eISSN: 2349-5715 pISSN: 2349-5707
Volume: 11, Issue 12, December-2024 SJIF 2019: 4.702 2020: 4.737 2021: 5.071 2022: 4.919 2023: 6.980 2024: 7,662

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DETERMINING THE RELIABILITY OF MONITORING AND CONTROL SYSTEMS FOR THE SIZE AND ALIGNMENT OF RAILWAY ROLLING STOCK

Abstract. In this article, the system of automation and telemechanics in railway plots is calculated on the basis of the Markov rule of reliability of a single element of devices for controlling and detecting movement of gabarite and derailment of devices located at the gabarite gate, transmitter and electrical centering post located in the relay cabinet, and the reliability of devices created on this The reliability of traffic composition gabarites and Trace Control and control system on railway lines was calculated using the Markov chain and Laplace modifier laws, and the first failure Times of the created device were calculated, thereby determining reliability indicators.
Key words: Reliability, electrical centralization, rolling stock, derailment, Markov chain, Laplace's law, failure, redundancy.

Introduction. Reliability is the property of providing continuous and safe control of train traffic on time in the specified modes and conditions of operation, maintenance and repair of the system [1].

Reliability theory is a science that studies the laws of failure of technical systems based on the use of developments in many fields of knowledge.

In the production and operation of railway signaling, centralization and interlocking systems and devices, it is a constant problem to calculate value indicators. Solving this problem is carried out at various stages in the system's operation [3,9].

The reliability indicators of the elements that make up the system are used to determine the reliability index of the system. Depending on the type of system, the calculation method is determined. The reliability of railway automation and telemechanics systems is determined as follows [5] (Fig. 1).

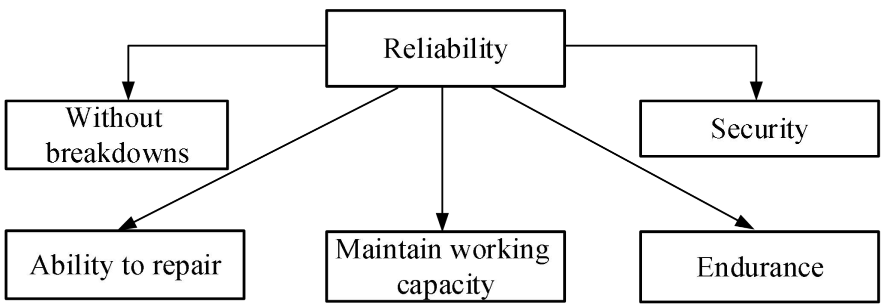

Figure 1. Reliability of railway automation and telemechanics systems

Method. The downtime distribution function Q(t) is called the failure probability. Thus, Q(t) is the probability that the failure time is less than t, or the probability that the object will fail within time t. The main indicator of failure-free operation is this failure probability P(t) is the probability that the object will work without failures for a certain operating time t.

$$P(t)+Q(t)=1 \quad (1)$$

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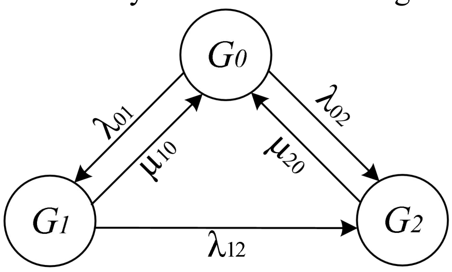
The function P(t) has the following properties:

- P(0) = 1 – this means that the device is operational in the initial state;
- $lim_{t\to} \; P(t) = 1$ – this means that the object cannot maintain its working state indefinitely;
- the value of $0 \quad P(t) \quad 1$ – P(t) is between 0 and 1;
- The $dP(t)/dt \quad 0$ -function is decreasing, and its reliability also decreases over time;

The occurrence of a failure in an object is a random event, that is, it may or may not occur during a certain interval. Therefore, probability theory is based on reliability theory. The reliability index λ(t) is called the failure rate (during system development and during practical operation). This, in turn, is of fundamental importance in increasing the reliability of systems [1].

