Digital twin of the management process of field service teams of an electric grid company

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Abstract. Modern electric grid companies are focused on minimum economically feasible costs and are aimed at improving the efficiency of financial and economic activities through the rational use of resources. The digital twin structure is proposed for the management of field service teams in the event of accidents and technological failures in an electric grid company. The digital twin includes an agent model, a system dynamics model, a geographic information system component, and modules with experiments. The description of the simulation model of management of field service teams in the event of accidents and technological failures is formalized, the input and output information on the model components is highlighted, the information is structured, and the scheme of the system dynamics model is created. Experiment designs for the digital twin of the management of field service teams in the event of accidents and technological failures in order to determine the best reliability and cost indicators are developed. The developed approach can be used to create digital twins of the management process of field service teams in the event of accidents and technological failures for various electric grid companies by selecting the parameters of simulation models according to the statistical reports by electric grid companies and connecting the appropriate GIS modules.

1. Introduction

No manufacture or service industry can function without electricity, and resource deficiency and climate change will lead to an increase in demand for electricity by 50% as early as in 2030 [1]. In the context of the implementation of the Industry 4.0 concept, the transformation of production and services should begin precisely with the electric grid. At the same time, particular attention should be paid to the issue of organizing the process of management of field service teams, the quality of which determines the time of work to eliminate accidents and technological failures, which ultimately affects the reliability of services provided, as well as overall customer satisfaction [2], [3].

The pursuit of the Industry 4.0 concept leads to the need to use digital twin technologies [4], [5], the main component of which are computer models that simulate the behavior and current state of a real system in a virtual environment, using real-time data from sensors and information systems, to predict and optimize performance. The digital twin of electric grid company's field service team management process can be represented as a digital object similar to a real production system, including operational data flow from the real object to the simulation model and feedback between them (Fig. 1) [6]. Among...
the known methods of building simulation models (discrete event, agent or system dynamics) it is necessary to choose a modeling approach, the end result of which should be not only the prediction or anticipation of future economic situations, but the understanding of the essence of the dynamics of the system in question [7], [8]. Multi-approach simulation models, combining agent modeling and system dynamics models will allow to bypass a number of limitations in the study of the management process of field service teams caused by the inability to obtain information about this process in various practical situations, when the system and environment parameters change over time and a number of management processes can be described only approximately [9]. A digital twin has the potential to improve an electric grid company's field service team (FST) management process by predicting future events, such as equipment faults or bottlenecks, based on current state and expected behavior, and then implementing appropriate reactions to improve near-real-time reliability.

2. Materials and methods for solving the problem of creating a digital twin to control the field service teams of an electric grid company

The management of field service teams is performed in accordance with the regulations for acting in the event of accidents and technological failures, which set forth the following procedure. In the event of an accident notification, a specialist of the Network Control Center (NCC) determines the complexity category of the accident, then determines whether the number of on-duty personnel in the base location of the FSTs is sufficient. On this basis, the NCC specialist forms a team and provides it with equipment. The numerical composition of the team depends on the complexity category of the accident and the estimated time of its elimination, the number of equipment depends on the numerical composition of the team (table 1).

In case the number of own on-duty personnel is insufficient, all the reserve personnel available at the FST location is dispatched to the accident site, and a contractor is engaged to equip the FSTs to the minimum composition. If necessary (when all own personnel are involved in the emergency response), the contractor is involved, and in such cases, the contractor's minimum size team is used. Considering that contractor's workers can be considerably more expensive for the enterprise, maintenance costs of the permanent personnel are compared to the labor costs of the outsourced personnel.

Table 1. FST numerical composition and number of equipment utilized in the event of accidents.

| Accident complexity category | Team composition, persons | Number of equipment, units | Accident elimination time, hours |
|------------------------------|---------------------------|----------------------------|----------------------------------|
| 1                            | 25                        | 5                          | 3.3 ± 0.2                        |
|                              | 21                        | 5                          | 3.8 ± 0.2                        |
|                              | 17                        | 4                          | 4.3 ± 0.2                        |
| 2                            | 15                        | 3                          | 2.6 ± 0.2                        |
|                              | 13                        | 3                          | 2.9 ± 0.2                        |
|                              | 10                        | 2                          | 3.2 ± 0.2                        |
| 3                            | 7                         | 2                          | 1.4 ± 0.2                        |
|                              | 5                         | 1                          | 1.7 ± 0.2                        |
|                              | 3                         | 1                          | 2.0 ± 0.2                        |

To determine the level of reliability of electricity supply, including by reducing the duration of power outages, the international SAIDI indicator is used [13]. SAIDI (System Average Interruption Duration Index) is the equivalent duration of interruptions in electrical power supply per customer, indicating the average outage time per customer in the electrical power supply system, and is calculated using the formula:
\[ SAIDI = \frac{\sum_{i=1}^{n} r_i N_i}{N_t}, \]

where \( N_i \) is the number of consumers in the system where \( i \)-th interruption in the electrical power supply occurred, \( i = 1, n \); \( r_i \) is the \( i \)-th interruption time in hours, \( i = 1, n \); \( N_t \) is the total number of consumers in the system.

