Uncertainty of the first type in industrial ecology

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Abstract. The effect of low-frequency electromagnetic fields on the human body of those working in the North of the Russian Federation in many cases remains difficult to identify. The reaction of the cardiovascular system to this factor in many cases is rather difficult to register within the framework of traditional statistics. However, it is possible to use artificial neural networks in two new modes. In this case, for each feature separation procedure \( x_i(t) \), we set the initial values of the weights \( w_{io} \) of the features \( x_i(t) \) chaotically, i.e. \( w_{io} \in (0, 1) \). We repeat the neural network setup many times (at least 1000 iterations) and the resulting samples \( x_i(t) \) are ranked. If the weights \( w_i \) after 1000 iterations show values above the statistical mean \( \langle w \rangle \geq 0.05 \), then such \( j \)-th features can be considered the main (or order parameters). As a result, we have now formalized the procedure for finding the order parameters, that is, we have formalized the system synthesis (finding the main features).

1. Introduction
The action of weak physical factors, which are studied in industrial ecology and throughout biophysics, in many cases do not cause significant changes in the human body. Very often, such (weak) industrial factors as vibration, electromagnetic fields - EMF (low power), low intensity sound, which are often found on an industrial site, are simply neglected.

However, if these factors act for a long time (for decades) and at the same time the person himself can be in special climatic conditions, then the effect of these factors can be significant (after prolonged exposure). This also applies to the influence of EMF on a person who lives in the North of the Russian Federation. Sudden temperature changes, low indoor humidity, and a long winter period can aggravate the effect of EMF. However, statistics may not reveal these effects [1-5].

Quite a lot of scientific publications are devoted to this problem, but we are now paying attention to the extremely low efficiency of the use of statistical methods for revealing the effects of EMF on the human body. Quite often, statistics cannot show the effects of EMF, but other (new) information methods allow it to be revealed. This is exactly what is presented in our article.

2. The concept of uncertainty of the first type
As noted above, quite often a situation arises when statistics cannot show the difference between really different physiological states or the same group of subjects (if it is in different ecological and other states) or for different groups that are compared. The absence of such differences is interpreted as the absence of the effect of EMF on a person (although in reality these people have a comparable life expectancy) [6-11].
In our case, we are comparing four groups of women, different in age and differing in environmental conditions. Now we are talking about the 1st group of women (up to 35 years old) and about the 2nd group of women (over 35 years old), who are not affected by EMF. On the opposite side, we compare two similar age groups with two similar (by age) groups, but they are already affected by industrial EMFs. As a result, we are now statistically comparing the samples of six cardio-vascular system (CVS) parameters for these different four studied groups of workers in the oil and gas sector of the North of the Russian Federation.

Recall that we are talking about $x_1$ - SIM - parameter of the sympathetic autonomic nervous system (ANS); $x_2$ - PAR - parameter of parasympathetic ANS; $x_3$ - SSS - heart rate parameters (number of beats per minute); $x_4$ - SDNN - standard deviation of RR (cardiointervals); $x_5$ - INB - Baevsky index; $x_6$ - parameters of cardiointervals (RR). These 6 CVS parameters form the CVS’s state vector $x = x(t) = (x_1, x_2, \ldots, x_6)$ in the six-dimensional phase space of states (PSS). At the same time, we have previously proved that any sample $x_i(t)$ is statistically unstable [1-5, 11-16].

Let us explain with a specific example the uncertainty of the 1st type. To do this, we will consider in detail the statistical calculation of one, basic parameter $x_2$ in the form of CI. Table 1, we presented statistical processing in the form of four samples of CI medians for 4 groups of women. Each group consisted of 25 people and each sample of any subject had a nonparametric distribution. In this regard, we work within the framework of nonparametric statistics.

**Table 1.** The results of the final statistical processing of 25 medians (Me) of individual (for each of 25 subjects) samples of cardiointervals of four groups of women not exposed (groups 1, 2) and exposed (groups 3, 4) to electromagnetic fields, presented in Me, 5% and 95% (percentiles).

