The Use of Computer Simulation in Preparation of Construction Works Carried Out by Helicopters

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Abstract. When constructing buildings on challenging terrain or in densely built urban areas, the potential of conventional "ground" construction technology is insufficient. In this case, a building can be constructed with the assistance of helicopters. The preparation of construction processes carried out by helicopters must respect the effects of randomly changing construction conditions, mainly weather, as well as specific helicopter working conditions. Weather conditions significantly affect helicopter parameters, especially its most important value in the construction technology – the maximum load capacity. The helicopter load is therefore not constant but it "changes in time". The complexity of this system can be modelled by using simulation models. The built-in model should allow us to investigate the behaviour of construction processes under realistic conditions and to evaluate the proposed structure of the process based on the required criteria. This presented article deals with the conceptual design of the simulation model of the helicopter-aided construction process, including the design of the simulation scheme. The key part of the simulation model, taking into account future weather conditions at the construction site, is designed in several steps with gradual approximation using various numerical weather prediction models. Partial work results suggest that although construction production is characterized by several specific features suitable for the use of simulation methods, to date, the simulation approach, up to a few exceptions, is not used. For this reason, it is the primary objective of this research to verify the suitability of simulation modelling in the preparation of building construction, thereby creating the conditions for eventual use of simulation models in building practice as well. Processing this topic belongs to the area of interdisciplinary research, so in the future the presented methodology could be also used outside the construction sector, especially in logistics in general.

1. Introduction
Construction–technological preparations of construction processes use mostly deterministic models, which approach the real world through appropriate coefficients. Models created in this way are relatively simple but, under certain conditions, are sufficient for planning technological procedures. However, for constructions performed in more complex conditions, the deterministic approach can be biased due to effects invoked by random changes [1].
This is predominantly caused by insufficient range of options of “ground” building methods in construction works on challenging terrain or in densely built urban areas. In such cases, the construction works may be carried out using a helicopter, for instance. Constructions works using helicopters are also referred to as aerial works.

Helicopter, owing to its characteristics, represents a practical and irreplaceable means of transport in many fields [2]. It is able to steer in all directions and, unlike conventional airplanes, is capable of stopping in mid-air – hovering. Such combination of characteristics is the very reason for use of helicopters in the building industry [3].

The actual course of aerial works is rather difficult to predict using deterministic models, mainly due to their specific nature caused by diverse random factors (mostly weather conditions) affecting helicopter operations [4]. Inaccuracies in time– and cost–planning then negatively impact the overall construction process, which, in turn, also impacts the planning of construction process and subcontractor coordination [5].

If we admit that random factors impact the process, the required outputs can only be achieved with certain probability. The most accurate representation of reality can be achieved by emulation of the actual object using a simulation model. In contrast with the deterministic approach, this is based on creation of mathematical-logical models [1].

2. Current use of simulation modeling in preparation of construction works

The essence of simulation modeling is creation of computer model of construction process and simulation of its progress in real world and subsequent experimentation with the assembled model [6].

Several authors have researched the use of simulation modeling in preparation of constructions, such as Mahmoodzadeh and Zare [7], who studied probabilistic prediction of effects of expected geological conditions, construction time and overall costs on road tunnel constructions. Similar issues were also studied by Liu et al. [8], who identified significant risk of project delays due to effects of adverse geological factors. According to the authors, exclusion of geological effects from simulation model causes underestimation of timing in project planning.

Alsudairi [9] analyzed potential of simulation approach in cost reduction of construction works, shortening construction times and building maintenance. Authors Song and Eldin [10] studied automated input data collection using sensors and its subsequent use in simulation models facilitating short-term scheduling based on up-to-date operative information. They also pointed out the significant limitations of traditional methods of time planning using the critical path method (CPM). Lindhard et al. [11] looked for ways of limiting the effects of variable nature of construction works through variable changes in sequence and managing the performance of respective actions.

Many authors have dedicated their works to simulation of future climatic conditions and investigating their impact on construction processes. To assess relevance of such effects, they have successfully used simulation approach, e.g. works by Lee et al. [12] or Jung et al. [13]. However, the research focused only on the “conventional” construction processes, mostly using traditional cranes and other common construction machinery. Process simulation of construction of unusual objects, such as offshore wind farms, was studied by Muhabie et al. [14], who simulated, besides meteorological conditions, also wave height and sea level status.

