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Determination of the level of redundancy of the complex construction flow of the cluster–territory of the existing city development

Among the methods of increasing reliability envisaged in the design, a special place is occupied by the use of redundancy. Redundancy is additional means (or capabilities) beyond the minimum required to perform a given function. Reservation is a method of increasing reliability by introducing redundancy. The special place assigned to this method is explained by the fact that redundancy most fully solves the problem of obtaining the required reliability with relatively unreliable elements. Depending on the type of redundancy used, the following types of redundancy are distinguished: structural — providing for the use of redundant elements; in the structure of the object (nodes, blocks similar to those available); temporary — providing for the use of excess time; functional — providing for the use of the ability of elements to perform additional functions; informational — providing for the use of the ability to perceive additional information coming to the object; load — providing for the use of the ability to perceive an additional load. One of the main ways to increase the reliability of systems is structural redundancy, which provides for the inclusion of additional facilities in the system. Structural redundancy differs in a number of ways: the reserve is switched on permanently or the reserve element is switched on as needed (replacement reservation, unloaded reserve); individual or group redundancy; the transition to the reserve element occurs instantly or it takes a finite time to switch; the system of health monitoring and reserve management is absolutely reliable or has ultimate reliability, etc. The variety of types of redundancy has led to the creation of dozens of different models that take into account the specific specifics of the systems.

Keywords: *resource reservation, intensity of specialized flow, complex construction flow, cost of maintenance of reserve resources, the principle of choosing the optimality criterion*

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The level of resource reservation (power type) is determined by the additional intensity that should ensure the performance of a given amount of work in the estimated time with a given reliability [1, 2]. To determine this level, taking into account the optimality criterion, the following sequence can be proposed:

1. Statistical data on the intensity of private flows in the studied investment and construction project of the real estate object are collected and analyzed.

2. The average statistical values of the alternating intensities of partial flows — *i*, as well as their variances σ^2 and average deviations — σ are calculated.

3. The earliest dates for the entry into operation of the main specialized flows of the complex flow are found. These deadlines are found as a result of analyzing the linear or network construction schedule of the entire facility as a whole. If the found average value of the intensity of the final specialized flow I_{sf} does not allow the completion of the construction of the facility as a whole within a specified period, then a corresponding increase in intensity should be ensured by attracting reserve resources [3–5].

4. The optimal level of reliability $P_t^{rel} \to P_{opt}^{rel}$ is determined for the corresponding specialized flow, which makes it possible to complete the construction of the facility as a whole in the optimal time period T_{opt}.

5. The average shift intensity of the final specialized flow I_{sf} is calculated, the value of which is determined, in addition to the many factors affecting it by the intensity of the preceding factors, also specialized flows interconnected by a single system of parameters of the construction flow, I_{sf} is necessary to comply with the construction period T_{opt}, which ensures the commissioning of the entire facility within the estimated time, according to the formula [6]:

$$I_{sf} = q_c^{sh} = \frac{Q_c\,(r = 0.5)}{\left(T_{opt}^{sf} - T_{depl}^{sf}\right)}, \qquad (1)$$

where T_{opt}^{sf} — construction period; T_{depl}^{sf} — the deployment period of the specialized (final) flow.

6. The required shift intensity is calculated I_{sf} according to the formula:

$$I_{sf}^{r} = q_r^{sh} = \frac{Q_c\,(P_t^{rel} = P_{opt}^{rel})}{\left(T_{opt}^{sf} - T_{depl}^{sf}\right)}. \qquad (2)$$

7. The necessary increase in the volume of work is determined Q^r:

$$Q^r = Q_c\left(P_t^{rel} = P_{opt}^{rel}\right) - Q_{ft}\left(P^{rel} < P_{opt}^{rel}\right), \qquad (3)$$

were $Q_{ft}\left(P^{rel} < P_{opt}^{rel}\right)$ — amount of work that will be completed on time T_{opt} at an intensity I_{sf}.

8. There is a deadline for which the volume $Q\left(P_t^{rel} = P_{opt}^{rel}\right)$ will be completed at an intensity I^{sf} and $P_t^{rel} < P_{opt}^{rel}$ by the formula [7]:

$$T_f = \frac{Q_c\,(P_t^{rel} = P_{opt}^{rel})}{I^{sf}}. \qquad (4)$$

9. The excess of the expected period over the optimal period T_{opt} ($P_{opt}^{rel} = T_{opt}$) is determined as a result of low reliability $P_t^{rel} < P_{opt}^{rel}$ by the formula [8]:

$$\Delta T = T_{ft}\left(P_t^{rel} < P_{opt}^{rel}\right) - T_{opt}\left(P_t^{rel} = P_{opt}^{rel}\right), \qquad (5)$$

where $\Delta T = \tau$ working or $d\tau$ calendar days.

