Construction Project Scheduling Taking into Account the Risk of Temperatures Below –10°C in Poland

Magdalena Rogalska 1, Zdzisław Hejducki 2

1 Lublin Technical University, Department of Building and Architecture, 20-618 Lublin, ul. Nadbystrzycka 40, Poland
2 Wrocław University of Science and Technology, Faculty of Civil Engineering, 50-370 Wrocław, Wybrzeże Wyspańskiego 27, Poland

Zdzislaw.hejducki@pwr.edu.pl

Abstract. The article attempts to determine the value of the duration of the building process depending on the risk of the occurrence of temperatures below –10°C in Poland. It summarizes the results of measurements of the temperature study over 62 years (from 1950 to 2011) in Poland. The number of days with temperatures below –10°C in future years was forecasted. The method of ARIMA (Autoregressive Integrated Process Average) STATISTICA STAT SOFT was used. Stationarity series was tested using an IDW Durbin Watson integrative statistics and homoscedasticity was tested by the Levene test. The forecast error was verified using autocorrelation and partial autocorrelation residues functions. On the basis of calculations, the risk values for outdoor works in each month in Poland was established. It is a part of BIM 6-D calculation. The calculated risk value can be used for the calculation in Risky Project Professional and in other programs. The proposed risk values and the method of calculation are the upcoming modification product, which has not been reported yet.

1. Introduction

Traditional building design was largely reliant upon two-dimensional technical drawings (plans, elevations, sections, etc.). Building information modeling extends this beyond 3D, augmenting the three primary spatial dimensions (width, height and depth) with time as the fourth dimension (4D) and cost as the fifth (5D). The creation of 5D models enables the various participants (from architects, designers, contractors to owners) of a construction project to visualize the progress of construction activities and its related costs over time. BIM-6D is assigned with all aspects of project life-cycle management information. According to the authors a very important element of the BIM analysis is omitted - risk analysis. Risk analysis allows to include in the calculation real circumstances relating to a particular construction project. We offer include risk analysis as BIM 6-D. Then BIM 7 -D will refer to the period of use (fig. 1).

The risk analysis can be performed using the computer program Risky Project Professional. Risky Project is advanced project risk management software with integrated risk analysis. Most projects contain many uncertain parameters: task duration, start and finish times, uncertainties in costs and resources, uncertainties in quality, safety, technology, and others. Risky Project analyzes project schedules with risks and uncertainties, calculates the chance that projects will be completed within a given period of time and budget, ranks risks, and presents the results in formats that are easy to read and understand.
Figure 1. The diagram of Building Information Modeling

Risky Project also helps you to perform project risk management: identify project risks, rank risks, identify mitigation and response plans, manage risk properties, including descriptions, probabilities and impacts, costs associated with risks, mitigation strategies, and all other information about risks, facilitate risk reviews, opening, and closing risks, conversion of risks to issues and lesson learned, save risk history. Risky Project performs both qualitative and quantitative risk analysis. If both the risk register and project schedule are populated, Risky Project performs quantitative risk analysis. If there is no project data (cost or schedule), Risky Project performs qualitative risks analysis. Risky Project performs two major functions: Risk Management: identification, recording, ranking, and reviewing risks, mitigation and response plans, and all associated risk information and Risk Analysis: determine how risks might affect your project. Risky Project performs both qualitative and quantitative risk analysis. A typical qualitative risk analysis workflow:

- Identify risks and add risks to the risk register.
- Define risk properties, probabilities, and outcomes.
- Analyze risks and prioritize risks.
- Assign mitigation and/or response plans.
- Update risk properties, probabilities, outcomes as necessary.
- Review status and properties of the risk and report information about risks.

A typical quantitative risk analysis workflow:

- Create a project schedule.
- Add risks, uncertainties, and other risk-related information.
- Run a simulation, perform an analysis and generate a report of the results.
- Update risks and uncertainties as necessary.
- During project execution, perform project tracking with risks and uncertainties at key phases or milestones to update forecasts.
- Report results.

In Risky Project risks are events that may or may not occur and has a probability between 0–100%. There is great difficulty determining the value of the probability. The article attempts to determine the value of the duration of the building process depending on the risk of the occurrence of temperatures below –10°C in Poland as one of risks.