Backup is divided into temporary, structural (device) and data backup. The developed system is a structurally redundant, renewable system. The performance process of a reserved renewable system is a random Markov process with discrete states [10,11]. The state graph of the regenerative reserved system is shown in Figure 2. The graph consists of three states of the system:



G_0 – healthy state;
G_1 – disabled, but able to work (ability preserved);
G_2 – unable to work (inability to work) but no ability preserved.

Figure 2. State graph of a reserved renewable system

A system moves from one state to another through a series of disturbances and restorations. If the flow of all events that move the system from one state to another is a Poisson flow, then the random process is a Markov process, which is given by a system of differential equations. The system is constructed according to the following rules for the given state graph. The product of the probability of a state is equal to the sum of the terms as many as the number of arrows connected to this state. Each term is equal to the product of the rate of the flow of events that moves the system along a given axis and the probability of the state from which the arrow originates. If the arrow comes from a certain state, then the arrow is directed to a certain state, this term has a minus sign [2,4].

$$\frac{dP_{l.0}(t)}{dt} = -\lambda_{01}P_{l.0}(t) - \lambda_{02}P_{l.0}(t) + \mu_{10}P_{l.0}(t) + \mu_{20}P_{l.2}(t); \quad (2)$$

$$\frac{dP_{l.1}(t)}{dt} = \lambda_{01}P_{l.0}(t) - \mu_{10}P_{l.1}(t) + \lambda_{12}P_{l.2}(t); \quad (3)$$

$$\frac{dP_{l.2}(t)}{dt} = \lambda_{02}P_{l.0}(t) + \lambda_{12}P_{l.1}(t) - \mu_{20}P_{l.2}(t). \quad (4)$$

where: λ_{01} – the rate of transition from a healthy state to a defective, operational state; λ_{02} – the rate of transition from a healthy state to a defective, non-operational state; λ_{12} – the rate of transition from a defective, non-operational state to a fully defective, non-operational state; μ_{10} – the rate of

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recovery from a defective, non-operational state to a healthy state; μ_{20} – the rate of recovery from a defective, non-operational state to a healthy state; $P_{l.0}(t)$ – the probability of the object being in a healthy state at a certain operating time t; $P_{l.1}(t)$ – the probability of the object being in a defective, but non-operational state at a certain operating time t; $P_{l.2}(t)$ – the probability of the object being in a defective, but non-operational state at a certain operating time t [6, 7].

Results. Below is the structural backup scheme of the transmitter part located on the column of the gauge gate of the control and management of rolling stock gauges [8]. (Figure 3).

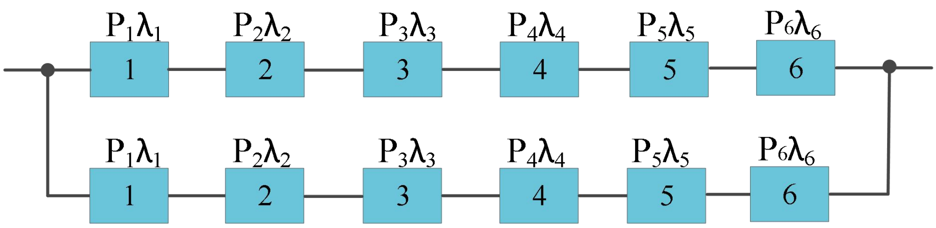

Figure 3. Structural backup scheme of transmitter devices on the gauge gate column of the system

The probability of the system operating without disturbances is found by the following formula:

$$P_j(t)=1-\left(1-\prod_{i=1}^{n}P_i(t)\right)^{m+1} \qquad (5)$$

where: $P_j(t)$ – the probability of the system operating without failures; $P_i(t)$ – the probability of each channel operating without failures; m – the number of reserves.