| But- | Group |
|------|-------|
|     | 1 | 2 | 3 | 4 |
| Me  | 5% | 95% | Me  | 5% | 95% | Me  | 5% | 95% | Me  | 5% | 95% |
| 1   | 550 | 540 | 665 | 710 | 650 | 775 | 730 | 670 | 795 | 730 | 645 | 770 |
| 2   | 780 | 685 | 865 | 830 | 750 | 890 | 740 | 615 | 850 | 830 | 760 | 910 |
| 3   | 750 | 685 | 840 | 740 | 700 | 810 | 730 | 680 | 790 | 790 | 705 | 840 |
| 4   | 835 | 770 | 920 | 730 | 640 | 820 | 690 | 615 | 815 | 690 | 625 | 750 |
| 5   | 840 | 745 | 935 | 780 | 695 | 850 | 670 | 570 | 780 | 720 | 640 | 820 |
| 6   | 740 | 665 | 820 | 860 | 800 | 920 | 720 | 660 | 770 | 1050 | 940 | 1140 |
| 7   | 710 | 630 | 780 | 880 | 825 | 940 | 770 | 710 | 830 | 740 | 690 | 770 |
| 8   | 630 | 570 | 695 | 880 | 745 | 865 | 655 | 590 | 730 | 660 | 600 | 720 |
| 9   | 630 | 580 | 760 | 830 | 730 | 910 | 760 | 625 | 880 | 800 | 690 | 845 |
| 10  | 850 | 725 | 990 | 980 | 875 | 1070 | 620 | 520 | 685 | 860 | 810 | 905 |
| 11  | 710 | 605 | 770 | 700 | 580 | 820 | 630 | 575 | 700 | 760 | 710 | 840 |
| 12  | 870 | 730 | 1010 | 660 | 600 | 710 | 670 | 600 | 750 | 705 | 610 | 750 |
| 13  | 680 | 610 | 750 | 870 | 820 | 930 | 690 | 600 | 790 | 930 | 880 | 980 |
| 14  | 580 | 520 | 680 | 810 | 690 | 900 | 560 | 520 | 630 | 640 | 565 | 710 |
| 15  | 790 | 710 | 870 | 950 | 870 | 1020 | 720 | 640 | 870 | 760 | 685 | 835 |
| 16  | 850 | 770 | 940 | 600 | 520 | 680 | 670 | 610 | 730 | 590 | 530 | 640 |
| 17  | 800 | 655 | 910 | 740 | 640 | 795 | 780 | 680 | 890 | 550 | 520 | 590 |
| 18  | 720 | 660 | 790 | 660 | 600 | 760 | 620 | 570 | 690 | 615 | 550 | 670 |
| 19  | 700 | 580 | 810 | 1040 | 980 | 1095 | 730 | 640 | 795 | 860 | 800 | 930 |
As a result, for each sample $x_6$ (RRs) of 25 people, we got our average median and we compared these samples of medians (within the framework of statistics) with each other. It turned out that of all six such paired comparisons, only one pair (comparisons of the 2nd and 3rd groups: 2-3) showed significant statistical differences. The remaining 5 pairs were slightly different according to Mann-Whitney test.

It turns out that all these four groups were different (in terms of age and the effect of EMF), but neither age, nor EMF, within the framework of statistics, give almost no differences. Physiologically (and biophysically) it looks very strange, but statistically it is justified. As a result, 5 more similar tables were built (for $x_1, x_2, x_3, x_4, x_5$) and in all these tables, as in table 1, we observed quite often the Mann-Whitney criteria $p \geq 0.05$. This means that the samples are statistically the same; they have one common geometric population.

In fact, this means the statistical coincidence of these samples. Statistics in this case cannot show differences between groups, which in a number of other studies showed a decrease in life expectancy under the influence of EMF.

Table 2. Results of pairwise comparison of the mean values of the ranks of the admissible level of significance of the parameters of heart rate variability of the examined groups 1 - 4 using the nonparametric U criterion Mann - Whitney.

| Parameter | Values of the criterion $p$ in pairwise comparison |
|-----------|--------------------------------------------------|
|           | 1 - 2    | 1 - 3    | 1 - 4    | 2 - 3    | 2 - 4    | 3 - 4    |
| SIM       | 0.052    | 0.045*   | 0.000*   | 0.778    | 0.001*   | 0.005*   |
| PAR       | 0.304    | 0.793    | 0.000*   | 0.516    | 0.003*   | 0.001*   |
| SSS       | 0.352    | 0.109    | 0.749    | 0.023*   | 0.224    | 0.202    |
| SDNN      | 0.084    | 0.050    | 0.000*   | 0.655    | 0.037*   | 0.108    |
| INB       | 0.107    | 0.084    | 0.000*   | 0.808    | 0.001*   | 0.007*   |

1 - women under 35 years old without exposure to EMF sources,
2 - women over 35 years old without exposure to EMF sources,
3 - women under 35 years old under the influence of EMF sources,
4 - women over 35 years old under the influence of EMF sources;
p is the achieved level of significance (at a critical level <0.05);
* - the groups statistically belong to different general populations.

Table 2, we present the results of pairwise comparison of all 5 first parameters of the CVS (from the entire vector $x(t)$). Obviously, out of 30 different comparison pairs for these 5 parameters, only 13 showed statistical differences. The other 17 different pairs of comparison of samples show no difference.
Mann-Whitney criteria for these 17 comparison pairs p≥0.05, i.e. they have one (common) general population (they do not differ statistically).

Obviously, these are very low values and statistical coincidence of the samples prevails. It shows that no significant changes occur either with age or under the influence of industrial EMF. However, these are all profound delusions, since EMF really affects life expectancy, causing it to shorten, and affects the quality of life (the incidence of other diseases is increasing, which we established separately).

3. Information methods for resolving uncertainty in environmental engineering

In connection with the emergence of type 1 uncertainty, there is an urgent need to create new methods and models to assess the influence of physical factors on the parameters of CVS and other functional systems of the human body in modern industry [4, 8, 11, 12].

