Flexible management for concrete curing at low temperature based on learning from cases

K. Andrzejczak[a], A. Karlowski[b], J.O. Paslawski[b]

[a]Institute of Mathematics, Poznan University of Technology, Poland
[b] Institute of Structural Engineering, Poznan University of Technology, Poland

E-mail: karol.andrzejczak@put.poznan.pl, ark_kom@wp.pl, jerzy.paslawski@put.poznan.pl,

Abstract

The right technological decisions-making during the construction process ensures online monitoring of process in progress and the external environment. The use of wireless technologies to collect data from sensors and transmit data creates new opportunities in this field. The most important of these is the ability to make a decision and its possible real-time correction.

The aim of this paper is to identify methods of decision making process during concreting based on a flexible approach and learning from cases.

The technology decision-making system is composed of three phases: (1) the strategic phase-based selection of avoiding adverse weather conditions or determining the effects of disturbances on achieving expected results despite difficulties; (2) the tactical setting in which the best concrete mix option adapted to actual and predicted operating conditions; (3) operational monitoring of the processes in progress and the environment, including simulation and warning systems, to possibly correct the decision in the form of additional actions in the event of an emergency. The purpose of this concept is to reduce risk by applying flexibility.

The case study shows the possibility of flexible management of construction processes using different technology (formwork heating, the use of admixtures, heating the concrete, the addition of PCM, etc.). First flexible tactics is based on robustness taken for normal and optimistic scenario. The second (complementary) tactic is adaptability that provides the ability to heat the concrete element in case of freezing emergency.

Keywords –

Flexibility; phased decision system; construction operation, concrete modification, robustness, learning from cases, risk management

1 Introduction

Fundamental problems related to construction management are mainly connected with the budget overrun, the expected time of completion (completion date of the construction project) and quality defects (not only during acceptance, but also during warranty and post-warranty period). The low efficiency of the manufacturing processes in construction is often emphasized compared to the other areas of the economy based on factory production. It is alarming that the expected positive effects of computerization in the construction industry are not confirmed in practice [1]. Data collection is a serious problem (data is growing very fast - big data [2]. In construction industry is still used to many traditional data collection methods (very limited automation). There is still no use in building a huge opportunity to learn from cases.

The purpose of this paper is to indicate the possibility of improving the management of construction processes based on flexible approach using learning from examples.

The following paragraph introduces the state of the art of building process management and development trends in the field of Construction Management with particular focus on Industry 4.0 in Europe and Made in China 2025 in Asia.

The concept of flexible management is discussed as a remedy for the problems arising from the dynamically changing environment and the typical decision-making situation some time before the occurrence of the event. Thanks to the proposed active flexibility (adaptability) and passive flexibility (robustness), the opportunity arises to adjust the decision and thus reduce the negative impact of the environment or use the opportunities. Presented case study takes into account the possibilities of improving decision-making process on the basis of learning from cases in technological decisions for concreting at low temperature. It stems on the experience of the authors and research conducted in Central Europe, but the results can be applied to countries with similar climatic conditions (humid continental climate) [3].

2 New ideas in Production Management

Serious problems associated with the implementation of construction projects are connected with the specificity of the construction industry and include, inter alia:

- Dependence on both internal variable environment - variable performance of process and external - variable execution conditions (weather, groundwater level, etc.)
- Long quality chains, resulting from the complexity of construction process.
- Extremely long life cycle of buildings compared to many products fabricated in other economy branches
- very slow pace of automation and robotics implementation
- The need to make decisions on the basis of incomplete data and well in advance (e.g. the ordering of ready-mix concrete 24 h before concrete delivery)
- Negligible impact on some important processes (e.g. maturation of concrete, especially in the case of large scale operations - transport infrastructure facilities).

The above factors with high complexity and a wide range of volatility generate significant levels of risk and uncertainty. In this situation, solutions are being sought to make it possible to make construction work similar to other areas of production (e.g. industrialization, automation, flexible process management, use of common management methods successfully used in other industries e.g. Lean Management, the concept of Industry 4.0 and Made in China 2025 in construction industry). The synergy of these approaches with BIM technology is a powerful potential for improving management methods in the construction industry.

