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Exploring the influence of Seasonal Uncertainty in Project Risk Management

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Abstract

For years, many research studies have focused on programming projects, assuming a deterministic environment and complete task information. However, during the project performance, schedule may be subject to uncertainty which can lead to significant modifications. This fact has led to an increasing scientific literature in the field. In this article we consider the presence of an uncertainty of seasonal type (e.g. meteorological) that affects some of the activities that comprise the project. We discuss how the project risk can be affected by such uncertainty, depending on the start date of the project. By means of Monte Carlo simulation, we compute the statistical distribution functions of project duration at the end of the project. Then, we represent the variability of the project through the so-called Project Risk Baseline.
In addition, we examine various sensitivity metrics - Criticality, Cruciality, Schedule Sensitivity Index -. We use them to prioritize each one of the activities of the project depending on its start date. In the last part of the study we demonstrate the relative importance of project tasks must consider a combined version of these three sensitivity measures.

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Keywords: Uncertainty and variability; Risk Management; Monte Carlo Simulation; Criticality; Schedule Risk Baseline

1. Introduction

Many research works have been devoted to project programming under the assumption of a deterministic environment and complete task information. However, during the project performance, uncertainty usually leads to

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re-schedule. This fact has led to the emergence of research on the topic ((C. B. Chapman et al. 2000), (Hillson 2002), (S. Ward & C. Chapman 2003), (Jaafari 2001), (Perminova et al. 2008), among others)
Some authors think that there are two types of uncertainty: Aleatory Uncertainty is a naturally occurring statistical process that exists in projects. We can find aleatory uncertainty in work activities for their cost and schedule. Epistemic Uncertainty is consequence of unexpected events that "might" happen in a project.
Both, aleatory and epistemic uncertainties are responsible of project risk. Aleatory uncertainty creates a risk that a project may be over budget or behind schedule due to the naturally occurring variances in work efforts, productivity variances, naturally occurring price volatility for material and labor. This "type" of risk can be handled with margin.
Epistemic uncertainty creates risk through a probabilistic occurrence of some event. Typical examples of epistemic risks are found in project's technology, processes, and other activities. Risk management is this type of uncertainty is often based on "risk response." There several classes of response, but two approaches to applying them.
"Buy down" the risk with planned work in the baseline. This approach rests on spending money and time to reduce the risk or even make it disappear. The second approach is based on providing Management Reserve (or contingency) to "handle" the consequences of the risk. All risk "types" can be found starting with the WBS. Look there of epistemic uncertainties that create risk.
Aleatory uncertainty and the resulting risk can be estimated using Monte Carlo Simulation assuming some confidence about variances in the project. Cost and schedule variances are the most common.
Some authors have chosen using the term "Uncertainty Management" better than the more established term "Risk Management" since this term not only includes risk and opportunity management but it also implies the identification and management of all the sources of uncertainty that give place and form our perception of risk and uncertainty.

(C. Chapman & S. Ward 2003) establish different areas where uncertainty can arise throughout the project life cycle (variability associated with estimates, uncertainty about the forecast basis, uncertainty about design and logistics, uncertainty about objectives and priorities, uncertainty about fundamental relationships between project parties). (Jaafari 2001) also includes a list of variable risks that are typically found on large projects: promotion risk, market risk-volume, market risk-price, political risks, technical risks,..
This list is responsible of the called Environmental risk: Probability that a given project will have adverse environmental impacts beyond its permitted limits and increased liabilities.
As an example from (C. Chapman & S. Ward 2004), a major construction project of North Sea oil can be affected by the condition of the sea, especially during November and December. Through risk analysis, the project manager could decide to use equipment more suitable to such adverse weather conditions to reduce the risk.
Similar examples can be found in civil engineering projects, which might be affected by rain, or construction projects in tropical areas, and others.

