

Analyzing building materials and their properties in connection with the theory of experiment planning

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Abstract. The task of planning an experiment can be divided into two stages: screening experiments conducting, step-by-step experiments performed on complete factorial design or on fractional replicates. As the number of publications on the practical use of plans-experiments in construction is insufficient, the paper presents appropriate recommendations in common form. Screening experiments are usually conducted with the aim of approximate orientation among many factors and for more precise future planning. These experiments can be carried out on the minimum fractional replicates making it possible to obtain the first order model. After obtaining the model, the factors that are included in it are appropriately ranked. Using the results of ranking, researchers take into account economic considerations, leave away unimportant factors and conduct experiments with remaining factors to obtain a mathematical model of the process. In order to find out the nomenclature of these factors, screening experiments are carried out. These experiments are performed to obtain an approximate dependence between the outcome of the process and the factors. This dependence is used to determine the influence that each of the factors has on the experience result. When the crucial factors are considered, it is possible to plan the basic experiment.

1 Introduction

The experiment is the main scientific research component, which implies a scientifically conducted experience with clearly-defined conditions [1-3].

The purpose of the experiment is:

- properties determination of the objects involved in the study;
- checking of hypotheses truth;
- and finally, a thorough study of the scientific research theme on the basis of all the data,

The main tasks of the study include:

- collection and analysis of data on the process involved (literature processing, specialists surveys and survey results analysis, screening experiment);
- hypothesis testing;

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- formula dependencies obtaining;
- object properties optimization (determination of optimal relationships, tracking of the optimum, etc.)

The subject of a scientific direction research is an experiment. But planned experiments are also used and are considered in applied sciences. In order for the experiment to become part of a certain scientific direction, it should differ by some features from any other experiment, no matter where it is conducted [8-10]. But it is impossible. Even if common features were formulated, the experiment would not be the subject of a separate science. Problems solved by different researchers had nothing in common and were completely determined by the specific nature of the knowledge field where they work. It is possible, only to determine the typical tasks that any experimenter is faced with.

2 Materials and methods

The mathematical apparatus of experimental planning theory is theory of chances, mathematical statistics, and also some sections of applied mathematics [4-7].

The theory of experimental planning can greatly facilitate the work of the experimenter; increase its effectiveness in carrying out ordinary experiments, i.e. experiments, which constitute the greatest part of modern experimental activity of scientists and engineers. An important factor in science development is an experiment - a series of experiments, set according to a special plan. Recently, it has become the subject of research and got special attention of engineers and specialists, due to the fact that the scale of experimental work at the present stage of science and technology development has reached a high level. This stage is characterized by an increase in the number of specialists engaged in experimental activities; the number of experiments being carried out has increased in many times, which has led to the complication of research facilities and equipment modernization, etc.

The process of selecting the number and conditions of testing to solve the problem involved with the required accuracy is called a planned experiment.

The general idea of the planned experiment is to increase experimentation by: reducing the number of experiments, simultaneous use of special algorithms, in the work of several variables that define the process; clear rules definition in reference to which a decision could be made on after every conducted experiment [11-15].

Problems at which a planned experiment can be applied:

- 1) search for optimal conditions;
- 2) construction of interpolation formulas;
- 3) choice of significant factors;
- 4) evaluation and correction of theoretical models constants;
- 5) choice of most suitable hypotheses about the phenomena mechanism, the study of diagrams -property.

To conduct any type of experiment, it is necessary to:

- develop a theory or hypothesis that will be subjected to verification;
- define gradually work to be experimented;
- determine methods and modes of interference in the research object;
- provide all the necessary conditions for experimental work to be carried out;
- develop techniques and methods for fixing the course and results of the experiment (instruments, installations, models, etc.);
- provide necessary service personnel.

The planned experiment is a series of tests, set according to a special plan, which allows to build a reliable mathematical model of the phenomenon or process studied in the most economical way.

3 Results

The result of the planned experiment is the first or second order regression equation (i.e., linear or square). The construction of the regression equation involves cumbersome arithmetic. That’s why, a very urgent task is to reduce the time-consuming experimental data processing.

For this purpose, factors coding is made when planning an experiment. Geometrically this means changing the point of reference. For example, in the concrete strength studying, depending on the time of its heat treatment, the number of hours of concrete heating can be 4, 6 and 8, Figure 1.