The probability of failure-free operation of each part of the reserved system is equal to the product of the probability of failure-free operation of the elements that make up the system.

$$P_{l.1}(t)=P_i(t)=P_1(t)\ P_2(t)\ P_3(t)\ P_4(t)\ P_5(t)\ P_6(t) \qquad (6)$$

The probability of failure-free operation is determined by (4.9) and (4.10).

$$P_{l.1}(t)=e^{-\lambda_{01}(t)}; \qquad (7)$$

$$P_{l.2}(t)=e^{-\lambda_{02}(t)}. \qquad (8)$$

Using the above, we find λ_{01}, λ_{02}, λ_{12}, $P_{л.1}(т)$ and $P_{л.2}(т)$.

$$\lambda_{01}=\lambda_{12}=5\lambda_1+\lambda_2+\lambda_3+\lambda_4+2\lambda_5+\lambda_6; \qquad (9)$$

$$\lambda_{02}=\frac{2\ \lambda_{01}}{3}; \qquad (10)$$

$$P_{l.1}(t)=e^{-(5\lambda_1+\lambda_2+\lambda_3+2\lambda_4+\lambda_5+\lambda_6)t}=e^{-27,97\ 10^{-6}t}; \qquad (11)$$

$$P_{l.2}(t)=1-(1-P_{l.1}(t))^2=2\ P_{l.1}(t)-P^2_{l.1}(t)=2e^{-27,97\ 10^{-6}t}-e^{-55,94\ 10^{-6}t} \qquad (12)$$

The expected probable time for the system to experience a failure is T

$$T=\int_0\left(2e^{-27,97\ 10^{-6}t}-e^{-54,94\ 10^{-6}t}\right)dt=54605\text{hour} \qquad (13)$$

T=56689 hour = 6 year 2 month

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Figure 4 shows the relationship between the probability of system failure and the probability of failure. Breakdown rates are listed in Tables 1 and 2.

Table 1

Table of failure rate of elements that make up part of the gauge gate devices of the device

№	Element	Number	λ, 1/million hours	Average recovery time, hours
1.	Infrared sensor (λ1)	5	0,034	0,5
2.	Radio module (λ2)	1	25,2	2,0
3.	Microcontroller (λ3)	1	0.05	1,5
4.	Resistor (λ4)	2	0,02	0,5
5.	Transistor (λ5)	1	0,5	0,5
6.	Optocoupler (λ6)	1	0,5	0,6

Table 2

Table of breakdown rates of elements that make up the EM device part of the device

№	Element	Number	λ, 1/million hours	Average recovery time, hours
1.	Resistor (λ1)	19	0,02	0,5
2.	Optocoupler (λ2)	8	0,5	0,6
3.	Transistor (λ3)	8	0,5	0,5
4.	Radio module (λ4)	1	25,2	2,0
5.	Monitor (λ5)	1	20	1,5
6.	Microcontroller (λ6)	1	0.05	1,5

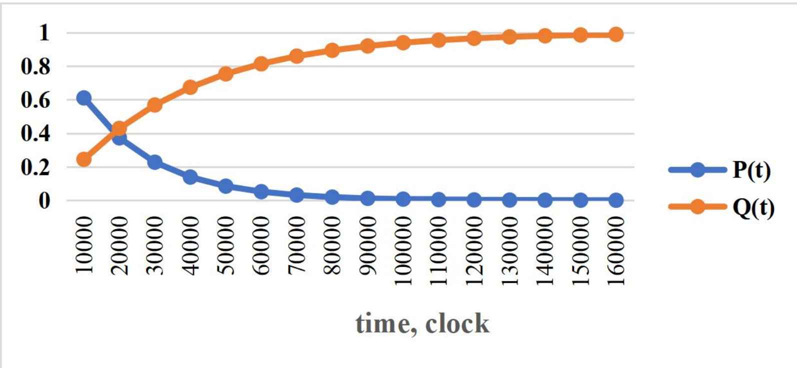

Figure 4. $P_{1.2}(t)$ and $Q_{1.2}(t)$ time dependence graph of

The probability of failure-free operation of the electronic part of the system $P_k(t)$ and the average operating time (T) before the first failure are also calculated in the same way (Figure 5).