The realization of the construction project in Poland is connected with the need to conduct works during periods of low temperatures. It is correlated directly with a significant increase in funding.
Contractors must meet additional technical and procedural requirements related to the preparation and execution of the works, as well as ensuring safety and health of workers. The works organization project is the basic document for the preparation of technical construction to carry out works during low temperatures. Among other things, the schedule of works must be drawn up, taking into account the risk of adverse weather conditions. According to [12], no works in the open air should be performed when:

- air temperature \( t < -15^\circ C \),
- wind speed \( v \geq 12 \text{ m/s} \),
- wind speed \( v \geq 8 \text{ m/s} \), while the temperature \( 0^\circ C \geq t \geq -5^\circ C \) (assembly works pause regardless of the temperature, and the large-size assembly pauses already when \( v \geq 6 \text{ m/s} \))
- wind speed \( v \geq 4 \text{ m/s} \), while the temperature of \(-5^\circ C \geq t \geq -10^\circ C \),
- wind speed \( v \geq 2 \text{ m/s} \), while the temperature of \(-10^\circ C \geq t \geq -15^\circ C \),
- there is freezing precipitation, fog, excessive frost or hoarfrost.

The construction processes most sensitive to low temperatures in Polish climatic conditions include earthworks, foundations, pile, concrete, masonry, waterproofing, plastering, flooring and painting.

2. Data analysis

The data regarding the number of days with temperatures lower than \(-10^\circ C\) in Poland in the years 1950-2011 was collected. Data from the years 2012-2016 are not available for now. The number of days in these years differ and it noted a downward trend. The number of days in the following years differ from one another. There was a downward trend observed. The comparison of the number of days with temperatures below \(-10^\circ C\) in Poland in the following years and over the years from 1950 to 2011 is shown in Table 1.

| t  | number of days with temperatures below \(-10^\circ C\) | year  | t  | number of days with temperatures below \(-10^\circ C\) | year  | t  | number of days with temperatures below \(-10^\circ C\) | year |
|----|---------------------------------------------------|-------|----|---------------------------------------------------|-------|----|---------------------------------------------------|------|
| 1  | 22                                                | 1950  | 22 | 23                                                | 1971  | 43 | 18                                                | 1992 |
| 2  | 29                                                | 1951  | 23 | 24                                                | 1972  | 44 | 13                                                | 1993 |
| 3  | 11                                                | 1952  | 24 | 23                                                | 1973  | 45 | 26                                                | 1994 |
| 4  | 22                                                | 1953  | 25 | 10                                                | 1974  | 46 | 6                                                  | 1995 |
| 5  | 24                                                | 1954  | 26 | 5                                                  | 1975  | 47 | 17                                                | 1996 |
| 6  | 46                                                | 1955  | 27 | 6                                                  | 1976  | 48 | 45                                                | 1997 |
| 7  | 16                                                | 1956  | 28 | 31                                                | 1977  | 49 | 20                                                | 1998 |
| 8  | 41                                                | 1957  | 29 | 12                                                | 1978  | 50 | 19                                                | 1999 |
| 9  | 10                                                | 1958  | 30 | 27                                                | 1979  | 51 | 6                                                  | 2000 |
| 10 | 18                                                | 1959  | 31 | 30                                                | 1980  | 52 | 6                                                  | 2001 |
| 11 | 16                                                | 1960  | 32 | 30                                                | 1981  | 53 | 23                                                | 2002 |
| 12 | 23                                                | 1961  | 33 | 22                                                | 1982  | 54 | 20                                                | 2003 |
| 13 | 25                                                | 1962  | 34 | 18                                                | 1983  | 55 | 27                                                | 2004 |
| 14 | 25                                                | 1963  | 35 | 15                                                | 1984  | 56 | 21                                                | 2005 |
| 15 | 63                                                | 1964  | 36 | 14                                                | 1985  | 57 | 16                                                | 2006 |
| 16 | 41                                                | 1965  | 37 | 46                                                | 1986  | 58 | 30                                                | 2007 |
| 17 | 30                                                | 1966  | 38 | 28                                                | 1987  | 59 | 8                                                  | 2008 |
| 18 | 17                                                | 1967  | 39 | 50                                                | 1988  | 60 | 5                                                  | 2009 |
| 19 | 30                                                | 1968  | 40 | 10                                                | 1989  | 61 | 15                                                | 2010 |
| 20 | 27                                                | 1969  | 41 | 4                                                  | 1990  | 62 | 34                                                | 2011 |
| 21 | 45                                                | 1970  | 42 | 3                                                  | 1991  |    |                                                   |      |
3. Forecasting Autoregressive Average Integrated Process

There is a possibility that the number of days with a $-10^\circ$C temperature is dependent on the number of such days in the previous years and the random component of the number of disorders of the preceding and the random component of these disorders. Taking into account such a possibility, a forecasting ARIMA method was used. The method of integrated autoregression ARIMA (Autoregressive Average Integrated Process) is used to predict the future value of a variable based on the same data. This method does not take into account the effect of predictors on the value of the dependent variable. Usually, it refers to a forecasting time series. The time series is a sequence of observations carried out in subsequent periods. In the time series, one can distinguish: a trend (a steady increase or decrease in the average level of the phenomenon at the time), periodicity (daily, weekly, seasonal), autocorrelation (the observations are not independent, but the ones that are close together are more alike than those located far from each other). The research and calculations using the ARIMA method were conducted by [1,2,3,4,5,6,7,8,9,10,11,13,14].