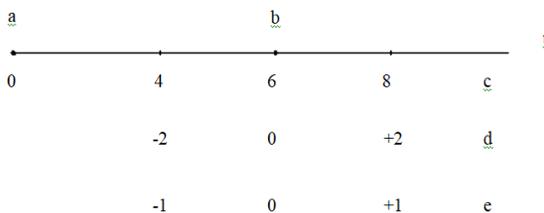


Fig. 1. Factor coding principles.

After taking an average heating time of 6 hours, we introduce the conditional reference point from this value (point "b" in Figure 1). In this case, the conventional values of heating hours will be -2, 0 and +2 (line "d" in Figure 1). Next, we divide the received conditional values by 2. As a result, a new system of measurements was formed, in which the heating hours are designated as -1, 0 and +1 (line "e" in Figure 1). Thus, a new system for calculating the time of concrete heating is obtained.

In the planned experiment, all factors are coded. In this case, the average level of each factor is taken as the main level, and for the variation interval - the difference between the mean and the maximum values of the same factors. In the example studied above, the "heating time" factor had a basic level BL = 6, and a variation interval VI = 8-6 = 2.

Thus, the coded value of the minimum concrete heating time will be "-1".

The advantage of factors encoding is computations significant reduction at further regression equation derivation. In order to further reduce the number of calculations, the code values of all the factors in one experiment are chosen to be equal to zero when calculating the average values and sums of squares of factor products with each other.

To confirm theoretical judgments, a planned experiment was carried out, that is, a series of experiments set out according to a special plan. The optimal composition of asphalt-concrete mixture was determined using the planned experiment. In a number of tests, the penetration of initial bitumen and the water saturation of asphalt-concrete samples on these binders were determined. The following materials were used in the tests: construction bitumen (CB) 60/90, construction bitumen (CB) 90/130; polymer –bitumen binders (PBB) 40 and PBB 60 welded in a colloid plant; samples of stone mastic asphalt (SMA)-20 on the basis of these binders (four different variants of binder, with the same percentage ratio (6.0%), which influence the water saturation of the asphalt concrete sample).

In the course of the experiment, the matrix-the inverse matrix of the left-hand sides coefficients of the system equations was determined and solution of the system was made by multiplying the inverse matrix by the matrix of the right-hand sides of the equations.

A summary table of four experiments was compiled, which made it possible to construct a reliable model for the dependence of the factor *x* and the effective sign of *y*. The result of the planned experiment was the regression equation.

In the course of the experiment, a graph was constructed and the quality of the constructed regression equation was evaluated.

As a result, the greater the penetration depth of the needle, the greater the water saturation coefficient, and therefore with the same bitumen consumption, the penetration of the mineral binder should be from 76 to 100 units in order for the water saturation coefficient to fall within the regulatory framework.

4 Discussions

Suppose that the task of planning an experiment for constructing the dependence "concrete strength - the time of its heat treatment and fluidity of concrete" is set. We assume that the heat treatment time can have values of 4 and 8 hours, and the fluidity of concrete, expressed through the cone slump of 6 and 12 cm. Let's assume that the experiment was carried out by the usual methods, Table 1. In this case, to construct the regression equation it would be necessary to solve a system of two equations with two unknowns.

Table 1. Conditions and results of conducting the experiments (in natural values).

Concrete strength, MPa (y)	Time of heat treatment, h (x_1)	Cone slump, cm (x_2)
19	8	12
17	4	12
26	8	6
21	4	6

In the case of factors coding, Table 2 system of equations includes zeros.

Table 2. Conditions and results of experiments (in coded notations).

y	x_1	x_2
19	+1	+1
17	-1	+1
26	+1	-1
21	-1	-1

Such simplification in calculations becomes especially noticeable with a number of factors of 3 or more, since it is difficult to solve cumbersome systems of equations manually, and in many cases it is impossible.

When planning an experiment, the factors must meet the following requirements: they must be manageable, independent of each other, measurable and to vary so that the difference in their extreme values is appreciable.

Factors management means that their numerical values can be regulated by the researcher. For example, the experimenter is able to change the numerical value of the concrete heating temperature, but cannot change the average monthly temperature of the outside air. In the first case, the factor is manageable, in the second case it is not.

In the experiment, the factors used were the concrete strength and its initial elasticity modulus. The experiment turned out to be not feasible, since both factors depend on each other. Introducing them into the experiment goes against the requirement of controlling them.