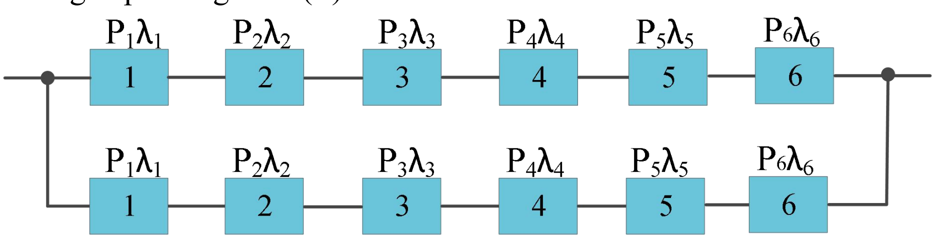

Figure 5. Structural backup scheme of the device's EM devices

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$$P_{k.1}(t) = P_i(t) = P_1(t)\ P_2(t)\ P_3(t)\ P_4(t)\ P_5(t)\ P_6(t); \quad (14)$$

$$P_{k.1}(t) = e^{-\lambda_{01}(t)}; \quad (15)$$

$$P_{k.2}(t) = e^{-\lambda_{02}(t)}; \quad (16)$$

$$\lambda_{01} = \lambda_{12} = 19\ \lambda_1 + 8\ \lambda_2 + 8\ \lambda_3 + \lambda_4 + \lambda_5 + \lambda_6; \quad (17)$$

$$\lambda_{02} = \frac{2\ \lambda_{01}}{3}; \quad (18)$$

$$P_{k.2}(t) = 2\ e^{-(9\ \lambda_1 + 4\ \lambda_2 + 4\lambda_3 + \lambda_4 + \lambda_5 + \lambda_6)t} - e^{-2(9\ \lambda_1 + 4\ \lambda_2 + 4\ \lambda_3 + \lambda_4 + \lambda_5 + \lambda_6)t} \quad (19)$$

$$P_{k.2}(t) = 2\ e^{-49,43\,10^{-6}\ t} - e^{-98,86\,10^{-6}\ t}; \quad (20)$$

$$T = \int_0 \left(2e^{-53,63\,10^{-6}t} - e^{-107,26\,10^{-6}t}\right)dt = 27970 hour \quad (21)$$

T=27970 hour = 3 year 2 month

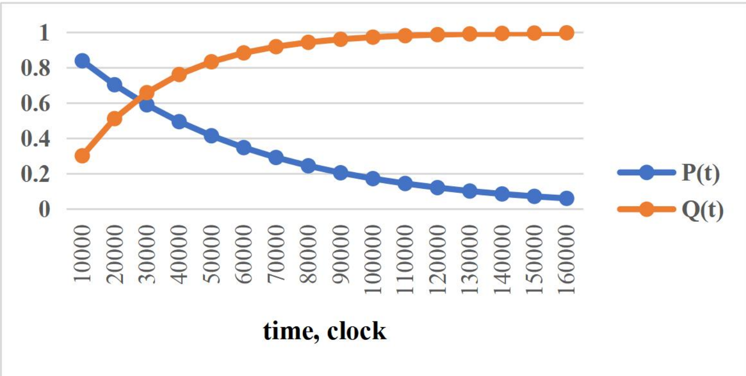

Figure 6. Time dependence graph of $P_{k.2}(t)$ and $Q_{k.2}(t)$

When the reliability indicators of the control and management device of the created rolling stock dimensions were calculated, it was found that the probability of the first failure of the two-channel system is 1.5 times lower than that of the one-channel system. In this regard, the device was developed as an active backup, dual-channel and regenerative device.

Below is a structural backup diagram of the part of the control and management of rolling stock that is located in the relay cabinet (Fig. 7).

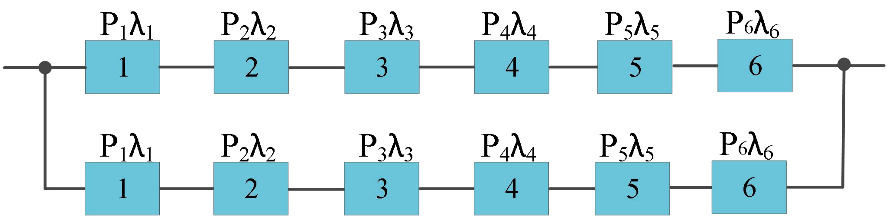

Figure 7. System relay cabinet devices structural backup scheme

The probability of the system operating without disturbances is found by the following formula:

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$$P_j(t)=1-\left(1-\prod_{i=1}^{n}P_i(t)\right)^{m+1} \quad (22)$$

where: $P_j(t)$ – the probability of the system operating without failures; $P_i(t)$ – the probability of each channel operating without failures; m – the number of reserves.

