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A model of synergistic management of a medical project portfolio based on the telegraphic equation

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Abstract. The relevance of the study was the need to improve the efficiency of managing the portfolio of medical projects for the development of hospital districts. The purpose of the article was to develop and use a model of synergistic management of a portfolio of medical projects for the development of hospital districts based on the telegraphic equation, which takes into account the synergistic relationships between projects and ensures maximum value from their implementation. The paper used the method of critical analysis of scientific literature on project management, information technology, synergistic management and medical project management, a model of synergistic management of a portfolio of medical projects based on the telegraphic equation, numerical methods, and the method of hierarchy analysis. An analysis of scientific papers on the available tools for managing medical projects was carried out. It was found that in 2024 there are no management tools that provide modelling of dynamic processes in systems with spatial and temporal interactions. The expediency of developing a model for synergistic management of a portfolio of medical projects using the telegraphic equation is substantiated. A model of synergistic management of a portfolio of medical projects based on the telegraphic equation is proposed. It involved 6 stages, which are based on the formation of a system of interconnected ordinary differential equations, which are a discrete analogy of the telegraph equation. Based on the developed model, a computer program was created that significantly speeds up the process of making management decisions on the implementation of project portfolios when their project environment changes. The adequacy of the computer program was checked. It was found that the created decision support tool provides accurate results in solving the problems of managing a portfolio of medical projects. The error between numerical and analytical solutions did not exceed 5%, which meets the requirements for such

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models. Based on the research, the status and synergistic effects of medical projects included in the hospital district development portfolio were quantified, and recommendations for project managers were developed. The obtained research results provide project managers with tools to quantify the status and synergies of healthcare projects in hospital district development portfolios in a given project environment, and recommendations for effective management of these portfolios have been developed

Keywords: portfolio management; synergistic effect; modelling; differential equations; partial derivatives

Introduction

The development and implementation of a model for synergistic management of a portfolio of medical projects based on the telegraphic equation is an urgent and scientific and applied task. The development of a model based on the telegraphic equation makes it possible to increase the efficiency of synergistic management of a portfolio of medical projects. In the current conditions of the healthcare system development, the management of medical project portfolios is important for improving the quality of medical services in the territory of the created hospital districts.

In his scientific work, M.P. Stovban (2023) substantiated the peculiarities of the introduction of a hospital district and changes in the finances of a medical institution. At the same time, it is necessary to ensure the optimisation of the use of available resources and the effective development of medical institutions that are part of hospital districts. J. Varajão *et al.* (2025) indicate that the growing number of projects and the complexity of the project environment, as well as the requirements for limited resources, necessitate the development of new approaches to project portfolio management. Such approaches should take into account the systemic interaction and synergies between implemented projects, as well as the ability of hospital districts to adapt to changes in dynamic project environment. One such approach is synergistic project management based on the use of mathematical modelling methods. Synergistic project management involves a systematic consideration of the impact of each individual project on the overall efficiency of the project portfolio. This takes into account the interdependence between individual projects and their resource constraints.

Scientists U. Ojiako *et al*. (2021) note that in 2015-2021, there was a growing interest among scientists in the use of systematic approaches and mathematical models for project management. This is especially true in the healthcare sector, which determines the complexity of medical projects, and the need to optimise limited resources and improve the efficiency of medical services for the population. Scientists K. Wahl & M. Wiesche (2024) propose various models for project management. In particular, these are deterministic, stochastic and dynamic models of project portfolio management aimed at improving the efficiency of project implementation through optimal resource allocation and monitoring of their implementation.

Many researchers emphasise the importance of taking into account the interaction between projects in a portfolio since managing individual projects does not allow achieving the desired result and maximising value. In their works, S. Singh *et al*. (2019) and H. Li *et al*. (2021) consider the concept of synergistic management, which is based on the joint implementation of projects, leading to an additional effect due to their interaction and sharing of resources. Synergy in a project portfolio can increase the efficiency of the entire portfolio, which is especially important in conditions of limited resources and the need to adapt to changes in the project environment quickly.

Another area of research focuses on mathematical modelling of dynamic processes in project management. In the works of L. Sales & S. Barbalho (2021), researchers propose dynamic project management models that allow predicting changes in the project implementation process and timely adjusting previously justified plans. However, most of these models do not take into account the spatial and temporal interactions between projects and their dependence on external factors of the project environment, which are basic components in medical project management.