One of the promising directions for solving this problem of uncertainty is the development and application of new information technologies based on artificial neural networks (ANN). The use of ANN quite often allows solving the problem of binary classification. In this case, there are samples of some state vector x(t) in the i-th state (in our case, for example, this is a group with its five parameters x_i in the form of samples). This state x_(t_i) should be separated from the state x_(t_j) - this is the 2nd group (over 35 years old without EMF) [4, 11, 12, 16].

According to table 2, these two states within the framework of statistics (see table 2) are not separated in any way (all 5 samples of the 1st and 2nd groups statistically coincide, everywhere p≥0.05). However, when using any ANN (for example, Neuro-Pro), these samples can show differences in our case. Clouds of points x_(t_i) and x_(t_j) for these two groups in the five-dimensional PSS, our ANN can separate. This raises one fundamental problem. If we re-enter the samples x_(t_i) and x_(t_j) into the ANN and repeat the initial values of the weights w_i of the features x_i(t), then all the values of the weights w_i (after setting the ANN) will be stably repeated. At the same time, ANN clearly shows the differences between the i-th and j-th groups [11, 16].

Since in real neural networks of the brain their state cannot repeat exactly two times statistically [7, 8, 17], we introduced chaos into the work of the ANN. In this case, at each setting of the ANN, we randomly choose w_i from some interval (0, 1), i.e. w_i ∈ (0.1). As a result, each iteration of the ANN has its own set w_i, which (after tuning) will give its specific values of w_i. As a result, after 1000 iterations, we get 5 samples w_i.

These samples of weights of the features are statistically processed and the ranking of the features x_i themselves is obtained. Those features that w_i < 0.5 we discard as insignificant. As a result, the ranking of the features x_i(t) obtained are the main ones and can be distinguished. Within the framework of the implementation of such an algorithm, it becomes possible not only to resolve the uncertainty of the 1st type (when statistics does not work), but also it is possible to single out the main diagnostic features x_i(t), i.e. find the order parameters [11, 16].

Application of this algorithm made it possible for each comparison (for each pair in table 2) to select the order parameters, i.e. solve the problem of system synthesis. For example, we present the results of statistically processed values of weights w_i after 50 iterations (neural network settings), samples x_i(t) for comparison groups 1-2. Obviously, the weights of the features x_i(t) are ranked in table 3. The most significant feature is x_1 (SIM), because its median Me_1 = 0.772. In second place there is x_5 (INB), its Me_5 = 0.075. These are significant diagnostic signs for a pair of comparisons 1-2.

Table 3. Results of statistical processing of weight values w_i after 50 iterations, sample x_i (t) for comparison groups 1-2.

| w_i   | SIM      | PAR      | SSS      | SDNN     | INB      |
|-------|----------|----------|----------|----------|----------|
| M ± σ | 0.772 ± 0.240 | 0.585 ± 0.249 | 0.574 ± 0.214 | 0.626 ± 0.256 | 0.675 ± 0.299 |

We emphasize that in statistics (see table 2) x_1 is also very close to p = 0.05, but x_5 (INB) is in third place (after x_4). Table 3 parameter x_5 ranks second in importance.
4. Discussion
In many cases, in industrial ecology, it is very difficult to identify in the parameters of the organism of workers the differences between the worker without external influences and in the presence of harmful factors of the industrial environment. In particular, it is difficult to identify the effects of exposure to low-frequency EMF in the conditions of Northern industrial production, in our article we are talking about the Khanty-Mansiysk Autonomous Okrug - Yugra, i.e. North of the Russian Federation.

It is in the North, where the body of employee outside of industrial production is already under stress, that it is most difficult to identify the effects of EMF. In a specific example with four groups of women (two different ages) under the influence of EMF and without EMF exposure, we identified the presence of type 1 uncertainties, when statistics cannot show a real difference between the groups (see table 1 and table 2). This is especially true for the comparison of groups 1-2 and 1-3, where there is only one pair of differences (according to SIM for 1-3 \( p = 0.045 \)), and for a pair 1-2 all samples are statistically the same (\( p\geq0.05 \)).

As a result, only the 4th group in the table 2 shows some more differences, and the remaining pairs for almost all \( x_i(t) \) coincide. In this case, type 1 uncertainty arises (statistics do not work well). To resolve this type 1 uncertainty, we propose to use the ANN in two new modes. These modes are constantly observed in the neural networks of brain operation, where chaos and reverberations are their main properties [7, 8, 17]. If we transfer these two properties to the work of already existing ANNs, then two new properties appear at once. First, we clearly separate the CVS samples (which statistics cannot do) and, as a result, we can rank the diagnostic features. In this case, we can select the main parameters from all \( x_i(t) \) and solve the problem of system synthesis (find the order parameters). New information methods for resolving type 1 uncertainties are emerging.

5. Conclusions
In industrial ecology, type 1 uncertainties often arise. In this case, statistics cannot show differences between groups. This is especially pronounced under the action of EMF. In this case, many samples do not differ (and there is no EMF effect on workers).

To recognize uncertainty of the 1st type, we propose to use the ANN in the mode of chaotic tuning and multiple reverberations (repeated ANN adjustments).

As a result, ANN separates all samples (they cannot be statistically separated) and reveals the main diagnostic features (order parameters). In this case, ANN solves the problem of system synthesis, which now has no solution in mathematics.

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