The probability of failure-free operation of each part of the reserved system is equal to the product of the probability of failure-free operation of the elements that make up the system.

$$P_{l.1}(t)=P_i(t)=P_1(t)\cdot P_2(t)\cdot P_3(t)\cdot P_4(t)\cdot P_5(t)\cdot P_6(t) \quad (23)$$

The probability of failure-free operation is determined by (4.9) and (4.10).

$$P_{l.1}(t)=e^{-\lambda_{01}(t)}; \quad (24)$$

$$P_{l.2}(t)=e^{-\lambda_{02}(t)}. \quad (25)$$

Using the above λ01, λ02, λ12, Pл.1(т) and Pл.2(т) we find.

$$\lambda_{01}=\lambda_{12}=5\lambda_1+\lambda_2+\lambda_3+2\lambda_4+\lambda_5+\lambda_6; \quad (26)$$

$$\lambda_{02}=\frac{2\cdot\lambda_{01}}{3}; \quad (27)$$

$$P_{l.1}(t)=e^{-(3\lambda_1+\lambda_2+\lambda_3+2\lambda_4+\lambda_5+\lambda_6)t}=e^{-26,392\cdot10^{-6}t}; \quad (28)$$

$$P_{l.2}(t)=1-(1-P_{l.1}(t))^2=2\cdot P_{l.1}(t)-P^2_{l.1}(t)=2e^{-26,392\cdot10^{-6}t}-e^{-52,784\cdot10^{-6}t} \quad (29)$$

The expected probable time for the system to experience a failure is

$$T=\int_0^{\infty}\left(2e^{-26,392\cdot10^{-6}t}-e^{-52,784\cdot10^{-6}t}\right)dt=56835\,hour \quad (30)$$

T=56835 hour= 6 year 6 moonth

Figure 8 shows the relationship between the probability of system failure and the probability of failure. Breakdown rates are presented in Tables 3 and 4.

Table 3

The elements that make up the part of the relay cabinet devices of the device are the breakdown frequency table

№	Element	Number	λ, 1/million hours	Average recovery time, hours
1.	Infrared sensor (λ1)	3	0,034	0,5
2.	Radio module (λ2)	1	25,2	2,0
3.	Microcontroller (λ3)	1	0.05	1,5
4.	Resistor (λ4)	2	0,02	0,5
5.	Transistor (λ5)	1	0,5	0,5
6.	Optocoupler (λ6)	1	0,5	0,6

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Table 4
Table of breakdown rates of elements that make up the EM device part of the device

№	Element	Number	λ, 1/million hours	Average recovery time, hours
1.	Resistor (λ1)	9	0,02	0,5
2.	Optocoupler (λ2)	4	0,5	0,6
3.	Transistor (λ3)	4	0,5	0,5
4.	Radio module (λ4)	1	25,2	2,0
5.	Monitor (λ5)	1	20	1,5
6.	Microcontrolle (λ6)	1	0.05	1,5

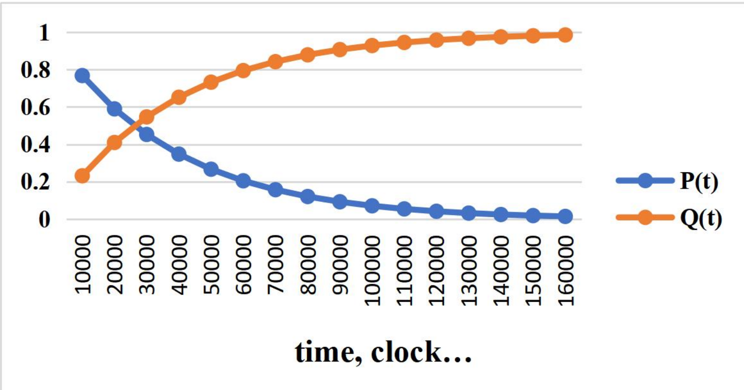

Figure 8. Time dependence graph of $P_{1.2}(t)$ and $Q_{1.2}(t)$

The probability of failure-free operation of the EM part of the system $P_k(t)$ and the average operating time (T) until the first failure are calculated in the same way (Figure 9).