The telegraphic equation, which is used to model dynamic processes with space-time interactions, has been successfully applied in various fields such as physics, economics, and computer science. In the scientific works of T. Wang & H.-M. Chen (2023) and K.S. Albalawi *et al*. (2023), the telegraph equation is used to model the propagation of signals and information in complex systems. This approach makes it possible to take into account the relationship between system elements at different points in time, which makes it effective for describing dynamic processes with existing changes. In the field of project management, especially medical projects, this approach can be useful for modelling the impact of one project on others through resources or other variables that change in time and space.

Based on the analysis of modern scientific literature, it can be noted that it is advisable to develop a model of synergistic management of a portfolio of medical projects using the telegraphic equation. Such a model will allow to consider the interrelationships between projects in the hospital district development portfolio, which will make it possible to identify additional synergies and increase the efficiency of managing these portfolios. In addition, this model will make it possible to increase the adaptability of the hospital district's medical project management system to changes in their project environment, as well as to respond quickly to these changes.

Therefore, it is worth noting that it is necessary to solve the scientific and practical problem of developing and implementing a model of synergistic management of a portfolio of medical projects for the development of hospital districts using the telegraph equation. It will ensure that the synergistic relationships between projects are taken into account, which is the basis for maximising the value of their implementation.

Materials and Methods

The model of synergistic management of a portfolio of medical projects is based on a system of interconnected ordinary differential equations, which are a discrete analogy of the telegraph equation. In a particular hospital district, a set of medical projects is implemented that use common resources allocated to the hospital district of a particular region. In particular, O. Malanchuk *et al.* (2023a) substantiated the feasibility of allocating common resources of hospital districts. The proposed model, in the form of a system of differential equations, allows for the taking into account of both the use of resources and their distribution between projects and the synergistic effects arising from the interaction of medical projects. The model of synergistic management of a portfolio of medical projects is based on the classical telegraph equation:

$$\frac{\partial^2 u}{\partial t^2} + 2\lambda \frac{\partial u}{\partial t} = c^2 \frac{\partial^2 u}{\partial x^2} + S(t, x), \quad (1)$$

where $u(t, x)$ – is a function that describes the state of the system (including a medical project) in time t and space x; λ – dissipation coefficient (reflects losses or delays in project implementation); c – rate of spread of impact or resources; $S(t, x)$ – sources or absorption of resources.

In the adapted management of medical projects, space x reflects resources or relationships between medical projects, and time t – reflects the process of implementing medical projects (life cycle stages). In the work of R. Czahajda (2019) substantiates the stages and feasibility of adapted management of medical projects at different stages of their life cycle. Taking this into account, a mathematical model for a portfolio of medical projects can be written, and the system of differential equations takes the form:

$$\frac{d^2 u_i}{dt^2} + \lambda_i \frac{du_i}{dt} = c^2 \sum_{j=1}^{n} A_{ij}\, u_j + S_i(t), \quad (2)$$

where $u_i(t)$ – is the state of the i-th project in time t; λ_i – is the dissipation coefficient for the i-th project; A_{ij} – is the matrix of dependencies between projects, which reflects the impact of the j-th project on the i-th project; $S_i(t)$ – is external factors of the project environment or sources of resources for the i-th project.

In the classical telegraphic equation (1), the coordinate represents space (the amount of resources, or the relationships between projects in the hospital district development portfolio). In the modified model (2), for synergistic management of healthcare project x portfolios, the index of projects is replaced by i, and now each project has its own parameters. Therefore x this formulation is no longer used, since the project space is modelled through indices i and j in the corresponding equation (2). Thus, this equation for the healthcare project portfolio does not need to be used x, since each project is already described through the index i and its interactions with other projects through the dependency matrix A_{ij}.

In the presented model (2), the status of each project $u_i(t)$ reflects its execution, which is described by such indicators as the degree of completion, resource efficiency, or other indicators. The dissipation rate λ_i determines how quickly a project loses its effectiveness due to delays, risks, or other negative factors in the project environment. The project dependency matrix A_{ij} reflects the impact of one project on another. High values in the matrix A_{ij} indicate a strong interdependence between the i-th and j-th healthcare projects. External factors of the project environment $S_j(t)$ include economic conditions, political decisions, technological changes, and other factors that affect the implementation of healthcare projects.

