MATHEMATICAL MODELS FOR TELECOMMUNICATION WORKFORCE MANAGEMENT

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The article is devoted to the problems of advanced workforce management systems WFM (Workforce Management) of post-NGN telecommunication operators, a formalized approach to the description of extended WFM functionality and mathematical WFM models are discussed. The proposed approach allows to develop new WFM tools for telecommunications operators to increase their performance, to manage more effectively the work schedules of engineering employees of the company, visit customer sites, and control the workload of engineers in real-time. Workforce Management systems (WFM) of Next Generation Networks (NGN) are becoming more and more important. Compared to the routine distribution of requests between telephone technicians in the repair bureau of the old Public Switched Telephone Network (PSTN) in the last century, the modern WFM system operates with a disproportionately large set of functions, a wide range of professional competencies and key performance indicators (KPIs). In partnership with WFM, other new information technology tools (IT-landscape) of the telecommunications operator, elements of BSS (Business Support Systems), human resource accounting (HR) software, enterprise resource planning (ERP) systems, other workforce planning, and management tools employee vacations, the timing of basic engineering operations at the operator's and customer's premises, and other support tools to optimize the performance of the required work by personnel, increase productivity and reduce costs.

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Introduction

Workforce Management systems (WFM) of Next Generation Networks (NGN) are becoming more and more important. Compared to the routine distribution of requests between telephone technicians in the repair bureau of the old Public Switched Telephone Network (PSTN) in the last century, the modern WFM system operates with a disproportionately large set of functions, a wide range of professional competencies and key performance indicators (KPIs). In partnership with WFM, other new information technology tools (IT-landscape) of the telecommunications operator, elements of BSS (Business Support Systems), human resource accounting (HR) software, enterprise resource planning (ERP) systems, other workforce planning, and management tools employee vacations, the timing of basic engineering operations at the operator's and customer's premises, and other support tools to optimize the performance of the required work by personnel, increase productivity and reduce costs [1-3].

From an operational point of view, WFM makes daily and even hourly decisions on personnel asset management, allows you to identify the most qualified, trained, and suitable telecom engineers for a particular task, effectively engage them in this work, optimize work schedules and movements, and carefully control the work performed. And to do all this in an optimal way and in real-time. That is why the elements of a formalized approach to describing promising WFMs, mathematical models, and the study of probabilistic characteristics presented in the article are certainly relevant.

Workforce Management

Carrier Workforce Management System is a specialized software designed to manage and optimize the use of the Operator's staff. The business processes implemented by this system are aimed at supporting the operational activities in the network, including the organization and management of field workers: engineers, repair teams, installation technicians, subcontractors/agents, etc.; organization of the work of operators of Call-centers of a telecommunications company, geographically distributed work of employees at commercial units for the sale of connections to the network (SIM-cards), service packages, the offer of new telecommunication services, the contracts preparing, etc.

In the Telemanagement Forum's eTOM Telecommunications Process Map, workforce management processes lie at the intersection of the Support and Availability and Resource Management areas, i.e. Efficient workforce management is essential to support day-to-day customer order processing and network troubleshooting. The task of automating the management of working time invariably confronts the telecom operator when the number of engineers and tasks to be performed becomes such that “manual” management becomes difficult or even impossible [2]. In addition, telecommunications of the 21st century impose new tasks on WFM that are not at all typical for traditional PSTNs. Firstly, the reality of today's telecommunications is that a company's qualified engineers represent something more than human resources, and more than human capital - they represent a critical, intellectual asset of the Operator, a combination of both tangible and intangible assets – a creation of a modern NGN network. Secondly, and no less important is the growing cost of searching, maintaining, and providing improved working conditions for the specialists needed by the Operator, as well as optimizing their workload and maximizing the efficiency of return. And thirdly, the growing demands for risk management, as well as regulatory and contractual obligations associated with modern HR management.

Figure 1 shows the interaction of WFM with other systems in the IT landscape, through which data is extracted, reformatted, allowed to calculate values, make decisions, create of qualify records, etc.