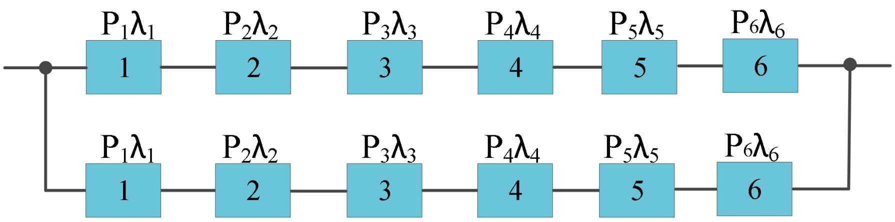

Figure 9. Structural backup scheme of the device's EM devices

$$P_{k.1}(t) = P_i(t) = P_1(t)\ P_2(t)\ P_3(t)\ P_4(t)\ P_5(t)\ P_6(t); \quad (31)$$

$$P_{k.1}(t) = e^{-\lambda_{01}(t)}; \quad (32)$$

$$P_{k.2}(t) = e^{-\lambda_{02}(t)}; \quad (33)$$

$$\lambda_{01} = \lambda_{12} = 9\ \lambda_1 + 4\ \lambda_2 + 4\ \lambda_3 + \lambda_4 + \lambda_5 + \lambda_6; \quad (34)$$

$$\lambda_{02} = \frac{2\ \lambda_{01}}{3}; \quad (35)$$

$$P_{k.2}(t) = 2\ e^{-(9\ \lambda_1 + 4\ \lambda_2 + 4\lambda_3 + \lambda_4 + \lambda_5 + \lambda_6)t} - e^{-2(9\ \lambda_1 + 4\ \lambda_2 + 4\ \lambda_3 + \lambda_4 + \lambda_5 + \lambda_6)t} \quad (36)$$

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$$P_{k.2}(t) = 2\ e^{-49,43\,10^{-6}\,t} - e^{-98,86\,10^{-6}\,t} \qquad (37)$$

$$T = \int_0 \left(2e^{-49,43\,10^{-6}\,t} - e^{-98,86\,10^{-6}\,t}\right)dt = 30346\,coam \qquad (38)$$

T=30346 hour = 3 year 6 month

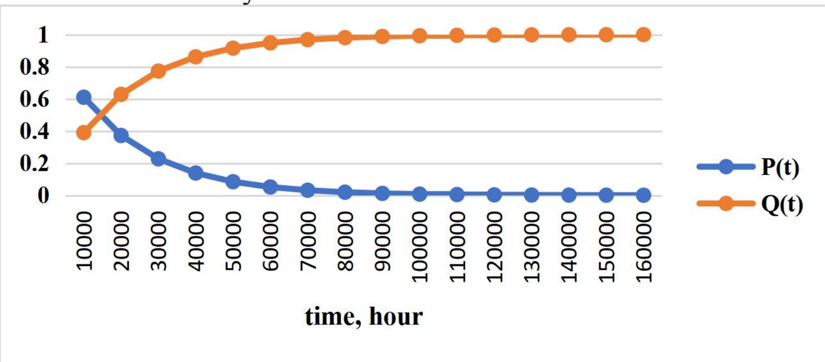

Figure 10. Time dependence graph of $P_{к.2}$(t) and $Q_{к.2}$(t)

The reliability of the system for monitoring and controlling the gauge and derailment of rolling stock on railway lines was calculated using the Markov chain and Laplace transform laws. It was found that the time to first failure of the transmission devices on the gauge gate pillar of the NGK is 6 years and 2 months, the time to first failure of the devices at the EM post is 3 years and 2 months, and the time to first failure of the devices located in the relay cabinet of the HTICHNPK is 6 years and 6 months, and the time to first failure of the devices located at the EM post is 3 months and 6 months.

Conclusion. When determining the reliability indicators of the developed devices, it was found that the probability of the first failure of a two-channel system is 1.5 times less than that of a single-channel system. From this point of view, the device was developed as an active backup, dual-channel and regenerative device.

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