To represent the evolution of the project uncertainty for each period of time, we use the Schedule Risk Baseline (SRB) defined by (Pajares & López-Paredes 2011). The evolution of the SRB indicates how risk is “eliminated” during Project runtime. We use Monte Carlo simulation that provides statistical data of the distribution function of the total duration of the project, for each period of execution.
Using Monte Carlo simulation and sensitivity analysis we also obtain information about how the activities contribute to the overall risk project. This result helps us to prioritize activities.
Traditionally, the importance of the project activity has been measured by the “Criticality Index”, this concept was introduced by (Martin 1965), which is defined as the probability that an activity belong to the critical path. (Williams 1992) points out that the classical criticality index not always offers complete information about the importance of the activities and proposed to use the “Cruciality Index”. He defines this index as the correlation between the activity duration and the project duration.
(Elmaghraby et al. 1999) study the impact of changing the mean duration of an activity on the variability of project duration. (Vanhoucke 2010) performs simulations for measuring the ability of four basic sensitivity metrics to improve the time performance during project execution. In addition to the two indicators mentioned above (Criticality Index and Cruciality Index), he analyses the impact of the Significance Index (SI) and the Schedule sensitivity index (SSI) as well.

The article is organized as follows: In section 2 we describe the project used to illustrate the case. In section 3 we integrate seasonal uncertainty with the activities uncertainty. In section 4, we perform a sensitivity analysis of the project activities and report the conclusions of the work.

2. Temporary risk analysis.

To illustrate our approach in this article, we use the project network proposed by (Lambrechts et al. 2008) in their research work on project programming. We can see the Activity-On-Node (AON) diagram shown in Fig. 1. We choose this network since it is simple but at the same time includes three parallel paths, different depth and a junction.

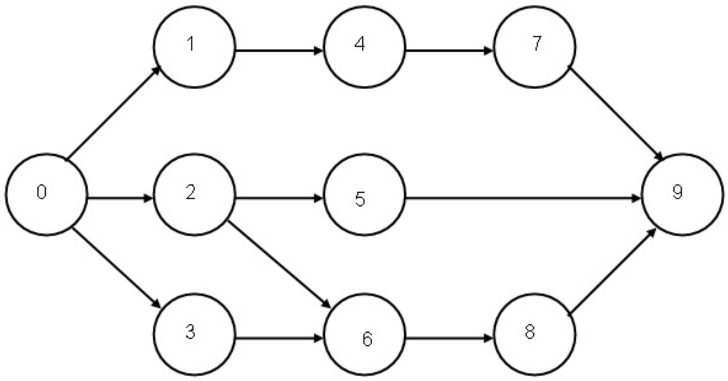

Fig. 1. AON project network.

The duration of the activities has been modeled as a normal probability distribution function with the parameters listed in Table 1. The cost of the activities is directly dependent on the activity duration and it is divided into a part variable, dependent on the duration of the activity, and a fixed one, independent of activity duration.

Table 1. Duration activities are modeled as normal distributions. Variable cost depends on duration.

Id. Activity	Duration	Variance	Variable Cost	Fixed Cost
A1	2	0,15	555	200
A2	4	0,83	1300	450
A3	7	1,35	48	45
A4	3	0,56	880	36
A5	6	1,72	14	20
A6	4	0,28	1210	40
A7	8	2,82	725	150
A8	2	0,14	100	150

Assuming average duration and a deterministic approach, the total duration of the project will be of 13 units of time, which it will correspond with durations of the path formed by the A1, A4 and A7 activities, and also with the duration of the path formed by the activities A3, A6 and A8. Therefore, we can deduce the existence of two possible critical paths, with the same duration.

The uncertainty associated with each activity implies that the duration is considered stochastic, following a probability distribution function. In addition, A7 activity is influenced by a "seasonal" uncertainty (meteorological uncertainty). This uncertainty will take place at certain times of the year and not in others, and in those times that may occur, the probability of appearance will be different from one period to other.

We assume, as seasonal uncertainty affecting A7 Activity, the existence of temperatures below 0° C (risk of frost) in the city of Valladolid (Spain).

We have statistics on days with temperatures below 0° C, sorted by months and years, in the town of Valladolid (Table 2).

Table 2. Days with temperatures below 0° C, sorted by years and months. Observatory of Valladolid.