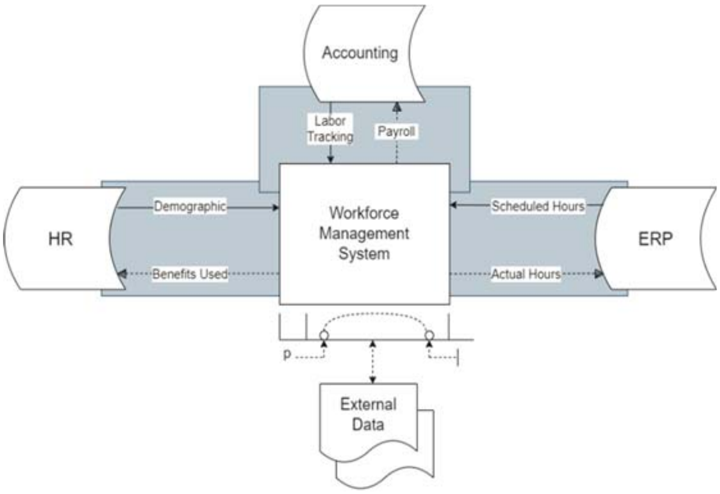

Fig. 1. WFM interfaces in IT-landscape

As can be seen in Figure 1, the implementation of a modern WFM system in the IT landscape of a telecom operator, data integration with other OSS/BSS subsystems, data exchange with ERP company resource planning systems, HR human resources, payroll, etc. are mandatory.

WFM synchronization with all these systems reduces manual data entry errors, significantly reduces the time required to exchange, download or retrieve data, simplifies and speeds up updates, and increases the productivity of modern telecom management. Accordingly, new models and methods for building the next generation WFM and integrating WFM as part of the IT landscape of post-NGN networks are needed.

Evolution of mathematical models of network management

Traditionally, the main probabilistic characteristics of the operational management of communication networks were considered to be the following two: the intensity of the flow of applications to the operational personnel of the network λ and the intensity of servicing these applications μ [2, 14,17].

The intensity of the flow of applications to the operating personnel λ (1/hour) is understood as the number of applications per unit of time to the engineering services of the Telco company for the repair, installation, and modernization of telecommunications equipment. In the context of this article, it is important to emphasize that the intensity of the flow of these applications has never been constant.

The non-stationarity of the flow of service requests was due to certain situations in the network: regular repair and maintenance work, commissioning of new switching nodes and stations and the corresponding commissioning, laying and modernization of linear cable structures, construction of base stations, commissioning of new services, etc.

The same can be said about the time of servicing orders by the engineering staff of the Telco. The service time for one requirement Tb is a random variable that can vary over a wide range. A random variable is fully characterized by a distribution law. In practice, most often they accept the hypothesis of an exponential distribution of service time, which occurs when the distribution density sharply decreases with increasing time t. For example, when the bulk of the requirements is served quickly, long-term service is rare. With an exponential distribution of service time, the probability of the event that the service time will last no more than t is equal to

$$P_{об}(t) = 1 - e^{-\mu \cdot t}.$$

The average service time 1/ μ is one of the most important characteristics of service devices, which determines the throughput of the entire system.

The load factor of engineering personnel with requirements r is the most essential WFM parameter of a telecommunications operator, which determines the value of μ. With an increase in the load factor of engineering staff R, the network maintenance costs decrease, but at the same time, quality indicators deteriorate, and hence the operator's competitiveness. Optimal management of personnel work allows you to reduce costs and not worsen quality indicators The calculation of the number of operational personnel and the organization of work of the repair bureau (determination of the value of μ) was carried out for certain time intervals of the operation of the communication network, within which the flow parameter λ can be taken constantly.

Figure 2 shows a continuous flow function $\lambda(t) \geq 0$, the average value of which can be considered constant over sufficiently large segments of the time axis $[t_n, t_{n+1}]$.

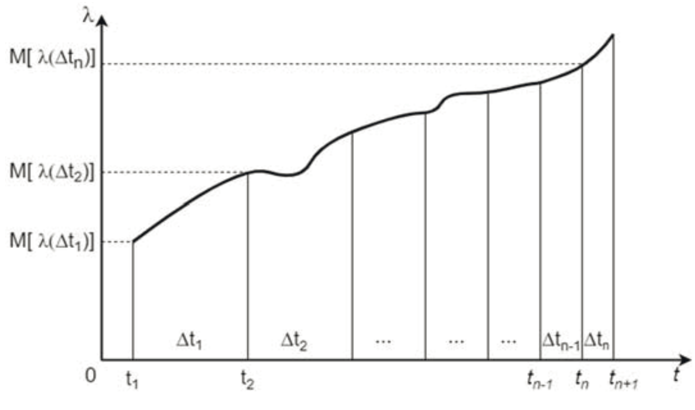

Fig. 2. Partitioning the demand flow function into intervals

The problem lies in the size of these segments, i.e. the duration of the intervals $[t_n, t_{n+1}]$, on which the values of λ(t) can be considered fixed. In ancient times, in the era of the public switched telephone network (PSTN), when the life of the exchange was calculated for 20+ years, this period was 10-15 years based on the development plan for the communication network. With the advent of mobile communications and dial-up Internet access, this interval has been reduced to 2-3 years, and now, when switching to 4G/5G networks, it is generally measured not in years, but in months [4,5].