2.1 State-of-art of Construction Process Management

Analyzing the methods of planning in construction basic milestones are two the following methods:

- Gantt charts [4], whose application exceeds 100 years already.
- Network models [5] (also with later versions of PERT), which have been in use since the mid-twentieth century, and thus are used for more than 50 years).

Both of these methods are well-known and are still in use (they are the basis of typical planning tools like MS Project®, Primavera®). Undoubtedly, their merits include the opportunity to present the planned course of the construction project. Disadvantages of traditional tools/planning methods rely primarily on not taking into account the all phenomena of interdependence and dynamics taking place between planned activities [6]. Attempts to take them into account are generally encountered by problems arising from the need to simplify these highly complex and difficult-to-foresee relationships.

From the point of view of these drawbacks, the following solutions deserve attention [6,7,8,9]:

- Simulation of building processes.
- Taking into account system dynamics.
- Use of resource buffers.
- Use a flexible approach.
- Lean Management and Six Sigma.
- Monitoring of environment and process in progress.

Naturally, the above list does not completely exhaust the possibilities of improving the methods of managing construction processes. It seems logical that, apart from the planning mechanisms themselves, elements that influence the effects of applied methods, such as communication methods, play a significant role [10]. It should be emphasized that the improvement of the communication method is a priority of the Industry 4.0 [11]. It is also worth noting that the synergies of the different methods are also used. In addition to classic examples such as Lean and Six Sigma Management, TRIZ and Axiomatic Design has to be noted [12].

In summary overview of the management used in Construction Management can identify three key viewpoints:

- accept variability and adopt appropriate financial and time buffers (Black Swan type [13, 14]).
- waste elimination for processes (Lean Management)
- applying a flexible approach that allows both passive (resistance) and active (adaptive) flexibility to be used.

Of course, it is possible to use synergies between the use of agile management and e.g. Lean Management [15].

Analyzing the gradual development of a flexible approach activity of researchers in the field of economics should be considered as important. Schumpeter, who introduced flexibility in action and adopted new methods of behavior as an element of innovation in 1934, proposed it as an element of innovation [16]. De Neufville proposed the first use of flexible management in 1972 [16], which a year later referred directly to transport systems [17]. The Kaplinski concept for cushioning in construction processes [18] is worth noting - for example in the delivery of concrete mix, the use of intermediate tanks. Another interesting application of flexibility is Haplin's proposal for rock processing [19]. At the next symposium, ISARC Bernold proposed the Flexible Construction System concept for the production of wooden beams [20]. Notes require discussion between a team led by Thomas [21] who created an interesting Lean Management concept in construction based on the idea of flexibility and Howell [22], which is faithful to the underlying assumptions of Lean Management (seeking to reduce the current performance variable).

The monographs de Neufville [23] and X [24] are very valuable sources of information on the elasticity of construction.

The presented concept of flexibility is based on the idea of FLAMENCO (Flexible Management in Construction) proposed in 2009 [25].

Intriguing concepts of introducing flexibility in the construction industry are undoubtedly Ofori's [26] work on organizational flexibility, Shahu [27], taking into account the advantages of introducing flexibility in construction projects, Olsson [28], which refers to large projects to avoid budget overruns. , Caunhye & Cardina [29] as a concept of robust optimization and appropriate decision-making.

Of course, the flexible application of the proposed approach in the construction management is justified under exposure to the impact of turbulently changing environment and a sufficiently large scale construction projects (airport, stadium, multi-level parking, etc.).

2.2 Industry 4.0

Industry 4.0 is a concept based on the fourth industrial revolution aimed at intelligent and flexible production [31]. Taking into account the unique opportunities created by the use of modern information and communication technology and more commonly used in the economy and society, a learning organization capable of acting (more and more self-reliant) should be identified in terms of risk and uncertainty.