Year	January	February	March	April	May	June	July	August	September	October	November	December	Total
1997	10	5	0	0	0	0	0	0	0	0	0	8	23
1998	8	7	3	2	0	0	0	0	0	0	11	22	53
1999	19	19	4	2	0	0	0	0	0	0	9	16	69
2000	28	5	5	3	0	0	0	0	0	0	5	2	48
2001	7	10	0	3	0	0	0	0	0	0	13	25	58
2002	9	11	2	3	0	0	0	0	0	0	1	2	28
2003	16	15	1	1	0	0	0	0	0	0	1	8	42
2004	14	17	10	2	0	0	0	0	0	0	9	10	62
2005	22	24	13	2	0	0	0	0	0	0	6	18	85
2006	17	20	4	1	0	0	0	0	0	0	1	19	62
2007	13	2	7	2	0	0	0	0	0	0	10	16	50
2008	12	5	8	0	0	0	0	0	0	1	6	18	50
Average value in the period 1997/2008	14,6	11,7	4,8	1,8	0,0	0,0	0,0	0,0	0,0	0,1	6,0	13,7	52,5
Variance	38,6	51,5	16,6	1,1	0,0	0,0	0,0	0,0	0,0	0,1	20,0	56,8	286,6

We suppose that the number of days with frost during the year is adjusted to a normal probability distribution function, for each of the months of the year, according to the available data in Table 2.

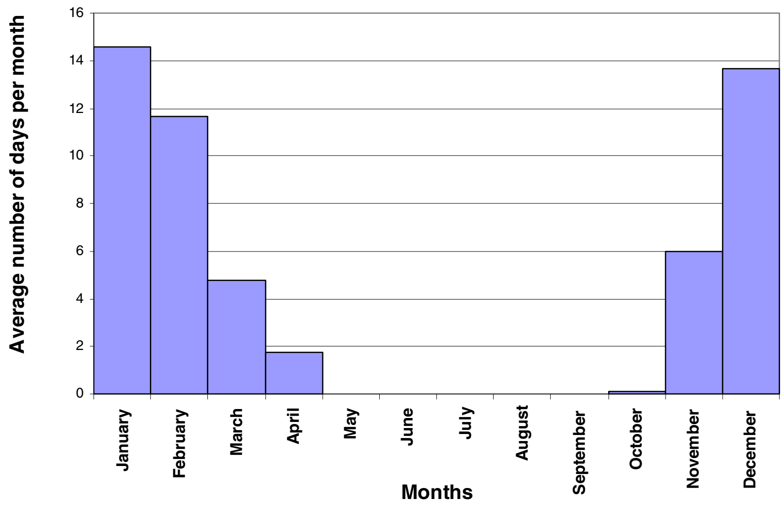

Fig. 2. Average value of days with temperatures below 0° C for months.

We represent in Fig. 2 the average value of days with temperatures below 0° C for months of the year, in the city of Valladolid.

We can observe how January and December are the months with higher average days with frost, followed by the month of February. We also observe that the appearance of this risk is very uncommon during the months from May to September.

We assume that this described seasonal risk would have a negative impact on our project A7 Activity, if it were to occur, that will cause a delay in the activity of 25% of the planned duration for that period.

3. Integration of project uncertainty and seasonal risk

Project activities include uncertainty in its duration, each one of them according to their probability distribution function, as well as the seasonal risk that affects A7 Activity.

We use Monte Carlo simulation to determine the risk of the project and we represent it through the SRB. (Pajares & López-Paredes 2011) define the Project Risk Baseline as “the evolution of ‘project risk value’ through project execution lifecycle. The risk of the project at any given time is calculated as the risk of the project pending tasks (those not yet completed), assuming that the project has performed as planned until that given time”.

We apply Monte Carlo simulation in each project execution period and we extract and represent the value of the variance of the total project duration, considering that only those pending tasks to execute contribute to the project duration uncertainty.

The project risk in each time period (measured as the value of the variance of the total project duration) is determined by the uncertainty of every activity coupled with the seasonal uncertainty (depending on the run-time of the project), that may impact negatively on A7 Activity.

From a deterministic point of view and considering weeks as the time unit of the project, the project lasts 13 weeks, being the duration of A7 Activity, 8 weeks.

Considering the stochastic nature of the project, the duration of the project depends on the probability distribution function of each activity. We show in this work that it also depends on the start date of the project as consequence of the seasonal risk of the project.