Let us describe this problem in a slightly more formalized way. The figures bounded by the graph of the function λ(t), the abscissa axis, and the straight lines $t_1, t_2, ..., t_n$ parallel to the ordinate axis (Fig. 2) are curvilinear trapezoids. From a geometric point of view, the definite integrals of the non-negative function λ(t) in the intervals $[t_n, t_{n+1}]$ are numerically equal to the areas of these curvilinear trapezoids. We need to take the value of the flow on each segment constant and equal to the mathematical expectation λn of the flow function λ(t) on the interval $[t_n, t_{n+1}]$. The reliability Δ of such an assumption is determined by the difference between the area of a rectangle with a base $[t_n, t_{n+1}]$ in Figure 2 and the area of a curvilinear trapezoid with the same base, determined by a certain integral

$$\int_{t_n}^{t_{n+1}} \lambda(t)dt.$$

From a mathematical point of view, the reliability of the decisions made is determined by the difference between the areas of curvilinear trapezoids and the area of the stepped figure in Figure 2, which in turn depends on the number of partitioning intervals *N*, most likely, unequal segments. The segments of the partition are chosen so that within each segment it is possible to approximately consider the flow parameter to be constant, taking into account the form of the graph of the flow function λ(*t*) in Figure 2.

It is this non-uniformity of the intervals $[t_n, t_{n+1}]$, the values of which varied from one to two decades in the PSTN era to one to two months during the transition to 5G, was discussed above.

Let us consider the re(e)evolution of mathematical models and methods for constructing the IT landscape of a telecommunications company, including WFM, which is caused by these processes of transition to 5G networks and, in particular, by an order of magnitude decrease in the durations of $[t_n, t_{n+1}]$ intervals.

On Figure 3 presents two approaches to the organization of Telco management, which we can define with a certain degree of conventionality as stationary planning by methods of queuing theory (line 1) and dynamic control by methods of artificial neural networks (line 2). Both of these approaches are present in varying proportions today in the management of communication networks. The balance between these two approaches changes in this way as the parameter x increases, the inverse of the stability interval $[t_n, t_{n+1}]$ $x=1/(t_{n+1} - t_n)$, increasing in a new way each time as the complex operational management at the next stage of development of telecommunications, as shown in Figure 3.

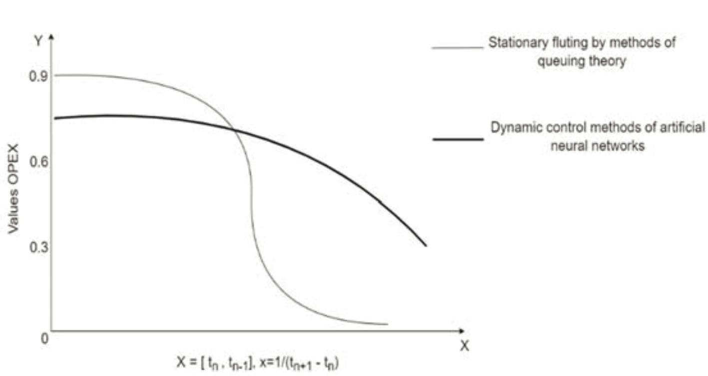

Fig. 3. Paradigm shift in post-NGN network management modeling

As networks become more complex and transition to fifth-generation heterogeneous networks, the efficiency of stationary network control planning in general [AG doctoral], and WFM in particular, is gradually decreasing, while new dynamic control approaches based, in particular, on artificial neural networks seem to be very promising, which is discussed in more detail below in the corresponding section of the article. But first, let's consider the approach proposed by the authors to the calculation of the probabilistic-characteristics of WFM.

Probabilistic characteristics of WFM

It should be noted that many software companies are working in the field of WFM today, many materials are published on practical WFM engineering methods using artificial intelligence models, deep machine learning, neural networks, and other robust methods of computer science [4]. Some of these methods will be considered in the third part of this work.