With regard to construction, it creates the following opportunities [28]:

- Smart construction site (effective trucking of construction operations/processes, materials, prefabricated elements, access control – theft protection, proactive process management – prevention of non-quality, lean management based on people, material and equipment trucking, etc.).
- Simulation and modelling (construction Health & Safety training, defect management using BIM technology, Virtual Reality, Mixed Reality and 7D BIM synergy).
- Digitalization and visualization (cloud computing, Big Data, Case based reasoning, Flexible/Agile Management, mobile computing).

Indicated directions for the applications of Industry 4.0 in construction are most consistent with the management of construction processes using the flexibility / agile management concept in Construction Management. The key benefits of using Industry 4.0 are:

- Enhancing the ability to collect real-time data about building processes and their surroundings.
- Transfering decision-making moments closer to the expected key events (limiting time-outs in decision-making).
- Correction of decision-making based on tactics of adaptability.).

2.3 Made in China 2025

The concept of "Made in China 2025" is concerned with smart production, simulation, modeling, and digitalization, and visualization, but assumes more strategic goals for replace foreign technology with China technology [29].

An important element combining the concepts of Industry 4.0 and Made in China 2025 is the engagement of Germany in both projects. One example is VW's involvement in the construction of new auto plants in China [30].

2.4 Flexible management in the construction industry

Flexible management of building processes in the proposed approach is based on the premise of introducing appropriate flexibility options (active and passive) that allow for adaptation to the changing environment (internal and external) in order to continue to work despite difficulties (possible and unpredictable) with little change in costs and execution time. It is assumed that the quality requirements are met despite these changes.

Flexible approach adopted in this paper is based on two components [32]:

- Passive flexibility (robustness) understood as a first component of flexibility to achieve the assumed results of the construction process in turbulent environment.
- Active flexibility (adaptability) as a second component of flexibility based on adaptation to changing ambient conditions based on monitoring of this environment and construction processes in progress.

The fundamental difference between the two elements is that independence from monitoring for passive flexibility is the key source of information needed to apply active flexibility tactics. By analyzing the typical application of flexibility in the concreting process, it can assumed:

- Application of passive flexibility to the most probable and optimistic scenario.
- Adoption of tactics of active flexibility appropriate for the pessimistic scenario.

It is therefore important to separate in time the tactics of flexibility in accordance with the two components of it, as illustrated in this case study.

3 Risk analysis in the decision system design

Decision making under uncertainty, and such conditions are faced in the construction projects, will be supported by carrying out risk analysis. The purpose of the risk analysis is to assess the degree of uncertainty in the implementation of the task and the cost prediction for the various states of nature. Risk analysis begins with the identification of critical factors or conditions because of the risk of non-completion of a construction investment project. Identification of the critical elements of investment implementation is the basis for:

- Clarification of various alternative of construction technology to carry out the tasks and activities already in the planning phase of the decision-making system
- Choice of appropriate technology to reduce its variability, in the sense of better tolerance of undesirable circumstances
- Determining whether the available construction technology and means of performing the task meet specific requirements (effectiveness)
- Set requirements and cost estimates for various job fulfillment technologies
- Document the acceptable level of safety and risk.

In designing of the decision system, three phases can be generally distinguished. In strategic planning phase of the building the great flexibility choice is given to decide when to perform a specific task. However, due to the large advance of the planning phase from the completion of the task, usually there is a lack of detailed information needed to make the final choice of method of operation. Risk analysis in such cases provides a basis for comparing different alternatives. In turn, in the operational phase there are already greater opportunities for access to more accurate forecasting data. This is due to the ability to take into account the experience and knowledge of those responsible for carrying out the construction task and for access to short-term data such as weather forecast. In such cases, a more precise analysis of the impact of the action can be made by more clearly specifying the decision-making system. Risk management refers to all activities, conditions and events that may affect the organization and its ability to achieve the goals and vision of the organization [31]. The design decision system refers to a construction company providing services within a certain range of tasks and under certain climatic conditions. Therefore, it is necessary to clarify any possible activities of this company and any possible conditions and events that affect the achievement of the objectives and vision of this type of company. For a better picture, the enterprise risk management task can be divided into three main categories:

- strategic risk,
- financial risk,
- operational risk.

