simulated data for the first five months of this project ([6], [7], [11]) ; the feature is the threshold set by the constraints imposed on each task.

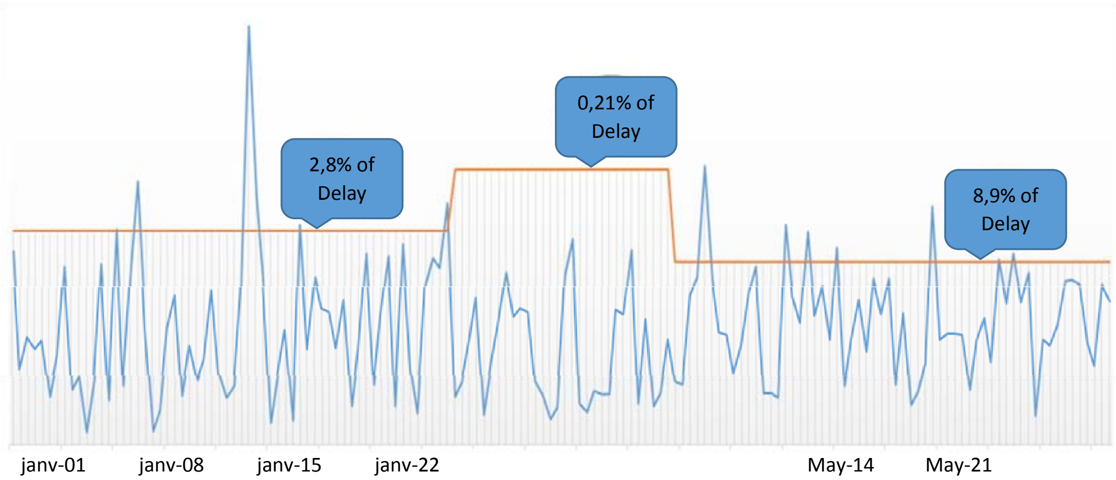


Fig.10. projection of schedule on the diagram of wind generated during the construction period

So, for the localization of the days which delay the project, we must make a projection on the simulated series, and then identify peaks which exceed critical thresholds. Furthermore, this location will allow us to avoid the extra cost of the project while adopted a planning on the available resources.

VI. CONCLUSION

The advantages of the Weibull function and the methods for estimating its parameters are widely described in the literature ([16], [17]), it was known for several applications:

- To estimate the wind energy potential of a particular location [12]
- To analyze the load cycle due to wind in the projected working life of a structure [13]
- To study wind effects around buildings for reasons of comfort especially ([10], [14])
- Etc.

This is the first time that will be introduced as a tool to help in the planning of construction projects.

In fact, fhe wind speed has a significant impact on the construction project tasks.

This is for example the case of works carried out with the help of cranes (like editing breakdowns, covers panels, liernes ...). The cranes have an operating limit (the case of tower cranes built in accordance with NF E 52-081 and NF E 52-082 standards and whose operating speed limit is 72Km/ h). Furthermore, 55Km/h is the limit called of impracticality for a set of construction works; particularly regarding the topographic surveying. A wind blowing at a speed below 50 km is not a major obstacle for common topographical measurements; From this speed, the vibrations are expected, so the measures risk being no longer reliable (the case of heavy operation reserved in particular to auscultation of structures and dams).

So if the speed threshold limit changes from one operation to another, it would be regrettable to stop the construction site in a wind blowing at 55Km/h because a task limited at this speed is programmed while another task whose threshold limit is 72km/h could be achieved, as it would be difficult to revise and insert immediately other tasks for reasons that could be related to particular materials ways when it comes to an outsourced task for example.

Our system makes it possible to measure the risk, through the Weibull distribution, optimizes the planning using the iterative system after analyzing tasks over their threshold limit speeds, manages and provides an adaptive and functional outcome.

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