The main goal of this section is different. It consists of the research and development of a mathematical model of the probabilistic characteristics of WFM processes for super-complex high-tech tasks that are carried out by WFM systems of Telco operators. Many publications are also devoted to similar studies and mathematical models. It deals with mathematical models of route optimization, scheduling, finding the shortest path on a graph, statistical analysis, mathematical planning methods, etc. Some of these publications, which are closest to this study, are listed in the list of references for the article.

We emphasize that the distinctive feature of this study is that it is focused on WFM tasks in high-tech companies. The production processes performed by postmen, pizza delivery men, and call center operators are easier to formalize and, therefore, are managed differently than the production processes performed, for example, by engineers from Rostelecom or Megafon, who perform different tasks at their facilities in different cases. connecting the Internet, TV, building and setting up a WiFi network in a private home or office, installing Private LTE base stations, etc.

Under these conditions, the theoretical foundations of the proposed model are based on the following assumptions. The production cycle consists of three phases. Phase 1 is the planning and preparation in the WFM system of the *i*-th variant of the execution of the *j*-th task by the engineering staff of the company with the mathematical expectation of the execution time $M[t_{1ij}]$ and the standard deviation of this time σ_{1ij}. We emphasize that, unlike simple WFM systems (mail, delivery of goods, Call-center operators, etc.), the formation of a variant of execution in our case of complex high-tech services, this time can be very significant and exceed the time of the work itself at the customer's facility (for example, designing a local office network, calculation, and purchase of equipment at the facility, etc.).

Works at the customer's site, including installation and configuration of equipment and/or maintenance, repairs, etc., are performed in phase 2 with probabilistic characteristics $M[t_{2ij}]$ and σ_{2ij}, respectively.

Phase 3 is the formation and analysis of a report on the work performed, entering the relevant into the Inventory system, evaluating the work of engineering personnel, transferring the equipment of the facility to warranty / post-warranty maintenance, etc. We denote the probabilistic-temporal characteristics of this phase by $M[t_{3ij}]$ and σ_{3ij}, respectively.

The mathematical expectation of the time spent on this option *i* is determined by the formula

$$M[T_{ij}]=\sum_{n=1}^{3} M[t_{nij}] \quad (1)$$

Of course, a more significant character, in this case, is not the average execution time of variant i, but the distribution function of a random variable (probability density), which is not very difficult to obtain under the assumption that the execution times of phases 1-3 are independent random variables obeying the normal law distributions with parameters *t* and σ:

$$\sigma_{ij}=\sqrt{\sum_{n=1}^{3}\sigma_{nij}^{2}} \quad (2)$$

Depending on the nature of the set of tasks $j = 1, 2, \ldots, K$, performed by engineering personnel at customer sites in the *i*-th version of WFM, the random variable of the cycle time T_{ji} can obey the normal distribution law, exponential distribution, uniform distribution or Rayleigh distribution.

For a normal distribution, the probability that the cycle duration does not exceed a given value τ is expressed by the known relation [6]

$$P\{T_{ij}\le\tau\}=\frac{1}{2}\left[1+\phi\left(\frac{\tau-M[T_{ij}]}{\sigma_{ij}\sqrt{2}}\right)\right], \quad (3)$$

where $\phi(x)$ – Laplace function

$$\phi(x)=\frac{2}{\pi}\int_0^x \exp(-t^2)dt \quad (4)$$

From formula (3) we obtain that for $M[T_{ji}]=\tau$ the probability

$$P\{T_{ij}\le\tau\}=\frac{1}{2}, \quad (5)$$

is obvious that to calculate the efficiency of the WFM scenario i of performing $j=1,2,\ldots, K$ tasks, checking the restriction of only the mathematical expectation of the cycle time to exceed the boundary cycle time τ is insufficient. It is also necessary to take into consideration the distribution function, or at least the second moment of the distribution - the standard deviation.

But such a calculation for each variant i is very time-consuming and excludes its implementation in real-time, when, for example, WFM tasks are handled by Artificial Intelligence.

Therefore, it is proposed to keep the analysis of *i*-variants based on the mathematical expectation $M[T_{ji}]$, but instead of the boundary time of its execution τ, choose another, smaller value, which we denote by τ_g guaranteed time of the working cycle.

The value of τ_g is calculated in such a way that it corresponds to a practically acceptable probability *P*. The exact value depends on the specific application so that the probability *Pg*, for example, would be at least 0.9.

