The mathematical modeling as the basis for the method of the rapid evaluation of the resources for the building of the physical level of modern civil engineering facilities information system

A B Semenov
Moscow State University of Civil Engineering, Yaroslavskoe shosse, 26, Moscow, 129337, Russia
andre62.55@mail.ru

Abstract. The author discusses the problem of information in the modern civil engineering facilities and proves the necessity for use of wire communication channels on physical level. The author demonstrates the insufficient accuracy of the existing methods for calculation of the cable consumption rate. To eliminate this drawback, it is suggested to apply mathematical modeling. The experimental data on real facilities parameters are given, the algorithm of a simple calculation is provided.

1. Introduction
The live of a modern man is literally permeated by information technologies. Without information support, it is impossible to work properly and live comfortably [1 - 5]. The information telecommunication system (ITS), which directly implements those functions, is built in accordance with the well-known 7 level open systems model. Its physical level can be formed in different ways, but in most of the cases, the wire communication channels are used. The latter are implemented on the basis of the structured cable system (SCS), according to the latest standards versions.

2. The problem at hand and the follow up on the issue
SCS is rather expensive facility, which requires major amount of expendable financial resources for its build-up. The economic benefit of its implementation lies in low operating costs. The experience of SCS implementation of civil engineering facilities demonstrates, that only 5% of the potential projects reach its implementation, the rest remain on the project proposal stage. With regard to the above mentioned, this value does not depend on the level of project elaboration. On the other side, the accurate resource calculation necessary for implementation of a information cable system is possible only on the basis of the designing results, which is a cost-intensive procedure.

With regard to those two particularities, the practice requires the availability of the method for resource evaluation for SCS designing. This method shall provide high calculation speed and high accuracy of obtained results combined with the simplicity of implementation.
To solve this problem, in real live the following basic approaches are used:

- computer aided design systems;
- different calculators.

Computer aided design systems, among which the most popular is NanoCAD-SCS, are basically semi-automatic systems as they require manual placement of separate telecommunication outlets, clear determination of TR location and plotting the routes of separate cables with points of transition to various levels. The automation of design process lies in an automatic formation of specification and cable logs, fulfilling requirements of the effective GOST standards for compiling technical documentation as well as its amendment on the basis of the results of implemented changes in accordance with the simulation modeling principles.

The well-known calculators (for example, Net Wizard), can be designed as interactive applications or Excel spreadsheet, which perform required calculations after inclusion of the source data. The basis for the calculators function is the fact, that SCS is distinguished as a system with a very high degree of casualty. This is the reason why it is enough to specify several key parameters to evaluate required resources and subsequently use the known statistical connections, which are being displayed with high correlation degree in real life SCS. For instance, it is known that the general expense item for building SCS is a horizontal subsystem, the main part of which, in its own turn, is formed by a horizontal 4-pair cable, figure 1. The expenses for the two other main parts (patch-cords, patch-panels and information outlets as connectivity) are statistically related to the expenses for the cable and are defined rather accurately [6].

![Figure 1. Typical SCS implementation expenses horizontal subsystem structure.](image1)

The primary advantage of the second approach is a high speed of obtaining the end result, the primary drawback is high risks of obtaining incorrect estimation of the required amount of horizontal cable due to the low quantity of considered parameters [7].

Furthermore, we consider the method, which is based on the mathematical modeling of the designed cable system, which ensures minimal error in calculation and high speed of estimation. It is assumed that SCS is built on the basis of a simple cable channel with the structure from figure 2.

![Figure 2. The structure of a simple cable channel.](image2)
3. The reasons of errors at calculation of the horizontal cable consumption rate by the statistical method

Cable calculators provide error, which is acceptable in real life, only for rare idealized SCS. The idealized models are such models, which take into account the work area with topologically proper shape in the form of rectangle or ellipse, additionally believing, that are distributed on it uniformly. Moreover, it is assumed, that Telecommunication Room is located at the center of the serviced area or displaced at a relatively small distance from it.

In such situation, it is possible to use the so called statistical method, at the basis of which a simple procedure lies. It is based on the preliminary estimation of the mathematical expectation of the average distance cable permanent link with subsequent execution of simple strictly determined mathematical operations, which allow taking into account the particularities of cable consumption rate of constructors, the final length of the factory packaging in a box and similar to it. The estimation of mathematical expectation is carried out according to the layout of SCS installation area.

In fact, there are segments in this area, on which there are no telecommunication outlets. In this case, the suggestion about uniform distribution is incorrect. In other words, the second part of the equation does work on engineering level of rigor.

\[ S = S_0 \cap \sum S_j \neq S_0, \]

where \( S \) – is the cable system installation area;

\( S_0 \) – is installation area of telecommunication outlets;

\( S_j \) – is the area without telecommunication outlets.

The typical examples of such topologies applicable to the modern office buildings are shown in schematic form on figure 3.

![Figure 3. The examples of the typical topologies of office buildings with expressed irregularity in distribution of telecommunication outlets in the serviced area and the displacement of telecommunication room (TR) from optimal central position (the areas without telecommunication outlets are marked by faint coloring).](image)

The disposition of telecommunication room relative to the area center can be sufficiently high, which signifies the so-called coefficient of form or displacement coefficient, figure. 4.