It is proposed to build a digital twin based on a simulation model of the management process of field service teams in the event of accidents and technological failures in electric grid companies, which takes into account the indicator \( r_i \), which directly affects the SAIDI indicator, and which is designed to determine:

- the minimum value of the average duration of electric power supply interruption \( \bar{r} \);
- a sufficient number of on-duty personnel \( A' \) of the FSTs and the number of equipment \( B' \) utilized when eliminating accidents and technological failures;
- the minimum value of the sum of costs \( Z \) connected with the remuneration of labor of both own and outsourced personnel, as well as the costs associated with the operation and rental of equipment involved in the elimination of accidents and technological failures.

The process under consideration involves many individual objects (FSTs, NCC, transformer substations (TS)) and their interrelation, so the main part of the digital twin will be built on the basis of the agent-based approach. When using the agent-based method, the medium level of abstraction is chosen: only significant factors (order of formation of the FSTs and acquisition of equipment, time of accident elimination, etc.) are included in the processing, and such factors as the materials used in the emergency and recovery works, time of arrival to the place of accident, etc., are not included. Given the complexity of the process under consideration, a system dynamics approach will be used to build individual components of the digital twin [5].

Let us consider the structure of the digital twin on the basis of a multi-approach simulation model of the management process of field service teams in the event of accidents in electric grid companies.

### 3. Structure and logic of a digital twin based on a multi-approach simulation model

The digital twin under development should simulate the management process of the FSTs in the event of accidents. The digital twin includes the system dynamics module of cost calculation, the agent model of FST management in the event of accidents, the animation module in the form of a GIS map, on which GIS points mark the power facilities, as well as the experiment module (figure 1). Anylogic simulation modeling package was chosen as the development environment.

![Figure 1. The structure of the digital twin on the basis of a multi-approach simulation model of the FST management process in the event of accidents in the electric grid company](image-url)
The Poisson probability distribution law with intensity of \( N \) accidents per day is chosen to simulate the process of accidents occurrence. The occurrence of accidents of the 1st complexity category is modeled with the probability \( P_1 \), the accidents of the 2nd complexity category – with the probability \( P_2 \), the accidents of the 3rd complexity category – with the probability \( P_3 \).

Based on the fact that every day field service teams (FSTs) with a total numerical composition of \( A \) people and \( B \) units of equipment are on duty, the process of their formation and outfitting with equipment in accordance with the complexity category of accidents and time of elimination of the accident (Table 1). In case the number of own personnel is insufficient, the system should have an implemented mechanism of time delay \( D \) for additional staffing of the FSTs with the outsourced personnel, equal to 3 minutes for each person of the outsourced personnel. The model reflects a simplified scheme of accrual of costs for labor remuneration of personnel and costs connected with operation and rent of equipment:

- labor costs for own personnel \( Z_1 \) are calculated on the basis of the constant component equal to \( S_1 \) (rub.) per day, and the variable component; the variable component is accrued only to the personnel that was involved in the elimination of accidents and their consequences, and is calculated on the basis of the time of accident elimination \( T \) and the rate equal to \( S_2 \) (rub.) per 1 man-hour;
- labor costs for the personnel of a contractor organization \( Z_2 \) depend on the time of accident elimination \( T \) and are calculated at the rate \( S_3 \) (rub.) per 1 man-hour of work performed;
- the costs associated with the operation of equipment \( Z_3 \) depend on the operation time and are calculated at the rate \( S_4 \) (rub.) per 1 machine hour of equipment operation;
- the costs associated with the rent of equipment \( Z_4 \) depend on the rented operation time and are calculated at the rate \( S_5 \) (rub.) per 1 machine hour of equipment operation.

The digital twin must represent the real state of the object, which requires data that describe the current and historical state of the object or process and are accumulated in a database (figure 1). This information, such as the geographic coordinates of the accident, the number of available FST personnel and equipment, can come from the user or sensors, including IoT (Internet of Things), and must be collected over time for further use and situation analysis. Collectively, this creates a virtual representation of the real system and its status.