The formula for τ_g is found from the following considerations. Solving the equation

$$P_g=P\{T_{ij}\le\tau_g\}=\frac{1}{2}\left[1+\phi\left(\frac{\tau_g-M[T_{ji}]}{\sigma_{ij}\sqrt{2}}\right)\right], \quad (6)$$

for τ_g we get

$$\tau_g = M[T_{ji}] + \alpha\sigma_{ij} \quad (7)$$

here α – guarantee coefficient – is calculated by the formula

$$\alpha = \frac{\sqrt{2}}{\phi(2P_g - 1)} \quad (8)$$

Using this technique, it is relatively easy to calculate the optimal *i*-th WFM strategy from the set of possible strategies for each operation interval $[t_n, t_{n+1}]$. Such an engineering technique has been implemented and successfully operates in the WFM system of the Argus platform, for example. But back to Figure 2 of this article [11, 12].

It is clear, that the effectiveness of the proposed mathematical model essentially depends on the nature of the curve λ(t) and the duration of the interval $[t_n, t_{n+1}]$. Relatively speaking, it is possible to calculate the optimal WFM strategy for a year, for a quarter, for a month, and finally, to recalculate and change this strategy in the middle of the working week or, even worse, during the working day, it can hardly be appropriate.

Then we should return to Figure 3 and the consideration made about the second curve in this figure

Neural networks in the Workforce Management

In recent decades, interest in neural networks has increased dramatically, this is largely due to the opportunities that have arisen with the widespread use of high-performance and relatively cheap computers. The growth of computing power made it possible to put into practice the ideas expressed by the ideologues of the study of artificial intelligence back in the 90s of the XX century [9]. One of these ideas is the Hopfield neural network - a fully connected neural network with a symmetric connection matrix, the block diagram of which is shown in Figure 4.

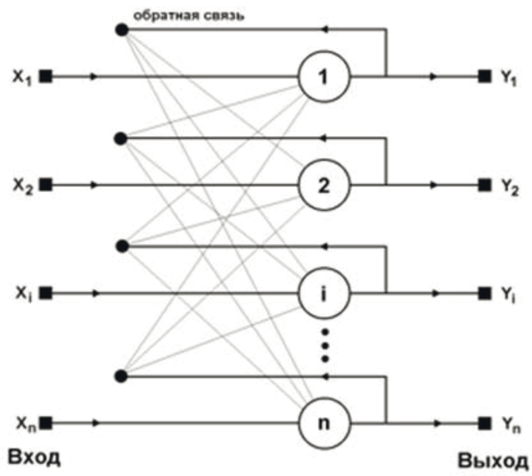

Fig. 4. Hopfield neural network block diagram

In the process of operation, the dynamics of such networks converge to one of the equilibrium positions. These equilibrium positions are local minima of a function called the energy of the network (in the simplest case, local minima of a negative definite quadratic form on an n-dimensional cube). The network can be used to solve some WFM optimization problems due to its associativity, as well as to reduce the Lyapunov function during the network operation [13]. This allows you to increase the quality of work of the company's engineers, ensure automatic adjustment of optimal routes for servicing facilities, and monitor the movements of engineering and technical performers in real-time or using GPS track recording.

A more detailed discussion of WFM optimization using the Hopfield neural network is beyond the scope of this article. Here we will consider the application of the apparatus of neural networks for Phase 3 of the WFM process.

Phase 3 of the WFM process discussed above is the analysis of reports on the work performed, entering the relevant ones into the technical accounting system, evaluating the work of engineering personnel, calculating KPIs, checking and saving a photo report from the facility, transferring the facility's equipment to warranty/post-warranty maintenance, appropriate documentation of the repaired and/or newly installed telecommunications equipment.

All these functionalities of the system help to reduce customer service time, i.e. reduce the time for the selection of performers and the time of the visit when calling the technical support dispatcher.

An effective automated tool for processing reports from engineering personnel of a telecommunications operator from customer facilities is a software subsystem that is part of WFM and is based on an artificial neural network for analyzing reports S_{ao}.