To use the model, you need to specify the size of the project portfolio in the form of the number n of healthcare projects. In addition, you should specify the synergy coefficient k, which affects the interaction between projects, enhancing or reducing their impact on each other, and the dissipation coefficient λ_i, which reflects the loss of efficiency of the i-th project over time.

To determine the coefficient of synergy k in the model of interaction between medical projects, mathematical expressions are used that reflect the impact of joint project implementation on their aggregate result. That is, the result of the implementation of a portfolio of medical projects. The basic formula for determining the synergy coefficient is used if there are two projects P_1 and P_2, and their individual results are R_1 and R_2. Then the total result from the simultaneous implementation of both medical projects can be denoted as R_{total}. In this case, the synergy coefficient k is defined as the ratio of the total result to the sum of the individual project results:

$$k = \frac{R_{\text{total}}}{R_1 + R_2}. \quad (3)$$

If $k > 1$, it indicates positive synergy – the result of joint implementation of medical projects is greater than the sum of their individual effects. If $k = 1$, it means no synergy. In this case, the result of project implementation is equal to the sum of individual results. If $k < 1$, it indicates negative synergy, i.e. joint implementation of medical projects worsens the overall result of their implementation in the portfolio.

The study assumes that for a given value of $k = 0.1$, there is a high negative synergy, as noted in O. Malanchuk *et al.* (2023b). Without this, the overall efficiency of the portfolio with these projects is significantly reduced. L. Wang *et al.* (2023) found that for a given value of $k = 0.2...0.3$, there is an average negative synergy. At the same time, there is moderate competition for resources between healthcare projects, which partially reduces the efficiency of the portfolio with these projects. For a given value of $k = 0.4...0.5$, there is a low negative synergy. At the same time, there is weak competition for resources between projects, which minimally affects the overall efficiency of the portfolio with these projects.

If there are multiple projects P_1, P_2, ... ,P_n, their results have different weights when forming the overall result of the project portfolio. Taking into account the weights of medical projects w_1, w_2, ... ,w_n, the formula for determining the synergy coefficient looks like this:

$$k = \frac{R_{\text{total}}}{\sum_{i=1}^{n} w_i R_i}, \tag{4}$$

where R_{total} – total result from the implementation of all projects included in the portfolio; w_i – weight of the *i*-th medical project; R_i – results of the *i*-th medical project.

In a dynamic project environment, the value of synergy can change over time. If we take into account the variability of the results of medical projects over time, then the synergy coefficient k depends on time t:

$$k(t) = \frac{R_{\text{total}}(t)}{R_1(t) + R_2(t) + \cdots + R_n(t)}. \tag{5}$$

Formula (4) allows modelling the dynamics of changes in the synergistic effect of forming a portfolio of medical projects during a given period of its implementation. Provided that the model takes into account the level of risk Risk_i for each *i*-th medical project, the synergy coefficient k takes into account the risks through the function of reducing the overall result due to risks:

$$k = \frac{R_{\text{total}}}{\sum_{i=1}^{n} (1 - \text{Risk}_i) R_i}, \tag{6}$$

where Risk_i – is the risk associated with the *i*-th medical project (values in the range from 0 to 1).

If healthcare projects share resources allocated to the portfolio, this also affects the value of the synergy coefficient k. For example, C_i – is the resources used by the *i*-th project. Then the synergy coefficient k, taking into account the feasibility of resource optimisation, is written as follows:

$$k = \frac{R_{\text{total}}}{\sum_{i=1}^{n} R_i - \alpha \cdot \sum_{i=1}^{n} C_i}, \tag{7}$$

where α – is the resource sharing impact factor (determines how effectively healthcare projects can reduce resource consumption through joint implementation in the portfolio).

Thus, the synergy coefficient k from the joint implementation of medical projects in a portfolio can be determined in different ways, depending on the level of management and the state of the project environment. The basic formula (3) reflects the interaction of the results of medical projects, and other modified formulas (4-6) take into account time factors, risks, and efficiency of resource sharing in the portfolio. For each specific portfolio of healthcare projects, the formula that best suits the characteristics of the projects and their project environment should be chosen.