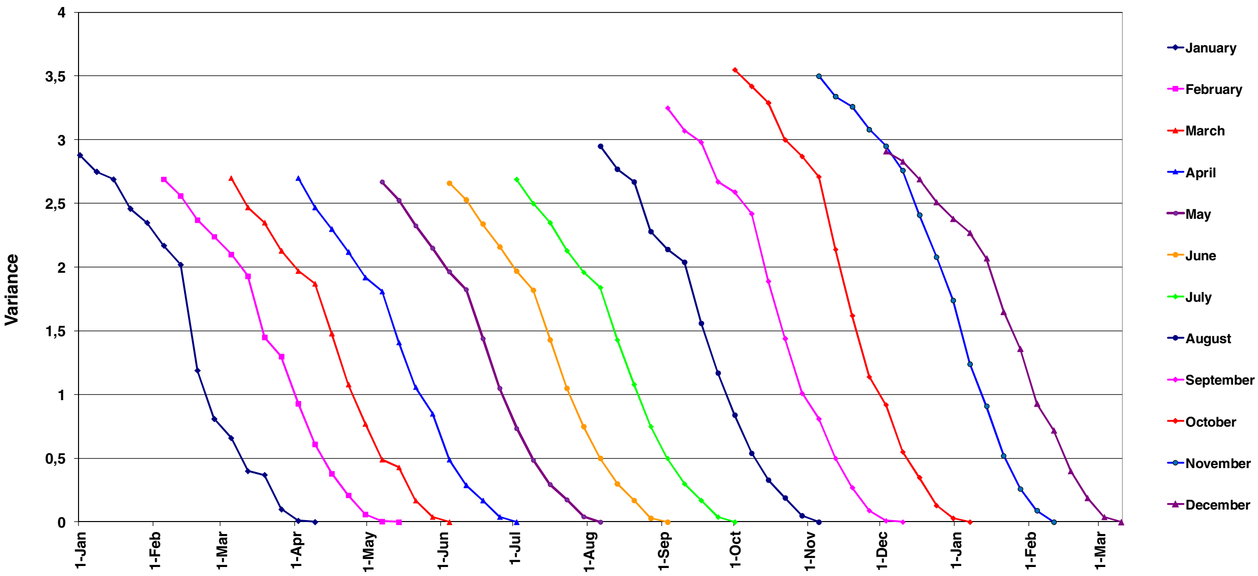

Fig. 3. Schedule Risk Baseline depending on the start time of the project.

In Fig. 3 we have represented the different SRB of the project based on the start date, assuming that the project starts its execution the first day of each month of the year.

In all cases, SRB decreases as the project progresses. As the project progresses and the activities are implemented, the project decreases uncertainty due to the activities already carried out.

We see how the simulations show variation in the initial level of the project risk (starting point of the SRB), as consequence of the impact on the A7 activity of seasonal uncertainty, which increases the overall risk of the project.

In those simulations where A7 activity is running on dates with greater probability of temperatures below 0 ºC (project that it begins in October), the level of risk is higher, while those simulations where A7 activity is running in dates with lower probability of temperatures below 0 ºC (project that starts, for example, in July), the level of project risk is lower.

We must bear in mind that the A7 activity is performed after activities A1 and A4. From a deterministic point of view, it requires 5 weeks since the start of the project until it starts the execution of A7.

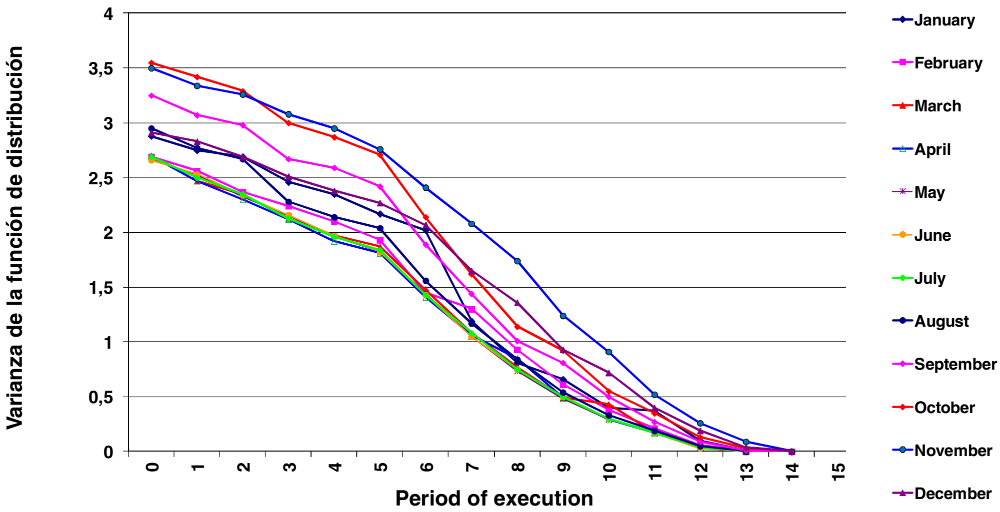

Fig. 4. Schedule Risk Baseline depending on the period of execution.