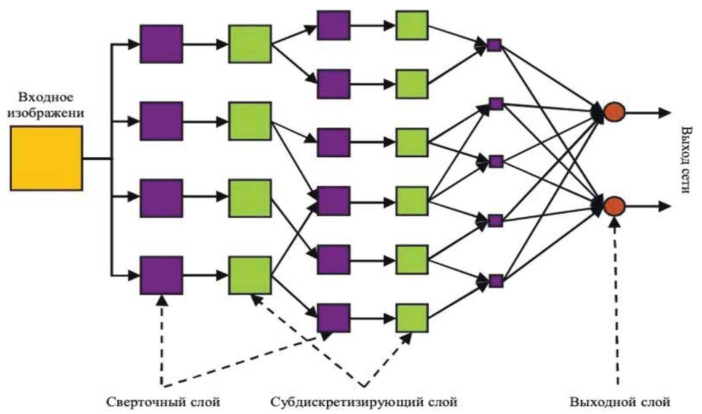

Fig. 5. Fragment of a convolutional neural network for analyzing reports

During the operation of the report analysis network S_{ao}, a purposeful change in the parameters of neurons (weights of inputs w_i and thresholds T_j.) is carried out, to implement the output function of the integral assessment of the report on the performance of work at the customer's facility, the function $F(X) = F(x_1, x_2,.., x_k)$. Here x_i ($i = l, 2, ..., k$) is a set of assessments of the performance of one or another KPI based on the submitted report.

To manage and control the work of engineering personnel in the field, an act signed by the client, a work order, passport data of the equipment installed at the subscriber, and another 'selfie' from the facility, are attached to each report on the work performed, are used. a photo of the employee at the client or at another place of work, which should also be attached to the report on the work done (Fig. 6).

The fact is that employees of a telecommunications company need to wear a uniform. It helps to identify their ownership, which is important not only from a marketing point of view but also from the point of view of customer safety.

Fig. 6. Photo reports from objects

This is also why, after completing the work, the engineer sends a WhatsApp report to the office, in which, in addition to indicating the work done, the equipment installed, the time of arrival and departure, photos from the place of work are attached, examples of which are given here.

Starting from 2021, in connection with the COVID-19 pandemic, the mandatory wearing of a mask has been added to the regulations for the work of engineers of a telecommunications company at customer sites. The fulfillment of this new requirement by analyzing photographs from electronic order fulfillment reports is verified by the neural network of S_{ao}.

Conclusion

The models and approaches proposed in the article allow the WFM tools of a telecommunications operator to effectively perform their functions, develop and manage the work schedules of engineering employees of the company, visit customer sites, distribute the load on employees with a given performance and add any related events (vacations, days off, sick leave), plan and control the workload of engineers in real-time, and generate and store reports on various indicators with the possibility of accruing bonuses based on the results of work performed.

From a strategic point of view, the value of the proposed approach to the operation of a modern WFM system lies in its interdisciplinary thinking, which is based both on traditional methods for calculating probabilistic and temporal characteristics, and on models of business intelligence BI, artificial intelligence AI, machine learning ML. As a result of this, and in contrast to human resource (HR) management systems, financial and marketing systems, and other information systems of the IT landscape of the Telecom Operator, the approach to WFM proposed in the article considers the engineering and technical staff as the main integrated investments of the Operator, which must be effectively managed in network-wide to ensure maximum performance, maximum return on this investment.

This allows the Operator to introduce new network technologies and services more efficiently and effectively, to carry out the strategic development of its NGN and post-NGN networks using the engineering and technical staff available to the Operator, increasing key performance indicators (KPIs) through advanced WFM system.

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МАТЕМАТИЧЕСКИЕ МОДЕЛИ ПОСТРОЕНИЯ СИСТЕМ WFM ТЕЛЕКОММУНИКАЦИОННЫХ ОПЕРАТОРОВ

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Аннотация
Статья посвящена проблематике перспективных систем управления персоналом WFM (Workforce Management) телекоммуникационных операторов пост-NGN, предложен формализованный подход к описанию расширенного функционала WFM, предложены функциональная и математическая модели WFM для перспективных инфокоммуникационных сетей операторов связи. Предложенный подход позволяет разрабатывать новые инженерные инструменты WFM, повышать их производительность, более эффективно управлять графиками работы инженерно-технического персонала операторской компании, пусконаладочными работами на объектах заказчиков, а также планировать, оптимизировать и контролировать загрузку телекоммуникационных инженеров в режиме реального времени.

Ключевые слова: *IT-ландшафт оператора связи, управление персоналом WFM, ключевые показатели эффективности KPI, вероятностно-временные характеристики ВВХ, глубокое машинное обучение DP, системы BSS/OSS.*

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