10. Losses (C_{loss}) are calculated from the delay in commissioning of an object or complex of objects

as a result of exceeding the construction period for the final construction flow by $d\tau$ days [9, 10].

11. The cost of maintaining the reserve resources $C_{r.r}$ should not exceed the value C_{loss} in accordance with the condition.

The following general recommendations can be made regarding the nature and conditions of the allocation of reserve resources [11, 12]:

- along with the collection and analysis of statistical data on the intensity of private flows, the level of unproductive time losses characteristic of each of them is also revealed;
- average values of total intra-shift losses (X) and the probability of whole shift $P(X_{cd})$ losses of working time in private flows are calculated. In each private flow, the amount of critical downtime X_{cd} is determined, taking into account the degree of loading of the main machine or the flow crew (of this private flow);
- REL (organizational and technological reliability) of private flows is calculated using the formula:

$$P_j^{rel} = e^{-\phi x_{cd}}, \qquad (6)$$

in individual flows, the degree of influence of various factors causing unproductive time losses is assessed and significantly influencing risk factors are identified [13];

- reserve resources are selected to neutralize the factors that significantly affect P_j^{rel} of private flows;
- measures are being developed to use reserve means of mechanization of machines or crews outside the flow or in the flow, depending on the technological content of this particular flow. This means that if a private thread is working flawlessly, backup resources are not idle outside of it (for example, on backup objects or in parallel threads). Thus, a significant part of the cost of maintaining reserve resources is repaid [14];
- the cost of maintaining all reserve resources $C_{sfr.r}$ of each specialized flow is calculated, where such resources are used. Then from $C_{sfr.r}$ the value of the economic effect C_{use} obtained as a result of the use of reserve resources and during periods of uptime of the flow is subtracted. Then the actual cost of maintaining reserve resources for the entire period of operation of the specialized flow will be:

$$C_{r.r}^{f} = C_{r.r}^{sf} - C_{use}; \qquad (7)$$

- P_j^{rel} of private flows is calculated, taking into account redundancy. To do this, new values of X_{cd}, $P(X_{cd})$, X_r are defined;
- condition $T = P_j^{rel}$ is checked for the final specialized flow as part of a complex one.

Thus, the assignment of the type of reserve resources and their distribution to specialized flows are made on the basis of an analysis of the REL of private flows, an assessment of the degree of influence of various factors causing unproductive time losses. Reserve resources are being selected to neutralize risk factors that significantly affect the reliability of private flows.

The presented basic principles for determining the level of redundancy assume:

1. The method of backup grips.

2. The main method of increasing the REL of the construction complex flow should be recognized as economically justified resource reservation. The main requirement for the optimality of reserving resources (such as capacity) is that the cost of maintaining these resources does not exceed the amount of the economic effect of increasing REL and reducing construction time. As a criterion for the optimality of the level of resource reservation during the construction of a complex of facilities, a minimum of total costs can be selected. The REL level, which allows the construction to be completed in the optimal time, is proposed to be considered optimal. Increasing REL with the help of reserve resources by maintaining the actual flow rate at a given level with the necessary probability [15].

3. The type of reserve resource is determined by destabilizing factors specific to this particular flow, since downtime due to the lack of a front of work cannot be used as reserve resources.

4. The use of reserve resources to increase P_j^{rel} of a complex construction flow can be justified only if it satisfies some criterion of optimality.

5. The requirements for the optimality of resource reservation, based on the optimality criterion, can be formulated as follows: the problem of the construction flow, which is insufficiently developed, is taken into account, while the issues of resource reservation are also included. It can be assumed that in the process of developing research on this very important problem, various methods of economic justification for reserving resources will be proposed. One of the possible methods of economic justification of resource reservation is proposed in order to increase the efficiency of the integrated construction flow, which allows taking into account the specifics of the urban construction complex.

In general, the principle of choosing the optimality criterion for reserving resources can be characterized as follows: there is a dependence between the reliability P_j^{rel} and the construction period T (Fig. 1).

But although with an increase in REL, the construction period decreases, and the economic effect of putting the facility into operation at an earlier date increases, this happens to a certain limit, after which a further increase in reliability becomes unprofitable. It follows from this that there is some optimum, after which a further reduction in the construction period of an object or group of objects becomes unprofitable.

Let's prove this position on a concrete example of the restoration of the housing stock of Mariupol (DPR).

Therefore, if we design a complex construction flow for a given construction period, then it is advisable to take the optimal period as such. Then, if the REL of the flow is such that the construction period T_r is longer than the optimal period, then it is necessary to increase reliability by so much that the construction period is equal to the optimal one — T_{opt} ($P_j^{rel} = P_3^{rel}$).