![Figure 4. The bar chart of the telecommunication room displacement coefficient from optimal value of real life SCS projects (average value is 0.64 at mean-square deviation of 0.22).](image)
All of this together leads to the fact that the displacement of permanent cable link lengths in real life projects begins to differ significantly from normal, which demonstrate the significant positive skew and platykurtosis. The well-known calculation methods ignore this fact. The implementation of correction, performed, for example, according to the “12/70 rule” (during the calculation of the mean length of PL, all lines with the length of more than 70 and less than 12 m are dropped) decreases the possibility of a miss, but does not eliminate it completely.

Based on the experimental data from figure 5 and figure 6, it is clear that in real life projects the skew and kurtosis coefficients can not only change exponentially, but also change its operator.

Relatively low values of skew $\gamma_3$ and kurtosis $\gamma_4$ coefficients allow defining actual probability-density function of cable lengths of permanent cable link by Gram-Charlier series

$$\phi_n(x) = \frac{1}{\sqrt{2\pi}} e^{-\frac{x^2}{2}} \left[1 + \gamma_3 (x^3 - 3x) + \gamma_4 \frac{(x^4 - 6x^2 + 3)}{4!} + \ldots\right],$$

where $\gamma_3$ - skew coefficient, $\gamma_4$ - excess coefficient, $x = L - x_0$, $L$ - permanent cable length; $x_0$ – average length permanent cable link.
The width of distribution $\phi_k(x)$ can expressively be defined by variation coefficient, determined as

$$k_v = \left( \int (x - x_0)^2 \varphi(x) dx \right)^{0.5} / x_0.$$ 

The data for real life statistics on figure 7 demonstrates, that the coefficient has such value, which allows accepting the following expression with the accuracy enough for performing engineering calculations:

$$\int_{-1}^{1} \frac{1}{\sqrt{2\pi}} x \frac{x^2}{2} dx \neq 0.$$ 

**Figure 7.** The distribution of variation coefficient of the horizontal subsystem mean cable lengths (average value is 0.42 at mean-square deviation of 0.11).

Considering the parity of polynomial $x^4 - 6x^2 + 3$, the following is also true:

$$\int_{-1}^{1} \frac{1}{\sqrt{2\pi}} x(x^4 - 6x^2 + 3) e^{-\frac{x^2}{2}} dx \neq 0.$$ 

The final positive distribution skew $\phi_s(x)$ is linearly dependent from the skew coefficient and changes the mean length of horizontal subsystem cable length on

$$\delta(\gamma_s) = \int_{-1}^{1} \frac{40}{\sqrt{2\pi}} \frac{\gamma_s}{3} x(x^3 - 3x) e^{-\frac{x^2}{2}} dx.$$ 

Computational result $\delta(\gamma_s)$ is shown on figure 9.

4. The estimation of benefit of applying mathematical modeling
It is known, that

- mean permanent cable link value is 39.2 m, which equals to 43.12 m with 10% margin, which is only 1% less than 43.57 m, which are obtained at 7 cable installation procedures with one standard 305 meter typical 4-pair horizontal cable carton box;
- skew coefficient 0.25 corresponds to value 43.12.
Figure 8. The expected error of determining the mean permanent cable link length, depending on skewness value.

Application of bar chart on figure 5 demonstrates that skew coefficient 0.4 is increased in 37% of all cases. The calculation in accordance with the standard method reduces the expected number of cable installations from one box by one: from 7 to 6, which corresponds to 17% increase in volume of supplied cable. The determination of consumption rate by means of modeling provides protection from such mistake.

5. Modeling algorithm

The calculation of horizontal cable consumption rate, which is required for implementation of a structured cable system, includes the following stages.

On the basis of the finite elements method idea and in accordance with ANSI/TIA-942B standard, the grid with cell size from $2 \times 2$ m (office buildings) and $2 \times 3$ m (engineering offices) shall be made for SCS installation area. One work place can be potentially arranged in each grid according to SNiP.

Here one indicates the place (coordinates $(a;b)$) of telecommunication room location as well as the areas without telecommunication outlet.

Considering the rules of necessity for arranging cable channels in parallel to architectural lines of buildings, the length $L_j$ of any of them is determined as $L_j = |a-x_j| + |b-y_j| + d$. The distance of vertical run of the cable channel is indicated as $d$.

The target value of mean cable length permanent link is $\bar{L} = \frac{1}{n} \sum_{j=1}^{n} L_j$.

The specified procedure is easily implemented even in general-purpose software applications, for example, in Excel spreadsheets.

6. Conclusions

1. The mathematical modeling allows for distribution of horizontal twisted pair cable consumption rate calculation for telecommunication outlet installation areas of no particular form and is represented as invariant in relation to the type of a building (office buildings and engineering offices).

2. The mathematical modeling, while retaining the simplicity of practical application, allows increasing the accuracy for determining the cable consumption rate for implementation of horizontal SCS subsystem.
3. The primary advantage of mathematical modeling application lies in elimination of the possibility of making major errors by means of taking into account the actual form of area, which is operated by cable system.

4. The achievable gain in accuracy potentially amounts to 17% in 37% of all cases.

References
[1] Volkov A A 2017 Industrial and civil engineering 9 4
[2] Semenov A B 2014 Structured cable systems for Data-center (Moscow DMK-Press) p 232
[3] Semenov A B 2018 Parallel fiber optic transmission in LAN and SCS (Moscow Gorjachaja linia-Telecom) p 272
[4] Semenov A B 2017 LAN 10 28
[5] Semenov A B 2017 LAN 12 36
[6] Chelyshkiv P D, Semenov A B 2019 Vestnik svjazi 2 4
[7] Semenov A B 2019 Last mile 3 32