Each factor must have a quantitative expression, i.e. be measurable. For example, if we take the quality of performance as a factor and measure it in a "good - bad" system, then no equation can be obtained as a result of the experiments.

The change in the numerical values of the factor in the experiment must occur within such limits, that when it would be impossible to attribute the value of the factor to a particular planned level. For example, in the experiment if the strength of concrete, varying within the range of 20-21 MPa, is taken as a factor, then, due to its random nature, it is quite possible to obtain a strength of 20.5 MPa.

In this case, there is an uncertainty in the attribution of the actual concrete strength to a level of 20 or 21 MPa. In the given example, the concrete strength should vary within the limits of 20-30 MPa [16-21].

Quite often the researcher has to study phenomena that have not been studied before. Then his aim is to find out the factors that most significantly affect the outcome of the experiment. There are not so many factors, as a rule. However, the number of contributing factors is always great. In order to clarify the nomenclature of these factors, the so-called screening experiments are carried out. Their goal is to obtain an approximate relationship between the outcome of the process and the factors. This dependence is used for a rough orientation in the influence that each of the factors affects the result of the experiment. Thus having clarified the most significant factors, the main experiment is planned.

There are concepts of full factorial experiment and fractional replication. A full factorial experiment covers all the possible combinations of factors. For example, if we present the experiment plan in the form of a cube, then in a full factor experiment tests are carried out at all the vertices of the cube, Figure 2. The planning matrix here looks like in Table 3.

In a full factorial experiment, the number of experiments is 2^p , where p is the number of factors. At 5 factors, the number of experiments is 32, at 6 - 64, at 7 - 128, etc. Thus, to conduct a full factor experiment does not make economic sense.

In this connection, the so-called fractional replications have been created representing the parts of the full factorial plan. For example, $1/2$ replication of the full factorial experiment is presented in Table 4.

Table 3. Planning matrix of the full factorial experiment.

№	X_1	X_2	X_3	Cube corners
1	+1	+1	+1	D
2	-1	+1	+1	C
3	+1	-1	+1	K
4	-1	-1	+1	J
5	+1	+1	-1	A
6	-1	+1	-1	B
7	+1	-1	-1	E
8	-1	-1	-1	F

Table 4. Planning matrix of the fractional replication.

№	X_1	X_2	X_3	Cube corners
1	+1	+1	+1	D
2	-1	+1	-1	B
3	+1	-1	-1	E
4	-1	-1	+1	J

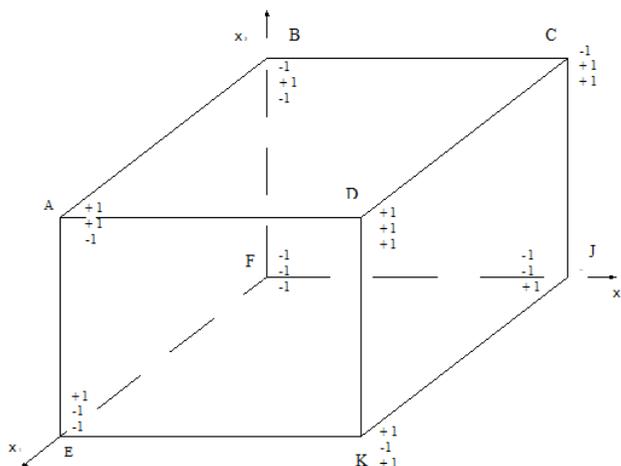


Fig. 2. Conditions for three-factor experiment presentation.

The number of experiments is half as much here, and the result, i.e. the equation of regression is the same.

5 Conclusions

The main conclusions of the paper can be formulated as follows:

1. Fractional replications can significantly reduce the scope of the experiment. This is another great advantage of the experimental planning theory.

2. The methods of experiment planning described in this work allow you to design orthogonal planning matrices. This means that, after the transformation of the matrix into a system of linear equations, all non-quadratic terms in the left-hand sides of the equations become zeroes.

3. The choice of clear and logical procedures, successive studies, allowed to prove that the bitumen consumption should be increased in order for the water saturation factor to fall within the regulatory framework from 1.0-4.0%.

4. Independence of factors from each other means that changing the value of one factor should not cause changes in the values of the other, which was proved in this research by the example of the concrete strength and the initial elasticity modulus.

5. Practically using this technique, it was possible to identify which factors of the external and internal environment influence greater on the construction materials analyzed in the work and what opportunities will ensure their best functioning when the goal is achieved.

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