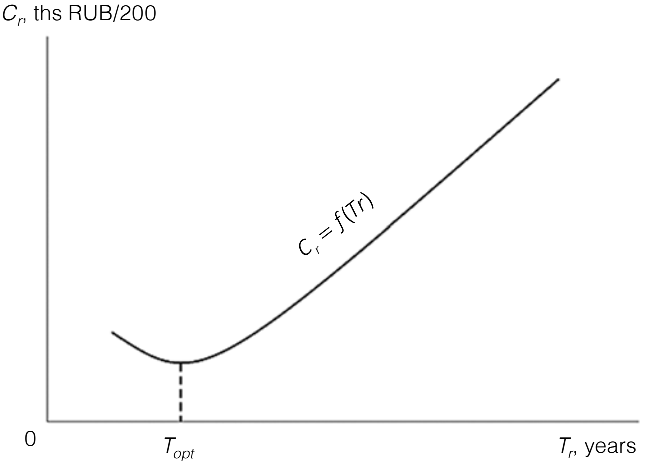

Fig. 1. Graph of the dependence of the total cost C_r on the duration of construction T_r

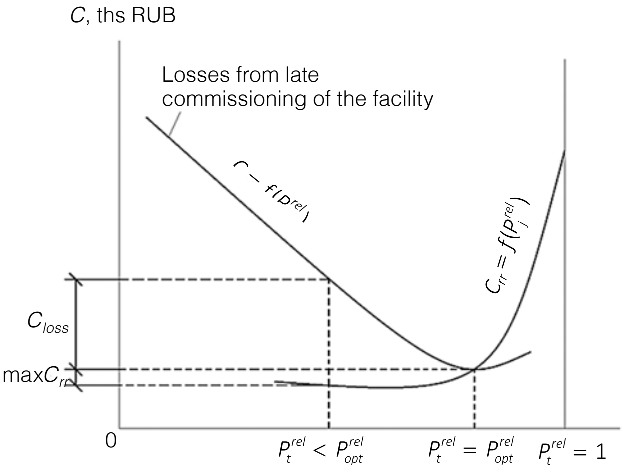

Fig. 2. The fundamental relationship between reliability, the cost of maintaining reserves and the magnitude of the economic effect

The minimum of total costs is taken as the criterion for the optimality of the construction period, and the dependence between the amount of total costs C_r and the duration of construction T_r is established. The nature of this dependence is shown in Fig. 2. A delay in the entry of the final object by τ working days will cause a delay in the commissioning of the entire complex by ατ calendar days, where:

$$\alpha = \frac{\tau_k}{\tau_{work}} = \frac{365}{\tau_{work}}, \quad (8)$$

is a coefficient equal to the ratio of the number of calendar days per year to the number of working days of the year.

Therefore, in this case, it is possible to compare the reliability of the final specialized flow for the restoration of housing stock with the criterion for the entire range of costs.

Certain costs are required to increase the REL of the complex flow. At the same time, of course, with increasing reliability, the cost of maintaining it at the required level increases, and the construction period decreases.

At the same time, with increasing reliability, losses from late commissioning decrease. Given the inverse relationship between the reliability P_j^{rel} and the duration of construction T, the cost function $C = f(r)$ will be the inverse of the one shown in Fig. 2.

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Определение уровня резервирования комплексного строительного потока кластер-территории сложившейся застройки города

Среди методов повышения надежности, предусматриваемых при проектировании, особое место занимает использование избыточности. Избыточность — дополнительные средства (или возможности) сверх минимально необходимых для выполнения заданной функции. Резервирование — это метод повышения надежности путем введения избыточности. Особое место, отводимое этому методу, объясняется тем, что резервирование наиболее полно позволяет решить задачу получения требуемой надежности при относительно малонадежных элементах. В зависимости от вида используемой избыточности различают следующие виды резервирования: структурное — предусматривающее использование избыточных элементов; в структуре объекта (узлов, блоков, аналогичных имеющимся); временное — предусматривающее использование избыточного времени; функциональное — предусматривающее использование способности элементов выполнять дополнительные функции; информационное — предусматривающее использование способности к восприятию дополнительной информации, поступающей на объект; нагрузочное — предусматривающее использование способности к восприятию дополнительной нагрузки. Одним из основных

способов повышения надежности систем является структурное резервирование, которое предусматривает включение в состав системы дополнительных объектов. Структурное резервирование различается по ряду признаков: резерв включен постоянно или резервный элемент включается по мере необходимости (резервирование замещением, ненагруженный резерв); индивидуальное или групповое резервирование; переход на резервный элемент происходит мгновенно или требуется конечное время на переключение; система контроля работоспособности и управления резервом абсолютно надежна или имеет конечную надежность и т.д. Многообразие видов резервирования привело к созданию десятков различных моделей, учитывающих конкретную специфику систем.

Ключевые слова: *резервирование ресурсов, интенсивность специализированного потока, комплексный строительный поток, стоимость содержания резервных ресурсов, принцип выбора критерия оптимальности*

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