On the basis of Durbin Watson, Dickey Fuller and Levene statistical tests, it was found that the series is stationary and homoscedastic. Therefore, there is a possibility of predicting the future using ARIMA. The ARIMA method searched such a predictive model, wherein there is no partial autocorrelation and the autocorrelation function and the rest of residues have a number of normal distribution. Having tested a number of models, the best result was achieved for the ARIMA $(1,0,1)$, $(1,0,0)$ model. A graph of actual and projected values of number of days with temperatures below $-10^\circ$C is shown in figure 1. The rest of the series have a normal distribution. The partial autocorrelation function and the autocorrelation function of the residues were counted. Both functions are correct. It can be assumed that the ARIMA model is correct. The number of days with temperatures below $-10^\circ$C were calculated using ARIMA$(1,0,1)$, $(1,0,0)$ model in STATISTICA Statsoft in years 2012-2023. The calculation results are shown in table 2.

Figure 2. Plot of real and projected series of days with temperatures below $-10^\circ$C

4. Calculation of risk

Assuming that the base is research by [15], average number of days with temperatures below $-10^\circ$C in Poland during the 59 years (Table 1) and with division by month Table 2) the percentage of days in
each month from November to March in the years from 2017 to 2023 were calculated (Table 3). Calculation examples for 2023, using the previously forecasted number of days with temperatures below –10°C, are given in Table 4.

**Table 1.** Predicted the number of days with temperatures below –10°C in years 2012-2023

| Number | Year | The number of days with temperatures below –10°C |
|--------|------|-----------------------------------------------|
| 63     | 2012 | 26,31177                                      |
| 64     | 2013 | 26,17524                                      |
| 65     | 2014 | 19,94242                                      |
| 66     | 2015 | 20,88312                                      |
| 67     | 2016 | 18,23804                                      |
| 68     | 2017 | 20,25598                                      |
| 69     | 2018 | 21,91591                                      |
| 70     | 2019 | 16,76225                                      |
| 71     | 2020 | 24,52040                                      |
| 72     | 2021 | 25,46495                                      |
| 73     | 2022 | 21,74776                                      |
| 74     | 2023 | 14,80341                                      |

**Table 2.** Calculation examples for 2023, using the previously forecasted number of days with temperatures below –10°C for Poland

| 2023 year | November | December | January | February | March | SUM |
|-----------|----------|----------|---------|----------|-------|-----|
| Poland    | 2        | 13       | 27      | 17       | 1     | 60  |

**Table 3.** The coldest month in a year – the number of cases in the period 1951-2010

| Region                  | November | December | January | February | March |
|-------------------------|----------|----------|---------|----------|-------|
| POLAND                  |          |          |         |          |       |
| Embankment              |          |          |         |          |       |
| Lake District           | 2        | 13       | 27      | 17       | 1     |
| Lowland                 | 2        | 14       | 25      | 18       | 1     |
| Upland                  | 1        | 11       | 29      | 18       | 1     |
| Near Carpathians        | 2        | 10       | 34      | 13       | 1     |
| Sudeten                 | 1        | 15       | 28      | 15       | 1     |
| Carpathians             | 1        | 14       | 29      | 15       | 1     |
Table 3. Summary of risk values [%] of days with temperatures below –10°C in Poland by month

| Year | November | December | January | February | March |
|------|----------|----------|---------|----------|-------|
| 2017 | 2,25     | 14,16    | 29,40   | 20,50    | 1,09  |
| 2018 | 2,44     | 15,32    | 31,81   | 22,18    | 1,18  |
| 2019 | 1,86     | 11,72    | 24,33   | 16,96    | 0,90  |
| 2020 | 2,72     | 17,14    | 35,59   | 24,81    | 1,32  |
| 2021 | 2,83     | 17,80    | 36,97   | 25,77    | 1,37  |
| 2022 | 2,42     | 15,20    | 31,57   | 22,01    | 1,17  |
| 2023 | 1,64     | 10,35    | 21,49   | 14,98    | 0,80  |

5. Case study
The time and cost of a construction project consisting of 5 successive processes was analyzed. The average execution time of each of them was determined. Based on the analysis of the possibility of shortening the execution time, resulting from: the use of equipment with higher efficiency, enlarging the front of the works so as to be able to locate more employees performing the same activities, the occurrence of more favorable than expected ground conditions, works. Similarly, forecasting the most unfavorable organizational conditions has established the longest execution time of processes from P1 to P5. The data was included in the Risky Project Professional spreadsheet. Figure 3 shows the screenshots with the implemented times. Processes P1 to P5 were normalized. The screenshot is shown in Figure 4.