Strategic risk covers aspects and factors relevant to long-term business strategies and plans, for example:

- mergers and acquisitions,
- technologies,
- competition,
- laws and regulations,
- labor market.

Financial risk relates to the company's financial situation and includes, inter alia:

- market risk related to costs of goods and services, exchange rates, etc.,
- credit risk related to debtors' payment problems,
- cash-flow risk associated with access to the company's capital.

Operational risk takes into account conditions and events that may affect the normal operation of a construction company. Such events are:

- Random events, including accidents, failures, defects or qualitative deviations of materials.
- Natural disasters, sabotage, unhappy workers.
- Loss of competence by leaving key personnel.
- Legal circumstances, such as those related to defective contracts and civil liability insurance.

This article deals primarily with operational risk.

The primary task of analyzing the risk associated with a particular activity is to identify any initiating event that, due to their negative consequences, is called "unfavorable events" or "conditional unfavorable events". Unfavorable events are a source of threats in the implementation of the planned tasks. An example of an unfavorable event is, for example, non-achievement of the frost resistance of the concrete at the given time period.

In addition, predictable disturbances should be considered (predictable with less or greater accuracy e.g., depending on weather forecast source).

The basic tasks in designing of decision system that take into account the risk analysis are:

(A) Planning (defining the scope of work undertaken, gathering information and organizing work; choice of analysis method)
(B) Risk assessment (identification of undesirable and disruptive (foreseeable); analysis of the causes of the risks and effects of the action);
(C) Risk management (comparison of technological alternatives; review of possible decisions and their evaluation);
(D) Decision-making;
(E) Evaluation of the results of the decision (often a few interrelated decisions);
(F) Learning from past experiences.

It is extremely important for individual decision phases to determine the conditional consequences of possible actions at different states of nature.

The decision-making process composed of three phases will be traced in the following case study.

4 Case study

This system deals with a three-phase approach to the planning, execution and monitoring of the concreting process. The subject system is related to the minimization of the risk of outdoor concreting processes without the possibility of covering - under conditions dependent on the influence of external factors such as temperature drop below 0°C and atmospheric precipitation. For simplicity, the ambient temperature is the leading parameter. A typical illustration of the problem is the implementation of the parking plate at the service station.

The adopted model was developed on the basis of long term research, experience and statistical analysis of weather forecast data. On this basis, it identifies three phases of the decision-making process related to the planning, preparation and implementation of the process of concreting (including concrete curing process).

Decision tree after case analysis in RapidMiner® is presented in Figure 1.

Phase 1 (corresponding to strategic level) involves setting time periods for which the planned task:

- it is possible to perform without major interruptions in the period from May 1st to May 31st for example, during which month there is no problem in the correct course of the concreting process

- it is possible to implement, but in the adopted period e.g. from 1st to 30th November, there may be time periods in which the implementation will not be possible. In the case of unfavorable conditions, specific actions need to be taken (modifications of the concrete mix in the form of PCM additive and / or other equipment such as heaters or heated formwork) or action must be stopped. The basic strategy in this phase of decision-making is to strive for implementation of concreting process during the favorable period.

Phase 2 - (tactical level) associated with the preparation for the concrete preparation process with typical weekly planning – e.g. 3-5 days prior to the planned execution date, based on the short-term weather forecast and the selection of the appropriate concrete mix (adapted to the optimistic and most likely scenario - passive flexibility with possible special actions planned in case of pessimistic scenario (active flexibility). The natural action associated with the aforementioned precautionary principle (failure to take action in the absence of reliable information on the conditions of concreting) will require the decision-maker to postpone the decision until the 24-h forecast is reached, which will provide high verifiability (often referred to as over 95% verifiability).

The decision matrix for the choice of concrete mixtures according to the current ambient temperature and the predicted temperature (24/48 forecast) is summarized in Table 1.

As shown in Table 1, in the case of concreting in the temperature range of 5 to 10°C and the predicted temperature drop in the range of -10 to -5°C, it is possible to use a specially modified mixture (e.g., admixtures for low temperature concreting and / or PCM). However, it is not possible to perform the process on the basis of normal concrete mix. Of course, in concrete situations it is possible to heat the concrete mix, but in this case it is not assumed to implement this option. Correct selection of technological options assuming a reliable forecast during this period will ensure reaching the frost resistance of the maturing concrete (5-10 MPa) despite the difficulties.