In Fig. 4 we represent the SRB depending on the period of project execution, integrating the simulations of each one of the months for the run-time.

We can see the diversity of risk level of each project simulated according to the month of beginning, as well as the different evolution of each of the simulations by time period. Some projects have lengthened his duration of 13 weeks up to finishing in the week 14.

This is due to the A7 activity and the presence of seasonal uncertainty which affects this activity, depending on the month of execution of the A7 activity and the greater or lesser probability of impact on this activity.

In those simulations where A7 activity is running in months with zero probability of frost (simulations from May to July) the average performance of the project is almost coincident, because uncertainty is provided only by the activities, there is not risk associated with seasonal uncertainty.

4. Sensitivity analysis

We use the data extracted from the Monte Carlo simulation to perform a sensitivity analysis of the project activities according to the beginning of the same month, bearing in mind the presence of seasonal uncertainty.

We represent for each activity, the evolution of three different indicators, depending on the start date of the project.

The three considered indicators are:

Criticality Index. The criticality index measures the probability that an activity lies on the critical path. It is a simple measure obtained by Monte Carlo simulations, and is expressed as a percentage denoting the likelihood of being critical.

The Criticality index often fails in adequately measuring the project risk. The main drawback of the CI is that its focus is restricted to measuring probability, which does not necessarily mean that high Criticality index activities have a high impact on the total project duration.

Cruciality Index. The Cruciality index is based on the Pearson product-moment correlation coefficient between the duration of activity and the overall project completion time. This correlation metric is a measure of the degree of linear relationship between two variables. However, the relation between activity duration and the total project duration often follows a non-linear relation.

Schedule Sensitivity Index (SSI). The project management body of knowledge (PMBoK 2008) mentions quantitative risk analysis as one of many risk assessment methods, and proposes to combine the activity duration and project duration sample standard deviations with the criticality index. In this paper, it is referred to as the schedule sensitivity index. The measure is equal to (ec. 1):

$$SSI = \left(\sqrt{\frac{\operatorname{var}(d_i)}{\operatorname{var}(Pyt)}} \right) \cdot CI \tag{1}$$

We represent in Fig 5 the Criticality Index of the project activities, depending on the month of beginning of the project.

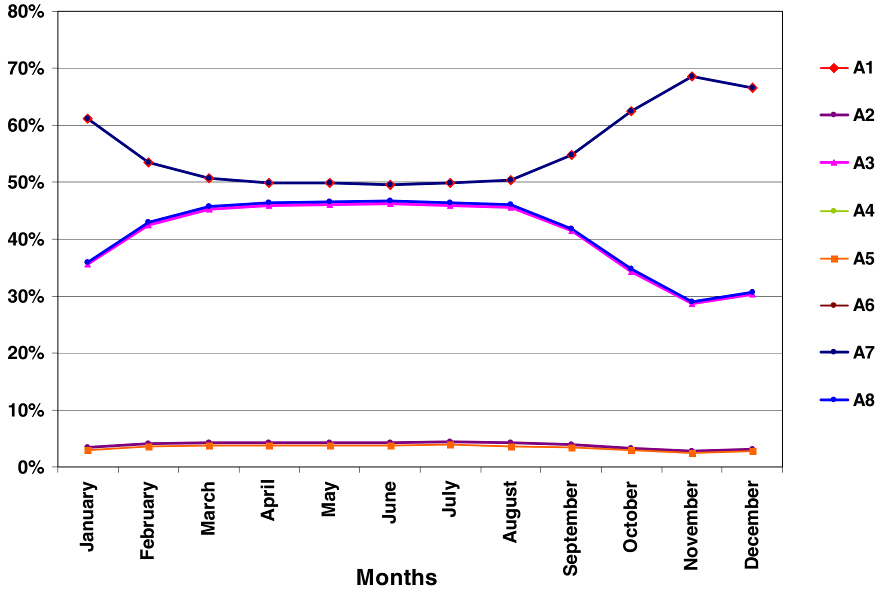

Fig. 5. Criticality Index.