Research in the field of simulation modeling in preparation of construction works is at the very beginning and many authors have emphasized the necessity of publishing further studies utilizing the simulation approach.

3. Application of simulation modeling in preparation of aerial works in construction industry

An essential prerequisite to the design of simulation model of aerial works is perfect knowledge of all important laws and rules involved in the process. The primary and the most sensitive element of the model is the helicopter. Therefore the following subchapter is firstly dedicated to its relevant characteristics.
3.1. Aerial works from technological and organizational point of view

Before the very performance of aerial works, the party preparing the construction (technologist) must select an appropriate type of helicopter because the ultimate factor limiting the use of a helicopter is its load capacity. This varies between helicopter types and is determined by the power of its propelling units as well as other technical parameters. Considering that the load capacity represents a limiting factor, the maximum weight of the transported load may be critical for selection of optimal helicopter type.

Helicopter may only be used if the weight of the cargo does not exceed the acceptable value, valid for the specific construction site, i.e. altitude and atmospheric conditions at the location. Meteorological conditions significantly affect the load capacity of the helicopter, which is the most critical parameter from the point of construction technology. Load capacity of a helicopter is thus not constant but it changes in time.

For this reason, the preparation stage of aerial works must consider daily air temperature changes because as the value increases, the load capacity of the helicopter significantly decreases. Another limiting factor is the wind speed, its direction relative to the terrain configuration, and also the visibility [15]. The formula for a specific known location of helicopter use can be mathematically expressed:

$$N_v = f(t, n, p, v_r, v_s, d)$$

where $N_v$ = load capacity or maximum takeoff weight of the helicopter, $t$ = air temperature, $n$ = altitude, $p$ = air pressure, $v_r$ = wind speed, $v_s$ = wind direction, $d$ = visibility.

In aviation, the relation between air temperature, altitude, and maximum takeoff weight of a helicopter is represented by a nomogram. Nomogram is valid for particular type of helicopter and is included in documents supplied by the manufacturer. This is actually an analogy to the load capacity diagrams used in the classic tower or mobile cranes.

The diagram expresses load capacity of helicopter based on respective factors. After subtracting the so-called standard load and fuel weight, which is determined based on flight distance, the “actual” load capacity of the helicopter can be expressed as maximum weight of load [16].

3.2. Aerial works from the point of weather conditions

Actual atmospheric conditions at the time and place of construction have critical impact on many works in the construction industry. In distant past, the weather factor was only considered in terms of season of the year. In Slovakia, the main construction season is usually considered to be April to November; conversely, heavy frost is assumed in January and February.

For expert long-term planning, the previous general assumptions have been replaced by statistical processing of measured meteorological data obtained through a stable network of meteorological and climatological stations of national meteorological institutions. In Slovakia, these services have been provided by the Slovak Hydrometeorological Institute (SHMÚ) for 65 years. Its activities include processing of climate characteristics in Slovakia, such as average monthly air temperature and average monthly atmospheric precipitations.

These values represent the long-term average weather limits within particular season, but it is the predictive numerical atmospheric models, which are used to forecast current weather at given time. According to the domain in which they are calculated, the models are classified as global, with global coverage, and local, which are calculated for a limited region. Global models are calculated in large meteorological centers such as ECMWF (European Centre for Medium-Range Weather Forecasts) since the calculations require high-performance supercomputers.

Considering that SHMÚ is a collaborating member of ECMWF, it has access to the IFS (Integrated Forecasting System) global model outputs. IFS is calculated twice per day at 00:00 and 12:00 UTC and the maximum length of calculated forecast is 10 days with approximate resolution of 9 km (Figure 1a). The international collaboration based at SHMÚ [17] develops and computes the ALADIN
(ALARO-1) system with 4.5 km resolution with domain covering the whole Europe (Figures 1b, 2a, 2b). Length of the forecast is 3 days.