Phase 3 (Operational level - real time management) -. During the process of concreting - in the early phase of concrete binding, the temperature range of the temperature changes in the concrete and the surrounding of the concrete is monitored. Based on the analysis of the temperature distribution within the element and its surface, in order to minimize the risk of damaging the structure of the concrete element as a result of a decrease below zero, it is possible to apply additional heating at the surface of the element to be made. This requires the use of continuous monitoring and simulation of temperature changes in the concreted element to take pre-emptive action. This is an example of the application of active flexibility in the case of a pessimistic scenario.

Table 1. Decision matrix for concreting at low temperature

temp. now [°C]	temperature forecast [°C]				
	5-10	0-5	(-5)-0	(-10)- (-5)	(-15)-(-10)
5-10	YES-CMN YES-CMM YES-CMP YES-CMMP	NO-CMN YES-CMM YES-CMP YES-CMMP	NO-CMN YES-CMM YES-CMP YES-CMMP	NO-CMN NO-CMM YES-CMP YES-CMMP	NO-CMN NO-CMM NO-CMP NO-CMMP
0-5	NO-CMN YES-CMM YES-CMP YES-CMMP	NO-CMN YES-CMM YES-CMP YES-CMMP	NO-CMN NO-CMM YES-CMP YES-CMMP	NO-CMN NO-CMM YES-CMP YES-CMMP	NO-CMN NO-CMM NO-CMP NO-CMMP
(-5)-0	NO-CMN YES-CMM YES-CMP YES-CMMP	NO-CMN NO-CMM YES-CMP YES-CMMP	NO-CMN NO-CMM YES-CMP YES-CMMP	NO-CMN NO-CMM NO-CMP YES-CMMP	NO-CMN NO-CMM NO-CMP NO-CMMP
(-10)- (-5)	NO-CMN NO-CMM YES-CMP YES-CMMP	NO-CMN NO-CMM YES-CMP YES-CMMP	NO-CMN NO-CMM NO-CMP YES-CMMP	NO-CMN NO-CMM NO-CMP NO-CMMP	NO-CMN NO-CMM NO-CMP NO-CMMP
(-15)-(-10)	NO-CMN NO-CMM YES-CMP YES-CMMP	NO-CMN NO-CMM YES-CMP YES-CMMP	NO-CMN NO-CMM NO-CMP NO-CMMP	NO-CMN NO-CMM NO-CMP NO-CMMP	NO-CMN NO-CMM NO-CMP NO-CMMP

Table 1 Legend: CMN - standard concrete mix; CMM- modified concrete mix; CMP - concrete mix with PCM; CMMP - concrete mix modified with PCM.

In general, however, the key technological decision is to use the tactics of robustness. The method of learning from the examples was used to adopt the correct decision. It assumes a continuous collection of information about the processes carried out, assuming also a negative case (when the concreting process was not successful).

Based on this, RapidMiner® has built decision trees to generate decision rules. When building a decision tree, the creation of a node results from the division of data that has reached it. This decision is made on the basis of one attribute. Attribute is selected to ensure the highest possible drop of class diversity in child nodes. It is possible to take action when generating a decision tree – e.g., stopping a break earlier if there is too little in the node (minimal leaf-size). The decision tree example is shown in Figure 1.

Based on a case-by-case analysis, you can determine the effectiveness of a technology option under certain execution conditions. One can also specify the cost of implementation for each technological option. Based on this information, one can gradually improve the decision table (Table 1) by learning from examples.