In this chart we observe that the activities are grouped into three different possible paths. The path formed by the A1, A4 and A7 activities is the way which is more likely to be critical for any start date of the project.

However, for the months of project start from April until July, the path formed by the A3, A6 and A8 activities approaching in percentage of likely to be critical to the previous one (A1, A4 and A7). The last group of activities is formed by the A2 and A5 activities, with a clear difference in the probability of being critical.

We observe that there are months in which increases the probability that the upper path is critical (A1, A4 and A7), decreasing at the same time the criticality of the lower path (A2, A6 and A8). The reason is that the A7 activity execution is performed in months in which the probability that the temperature is below 0 ° C is high. As result, it increases the duration of the activity and, therefore, the duration and criticality of the path formed by the A1, A4 and A7 activities.

In any case, it is reasonable to think that it can increase the criticality of A7, because it has increased the probability that the duration of the activity can be greater. It has also increased the criticality index of A1 and A4 activities in the same proportion, but the duration of these activities has not changed.

This is one of the reasons why this index is not fully reliable and should be studied together with the other indices.

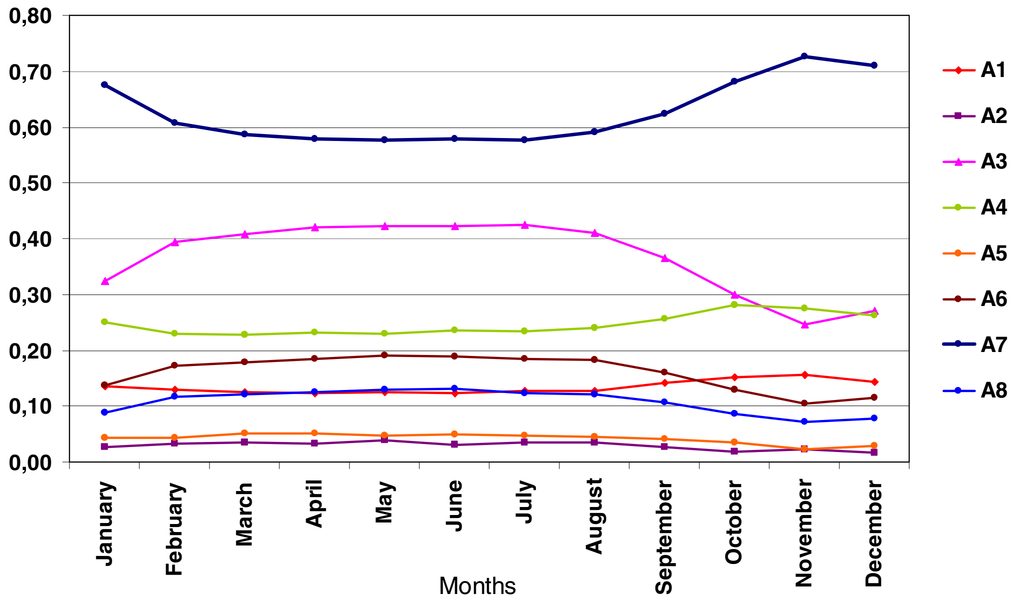

Fig. 6. Cruciality Index.

In Fig. 6 we represent the Cruciality Index (or correlation between the duration of the activity and the total project duration) of each activity, depending on the month of beginning of the project.

The most crucial activity is A7 Activity, for any period of beginning of the project. Subsequently the most crucial activity is activity A3 and then A4, except for simulations with start date on November, where the A4 activity is more crucial than the A3 activity.

We see that the cruciality is represented by activities independently, without being grouped, as it was the case with the criticality.

The Cruciality of the A7 activity grows in those simulations where this activity is executed in months with probability of temperatures below 0° C, standing out from the rest of activities.