![Figure 1a, 1b. Orographic representation of Slovakia using numeric models of variable resolution numeric models](image)

![Figure 2a, 2b. Profile of wind speed and direction calculated by different runs of the ALADIN model (SHMÚ ALARO-1) for Bratislava, on 06/03/2019, 06:00 UTC](image)

3.3. Concept of proposed simulation model of aerial works

The proposed simulation model of aerial works in construction industry will include effects of random factors, mostly the aforementioned weather conditions, which have the highest impact on helicopter operation in this construction technology, affecting its “true” load capacity.

3.3.1. Meteorological securing of input data. It represents a key part of the simulation model and has been designed based on a series steps with stepwise data approximation using various numeric weather predictive models. Relevant numeric weather forecast in stable condition predicts 10 days at most. Therefore, in this part, we propose methodology in 2 steps including scheduling of aerial works 10 days before the required date.

The first step is based on the IFS model and is implemented 10 to 3 days before the planned work date. To simplify the simulation model, its first implementation does not include solution of the whole
path and profile of the helicopter flight but only solutions for 3 selected important points. These points are the helicopter’s airport of origin, ground base in the terrain, and the very construction site.

From the technological point of view, in this step, we can update the forecast every 12 hours because it is based on the aforementioned IFS model; the updates are performed at 00:00 and 12:00 UTC. Even if predictability of the particular situation was good and regional forecast did not change between respective runs of the model, there is strong expectation that individual point forecasts will differ. For this reason, meteorology uses so-called ensemble (probabilistic) forecasting, which provides more valuable information than deterministic forecasting. Atmospheric model is calculated for a fixed defined raster with defined levels. In each temporal and spatial step, we will obtain 3D profile of temperature, relative humidity, wind speed and other parameters.

In the second step, from 3 days before the planned start the expected date, we already use local models with higher resolution. This should allow us to confirm the predicted nature of the weather and adjust the actual date and duration of the works. Within this interval, we will be able to re-evaluate our decision every 6 hours, at 00:00, 06:00, 12:00 and 18:00 UTC, or every 1 to 3 hours with use of so-called “rapid update” models.

SHMÚ is a member of the Regional Cooperation for Limited Area Modeling in Central Europe (RC LACE) [18] and its numerous joint activities include the development of probabilistic system LAEF (Limited Aladin Ensemble Forecast) [19], which is a suitable information resource for this step of the proposed simulation model. Calculation of the 16 factors of the multi-physical ensemble ALADIN (ALARO-1) is run twice a day (00:00 and 12:00 UTC) and the forecast length is the aforementioned 72 hours.

3.3.2. Creation of simulation model. The respective methodological steps of creating the simulation model as well as the first step – imaging of aerial works and obtaining the necessary input data have been described in detail by us previously (e.g. [20]). One of the sources of input data was a construction project of three cableways in the mountain town of Szczyrk (Poland), realized in 2017. Laying of concrete footings and mounting of track pylons for all three cableways was carried out using a helicopter. This operation used an Mi-8 helicopter.

The following procedural step is creation of the simulation scheme, which is used as the basis for actual simulation model of aerial works. This step must also incorporate elaboration of exact sequence of actions of the helicopter (technological method). Using the knowledge obtained through imaging, we have determined the following technological method of the aerial works:
1. accurate terrain reconnaissance;
2. choice of appropriate landing site for the helicopter, mainly used for refueling during the works;
3. choice of deposition site for assembled structures; this place is not intended for helicopter landing, the load is lifted with the helicopter hovering;
4. choice of means of attachment – hooks, chains, etc., depending on the nature of transported loads and terrain configuration;
5. inspection of trajectory before the flight due to possible occurrence of obstacles;
6. actual assembly or concreting works using a helicopter according to previously elaborated flight sequence, which must also be available at the loading site, whereas the actual transport flight consists of 3 basic stages [15]:
   a. suspension of the load, departure of the helicopter with the load while accelerating to transit speed;
   b. flight of the helicopter at transit speed along the flight path (speed cannot be influenced, it is specified by the helicopter type);
   c. deceleration of the helicopter to zero, unloading – disconnecting of the load.