In conclusion, the following algorithm can be specified:

1) building a data table
2) generating decision tree
3) filling / improving decision table (flexibility options for given conditions / scenarios)
4) assessment of current conditions + forecast

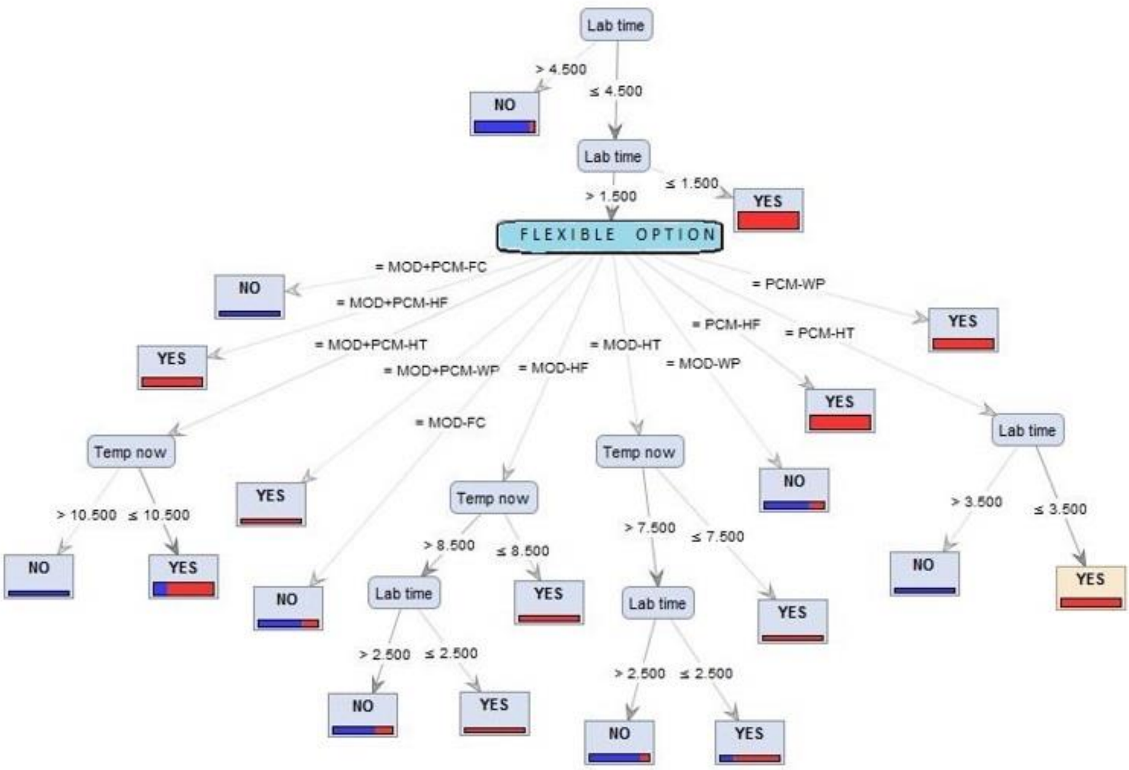

Fig. 1. Decision tree after case analysis in RapidMiner®

5) decision making - choice of passive and active flexibility
6) decision implementation
7) monitoring and decision-making (maturing of concrete)
8) assessment of effectiveness and cost of adopted tactics
9) return GO TO (1).

Right parity of passive and active flexibility in operation management assures quality in adverse weather condition.

5 Conclusions

Presented theoretical bases together with the case study discussed above allows to draw the following conclusions:

1. Construction process management requires improvement, for example by implementing methods successfully used in other sectors of the economy.
2. Industry 4.0 and Made in China 2025 should be regarded as exceptionally conducive to development, which emphasizes the use of: smart construction site, simulation and modeling, and digitalization and wireless technology.
3. The introduction of Flexible Management for the management of construction processes is a logical consequence of these directions.
4. It is important to estimate the appropriate share of passive and active elasticity parities taking into account their economic effectiveness and implementation efficiency.
5. Due to the specificity of construction (dependence on often turbulent environment) it is important to choose the source of information about current and anticipated environmental conditions (e.g. weather) and the selection of key factors characterizing this environment.
6. Based on collected data, the decision-making system improves its decision rules (use of expert rules, learning examples, machine learning etc.)
7. Particularly important is the use of learning from examples, which may assist in the selection of technological options and the appropriately reliable source (or sources) of weather forecasts.

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