Finally, we also see there are activities that they have little importance in terms of the risk of this project (activities A2 and A5). The importance of these two activities was also reflected in the criticality index

Despite the fact that, in this project, the indicator of cruciality behaves better than the indicator of criticality, offering a more faithful reflection of the performance of the project activities, it is not always the case and both must be used to properly understand the project and the activities that compose it.

Finally, in Fig. 7 we represent the last of the indices that we have analyzed, SSI, for each activity, and depending on the start date of the project. The figure shows the value of the criticality weighted by the ratio of the standard deviation of the activity and the standard deviation of the project.

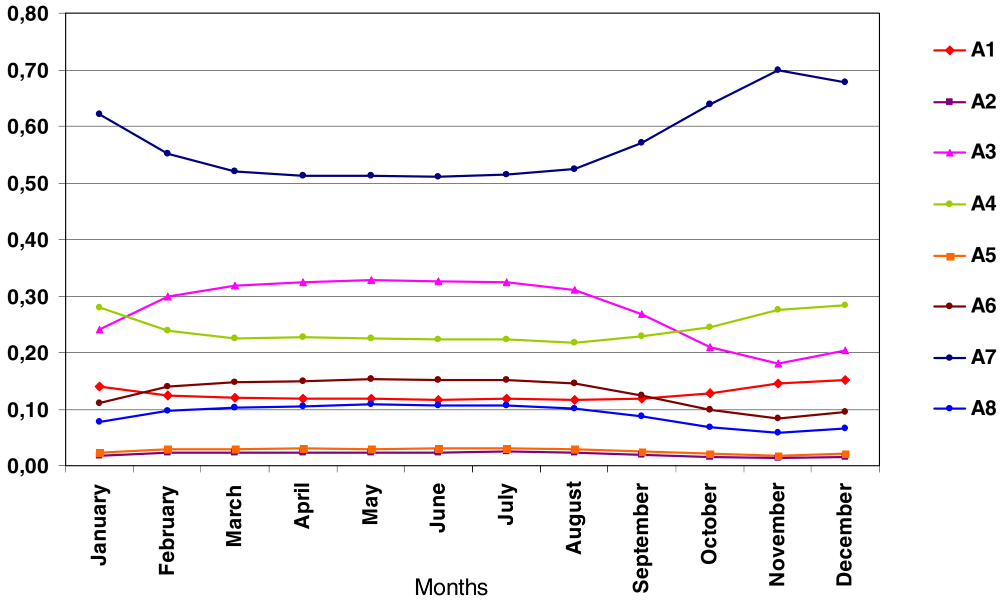

Fig. 7. Schedule Sensitivity Index.

In this case their representation is similar to Cruciality with A7 Activity is more priority over other activities for every month. This activity increases its importance in those months in which the probability of temperatures below 0 ° C is higher.

In this index, A4 activity becomes more important (also in relative terms) than A3 activity in simulations from October to January, although these differences are not especially striking.

5. Conclusions

In this article we have considered the existence of a seasonal risk which can have a negative impact on some of the activities of the project.

Our work includes two different analyses. In the first one, we have studied the variation in the level of risk of the project, and we have represented the variation of the Schedule Risk Baseline of the project according to the beginning of each month.

The level of the project risk represented by the graph of the SRB increases when the activity affected by seasonal uncertainty is performed in periods with higher probability of frost. Our results show that projects that are subject to seasonal uncertainties of any kind can negatively impact on the project. An analysis considering at the same time the stochasticity associated with the activities with seasonal uncertainties allows us determine the start date of the project with lower risk for breaking the scheduled baseline.

In a second part of the article we have analyzed the individual risk contribution of the activities depending on the start date of the project. For this purpose we have calculated some of the more common prioritization indices used in the literature, such as the Criticality Index, Cruciality Index and Schedule Sensitivity Index.

On one hand, we have verified that the isolated use of any of the indices does not give us the whole picture of risk management. Our analysis suggests that some indicators should be combined together to understand the individual contribution of tasks in terms of risk.

On the other hand, we have represented the evolution of the different indices according to the start date of the project for each activity. We have shown how the activity which is exposed to the seasonal risk becomes more important since it increases the probability that the risk occurs, i.e., during the winter.

Other activities modify its importance, depending on the month of beginning of the project, despite not being directly affected by the seasonal uncertainty.

Acknowledgements

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