This technological method was then subjected to in-depth analysis in order to determine the extent of activities, which affect duration of one flight cycle. The above makes it clear that the flight cycle is only expressed in the point 6.) and its duration can only be influenced in stages a), c) – load
suspension and its guiding into the unloading area, disconnecting of the load. The flight duration can then be mathematically expressed:

\[ t_c = t_{bz} + t_z + t_{ln} + t_s + t_{bo} + t_{lp} \]  

(2)

where \( t_c \) = flight cycle duration, \( t_{bz} \) = time required to suspend the load, \( t_z \) = time required to accelerate the helicopter to transit speed, \( t_{ln} \) = time required for helicopter flight at transit speed to the point of construction, \( t_s \) = time required to decelerate the helicopter to zero, \( t_{bo} \) = time required to disconnect the load, \( t_{lp} \) = time required for flight (return) of the helicopter to the loading site, including the times required to accelerate and subsequently decelerate to zero at the loading site.

Based on the analysis of helicopter activity in line with the analysis of realized construction–assembly works, we subsequently proposed a flow chart of the overall aerial works process, which represents the simulation scheme. It simplified version is attached as Annex No. 1.

4. Results and discussions

The actual simulation model can be created using a variety of software available on the market. Outputs of the simulation can be subsequently implemented into the processes of construction–technological preparation. That means the basic technological documents (construction schedule, financial plan, etc.) will more accurately match the actual construction due to their optimization based on outputs from the simulation model, mainly in terms of defining the necessary temporal and financial reserves and implied technological impact.

The primary principle of simulations in preparation of constructions is the most faithful imitation of situation at an actual construction site. Therefore, creation of technological process or simulation scheme must answer many specific questions, mainly the following:

- what method is used in what intervals to refuel the helicopter during aerial works;
- what is the basis for pilot’s decisions in relation to overall logistics of these works;
- which tasks carried out during the works can and cannot be disregarded in the simulation;
- what are the critical aspects that decide deployment of specific helicopter type at a specific construction.

In order to achieve maximum authenticity of aerial works and, therefore, increase the quality of the simulation model, these points were solved in collaboration with flying practice. In spite of the efforts made, it is possible that after creation and activation of the model, the simulation scheme will require minor corrections (generalization).

Considering the nature of aerial works in construction industry or construction methods in general, the simulation model will be based on principles of discrete and continuous simulation. Even with such design of fully automatic decision system (model), for practical reasons, the plan of works should be consulted, during the last 48 or 24 hours before the actual realization, with professional meteorologists in service, who observe current weather conditions in so-called synoptic room 24 hours a day.

5. Conclusions

Presently, simulation modeling is commonly applied in several industrial sectors, e.g. in engineering industry. Construction production has several specific characteristics that make the use of simulation methods appropriate but the approach has not been used to date with only few exceptions. Therefore, the primary objective of the research is verification of the appropriate use of simulation modeling in preparation of constructions. For verification, selected processes were realized using helicopters, for which use of other methods results in very inaccurate results.

This paper focused on conceptual design of simulation model of aerial works, which we view in the broader framework with focus on possible use of computer simulation in preparing realization of such constructions. Based on the knowledge obtained through imaging as well as on relevant information from construction practice, we proposed and created a simulation scheme of aerial works. One of its
important components is solution of impact of weather conditions on construction works, whose algorithm was proposed based on various already existing numeric predictive weather models (IFS, ALADIN).

Using this information, further research will lead to creation, activation, and verification of actual simulation model and then conclusions will be made. Approach to the topic represents interdisciplinary research, therefore in future, the results could possibly be used outside the construction industry, mainly in general logistics.

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Annex No. 1: Flow chart (simulation scheme) of aerial works in building industry (Authors)

Request for realization of the construction process: concreting, assembly

Date and price requirements, construction site, properties of fresh concrete

Weight of load

Load slenderness, buildability, fresh concrete properties

Air temperature, altitude etc. (see Chap. 3.1.)

Technologic preparation, terrain reconnaissance, selection of landing area etc. (see Chap. 3.3.2.)

Realize the construction with the help of a helicopter?

Selection of a suitable helicopter type

Check of loads in relation to the helicopter

Is it technically possible to use a helicopter?

Determining „real“ helicopter bearing capacity

Is it possible to transport the given loads under given conditions?

Realization of aerial works

End

Realization by a conventional technology

Is it possible to adjust loads?

End

Is it technically possible to use a helicopter?

Technical adjustments of the load

Shifting construction works to another date