Figure 3. The shortest, most probable and longest execution times of P1-P5 processes - Risky Project Professional spreadsheet screenshot.

Figure 4. Example of probabilistic parameterization of process P1, time distribution of normal process execution time.

The costs of performing individual processes were then introduced, taking into account the most favorable and least favorable conditions. The minimum, most probable and maximum values were taken into account: labor cost, equipment cost, construction material price, achievable rebates, profit
level, and indirect costs. The data is summarized in the Risky Project Professional spreadsheet, figure 5.

![Figure 5. Lowest, most likely, and highest cost of execution of P1-P5 processes - screenshot of the Risky Project Professional spreadsheet.](image)

As in the case of execution times, the normal costs of the processes from P1 to P5 were normalized. Monte Carlo calculations were then made using Risky Project Professional. The simulation results are shown in Figure 6.

![Figure 6. Calculate the time and cost of a task for a certain probability - a screenshot of the Risky Project Professional](image)

Calculated time and cost of project implementation for probabilities of completion of 50, 60, 70, 80, 90 and 100% in no time than generated and at a cost not higher than calculated. These values are presented in tab. 10. They will be used as comparative values with similar values taking into account risk. Then the risk of a temperature below -10°C was introduced, according to the calculations in table 6, where the weighted average probability of risk was calculated (some processes were completed in a few months).

| Process | Date       | October | November | December | January Probability | February | March | April | May | Summary risk [%] |
|---------|------------|---------|----------|----------|---------------------|----------|-------|-------|-----|------------------|
| P1      | 2.10-17.11 | 29      | 17       | -        | -                   | -        | -     | -     | -   | 0,83              |
| P2      | 20.11-22.12| -       | 10       | 22       | -                   | -        | -     | -     | -   | 10,46             |
| P3      | 25.12-18.01| -       | -        | 6        | 18                  | -        | -     | -     | -   | 25,59             |
| P4      | 19.01-22.03| -       | -        | -        | 12                  | 28       | 22    | -     | -   | 15,33             |
| P5      | 23.03-01.05| -       | -        | -        | -                   | -        | 7     | 30    | 1   | 0,2              |
Monte Carlo calculations were performed using the Risky Project Professional program taking into account introduced risk of temperatures below -100°C. The simulation results are shown in Figure 7.

Figure 7. Results of calculations of time and cost of task for a given probability taking into account risk of temperature below -10°C - screenshot of Risky Project Professional.

Calculated time and cost of project implementation for probabilities of completion of 50, 60, 70, 80, 90 and 100% in no time than generated and at a cost not higher than calculated. These values are presented in Table 7.

Table 7. Summary of time and cost of project implementation without taking into account the risk of days with temperatures below -10°C and taking into account that risk for different probability values.

| Probability[\%] | Process [\$] | Process+RISK [\$] | Process [day] | Process+RISK [day] |
|----------------|--------------|--------------------|---------------|------------------|
| 50             | 808939       | 808333             | 159,55        | 165              |
| 60             | 813484       | 813181             | 161,65        | 169,74           |
| 70             | 818636       | 818333             | 163,75        | 174,57           |
| 80             | 825000       | 825000             | 167,29        | 180,60           |
| 90             | 831666       | 831969             | 169,95        | 192,92           |
| 100            | 851666       | 853484             | 179,25        | 219,48           |

Planning, scheduling is an important part of the construction management. Planning and scheduling of construction activities helps engineers to complete the project in time and within the budget. This risk is very important because, according to the labor law, construction works must not be conducted at temperatures below -10°C degrees in Poland. As can be seen from Figure 8, this results in a very significant extension of the construction work.

6. Conclusions
The article attempts to determine the value of the duration of the building process depending on the risk of the occurrence of temperatures below –10°C in Poland. It summarizes the results of measurements of the temperature study over 62 years (from 1950 to 2011) in Poland. The number of days with temperatures below –10°C in future years was forecasted. The method of ARIMA (Autoregressive Integrated Process Average) STATISTICA STAT SOFT was used. Stationarity series was tested using an IDW Durbin Watson integrative statistics and homoscedasticity was tested by the Levene test. The forecast error was verified using autocorrelation and partial autocorrelation residues functions. On the basis of calculations, the risk values for outdoor works in each month in Poland was established. It is a part of BIM 6-D calculation. The calculated risk value (Table 5) can be used for the calculation in Risky Project Professional and in other programs. The proposed risk values and the method of calculation are the upcoming modification product, which has not been reported yet.
Figure 8. Visualization of project implementation times without taking into account the risk of days with temperatures below -10°C and taking into account that risk for different probability values.

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