4. Experiments
To verify the adequacy of the conclusions on the real system, obtained as a result of references to the digital twin, we compared the values of the output data of the simulation model with the values of similar indicators in the real system. Let us consider the implementation of the model based on the data from the annual reports of Lenenergo PJSC for the period from 2015 to 2019. The average duration of consumers' electric power supply interruption according to Lenenergo PJSC reports is 2.38 hours (table 2).

| Year | Average value |
|------|--------------|
| 2015 | 3.8          |
| 2016 | 2.9          |
| 2017 | 2.0          |
| 2018 | 1.7          |
| 2019 | 1.5          |
|      | 2.38         |

To assess the adequacy of the digital twin for the average duration of consumers' electric power supply interruption indicator, the results of a simple experiment were compared with the average value of the Average Duration of Consumers' Electric Power Supply Interruption indicator, calculated on the basis of annual reporting data (table 3).
Table 3. Comparative analysis of the Average Duration of Consumers’ Electric Power Supply Interruption indicator values.

| Experiment No. | Average duration of electric power supply interruption for one year of simulated time, hours | Relative deviation from the average value of the indicator calculated on the basis of annual reporting data, % |
|----------------|------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------|
| 1              | 2.286                                                                                   | -3.95                                                                                             |
| 2              | 2.279                                                                                   | -4.24                                                                                             |
| 3              | 2.283                                                                                   | -4.08                                                                                             |
| …              | …                                                                                       | …                                                                                                |
| 100            | 2.287                                                                                   | -3.91                                                                                             |
| Average value  | 2.286                                                                                   | -3.95                                                                                             |

The performed analysis allows to conclude that the deviation of the Average Duration of Consumers’ Electric Power Supply Interruption indicator obtained from the results of the experiments, from the average value of this indicator, calculated on the basis of annual reporting data, is acceptable for all experiments as a whole, as well as separately for each experiment.

The digital twin structure includes the following elements (figure 2):
- the “map” GIS-map is used to define the GIS space within which the agents “reside”. The map type is tiled, downloaded from the AnyLogic software vendor’s website (OpenStreetMap server);

![Digital Twin Structure Diagram](image)

**Figure 2.** Animated diagram of the management model of the FSTs in the event of accidents in an electric grid company
collections are used to define a data entity combining several elements of the same type (GIS points). The “locations” collection combines point objects (GIS points) denoting transformer substations and other power facilities, while the “stagingPoints” collection combines staging points for the FSTs. GIS points placed on the map have their latitude and longitude coordinates set in degrees;

- animation diagram of the system dynamics model;
- time graphs designed to display the time trend of own personnel labor costs, labor costs of contractor organization personnel, costs associated with the rental of equipment, costs associated with the operation of own equipment;
- the Average Duration of Consumers' Electric Power Supply Interruption graph, which displays the average duration of interruption of electric power supply to consumers for all time;
- the Average Duration of Consumers' Electric Power Supply Interruption histogram, which displays the data on the distribution of the duration of interruption of customers’ electric power supply in set intervals.

Depending on what task is required to be solved using the digital twin, and what system information is required, a series of experiments with the simulation model was conducted, with resource constraints taken into account. To determine the optimal number of on-duty personnel and optimal number of equipment to minimize costs (optimization experiment No.1), and to determine the optimal number of on-duty personnel and optimal number of equipment to reduce the duration of power interruption (optimization experiment No.2), the following resource constraints are set (table 4).

| Parameter       | Type              | Optimization experiment No.1 | Optimization experiment No.2 |
|-----------------|-------------------|------------------------------|------------------------------|
|                 | Min   | Max   | Step | Min   | Max   | Step |
| “numberofStations” | fixed   | 153   |      | 153   |      |      |
| A set of values | 75 | 87 | 1 | 87 | 200 | 1 |
| B set of values | 20 | 38 | 1 | 38 | 80 | 1 |

As a result of the performed optimization experiment No. 1, the best result (the best allowable value of the target function), \( Z = 224,609,199.40 \) rubles, was determined, which was achieved with the following values of parameters: \( A' = 75 \) and \( B' = 37 \) (figure 3). The numbers of iterations are plotted on the \( X \)-axis, and the value of the target functional \( (Z) \) is plotted on the \( Y \)-axis.

![Figure 3. Optimization experiment No.1](image)

As a result of the performed optimization experiment No. 2, the best allowable value of the target function, \( \bar{r} = 2.238 \) hours, was determined, which was achieved with the following values of...
parameters: $A' = 111$ and $B' = 50$ (figure 4). The numbers of iterations are plotted on the $X$-axis, and the value of the target functional ($Z$) is plotted on the $Y$-axis ($\tilde{r}$).

![Figure 4. Optimization experiment No.2](image)

5. Conclusion
The structure of the digital twin proposed in this study, based on the simulation model of the management of FSTs in an electric grid company, makes it possible to create multi-approach models of management of field service teams in the event of accidents and technological failures.

The positive impact of the implementation of the digital twin of the management of field service teams in the event of accidents and technological failures is: an increase in the satisfaction of end users by reducing the average duration of interruption to electric power supply; an increase in efficiency in making tactical decisions in the optimization of resources involved in the elimination of accidents (technological failures).

The combination of these effects will ensure the proper performance of the social function of electric grid companies under the existing economic conditions and market model. The developed structure of the digital twin based on the simulation model allows for adding and/or changing the significant factors affecting the level of abstraction, changing the algorithms of formation by field service teams, replenishing the collection of locations of power facilities on the GIS map, and changing other settings, which will allow the system to adapt to the changing conditions of an electric grid company.

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