When modelling the interaction between healthcare projects in a portfolio, the dissipation coefficient λ plays an important role. This coefficient reflects the loss or reduction of effects in a portfolio of healthcare projects due to various factors, such as resource constraints, delays in project implementation, or external influences. Using the telegraphic equation (1), which combines the characteristics of wave and diffusion processes, the dissipation coefficient λ determines how quickly the energy (or effects of interaction between healthcare projects) decreases over time. Dissipation λ is related to the expenditure of resources for the implementation of medical projects, then the formula for determining it will be as follows:

$$\lambda = \frac{\sum_{i=1}^{n} C_i}{\sum_{i=1}^{n} R_i}, \tag{8}$$

where C_i – is the cost of resources for the implementation of the *i*-th medical project; R_i – is the effectiveness of the *i*-th medical project; n – is the number of medical projects in the portfolio. Provided that the dissipation λ takes into account the risks and uncertainties that affect medical projects, then the quantitative value λ will be determined by the formula:

$$\lambda = \frac{\sum_{i=1}^{n} \text{Risk}_i}{n}, \tag{9}$$

where Risk_i – is the risk level for the *i*-th medical project (values in the range from 0 to 1); n – is the number of medical projects in the portfolio. Provided that the dissipation λ takes into account time delays in the implementation of medical projects, the formula for determining this coefficient will be as follows:

$$\lambda = \frac{1}{\tau}, \tag{10}$$

where τ – is the typical delay time in the implementation of a medical project portfolio.

The value of the dissipation λ depends on the specifics of the healthcare project portfolio and the conditions of their implementation. A high value of dissipation λ indicates significant losses or a rapid decline in the effects of the projects in the portfolio. This may be the result of high risks, high resource costs or strong external influences. The average value of dissipation λ indicates moderate losses or a steady decline in the effects of the projects in the portfolio. At the same time, the project portfolio is characterised by a balanced level of risks and resource costs. A low value of dissipation λ indicates minimal losses or a slow decline in the effects of implementing projects in the portfolio. This is the result of efficient resource management, low risks, or favourable conditions for the implementation of medical projects.

The dissipation ratio λ plays a key role in determining the dynamics of the implementation of medical project portfolios. A high value λ leads to a rapid decrease in the interaction between medical projects, which reduces the value of synergy and the efficiency of the medical project portfolio. The optimal value strikes a balance between preserving the effects of interaction and adapting to the changing conditions of the project environment of medical project portfolios. In addition, known quantitative knowledge λ allows to predict how changes in the interaction between healthcare projects affect the overall performance of their portfolio over time.

The dissipation λ factor is an important parameter that reflects the interaction between medical projects in a portfolio. It allows to take into account efficiency losses due to various factors such as resource constraints, risks and time delays. The quantitative value λ is determined based on the results of the preliminary analysis of resource costs, risk levels, and time characteristics of the medical project portfolio. The determination of this coefficient is the basis for accurate modelling of the dynamics of interaction between medical projects, which contributes to more efficient management of the portfolio and achievement of optimal results in the activities of hospital districts.

The main indicators of the initial state of each medical project include the degree of completion, project budget, share of available resources and probability of risks, and a dependency matrix is formed based on the analysis of the relationships between projects. This dependency matrix A_{ij} is a square matrix of size $n \times n$ (where n – is the number of projects in the portfolio), which reflects the elements A_{ij} of the degree of influence of the j-th project on the i-th project. When constructing the matrix, it is important $A_{ij} = 0$ to ensure that the values for all i-th projects are the same. This is due to the fact that the individual i-th project does not affect itself:

$$A = \begin{bmatrix} 0 & A_{12} & A_{13} & \dots & A_{1n} \\ A_{21} & 0 & A_{23} & \dots & A_{2n} \\ A_{31} & A_{32} & 0 & \dots & A_{3n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ A_{n1} & A_{n2} & A_{n3} & \dots & 0 \end{bmatrix}. \tag{11}$$

Subsequently, the impact is quantified A_{ij}. For each pair of projects (i, j), the degree of impact of the i-th project on the j-th project is assessed on a scale from 0 to 1 (0 – no impact, 1 – maximum impact). Fractional values are used to reflect different degrees of impact. That is, for some pairs of medical projects, the degree of influence of the i-th project on the j-th project is – $A_{ij} \in [0,1]$.

The next step is to normalise the dependency matrix A between individual projects. The sum of all the influences on a given medical project is normalised to avoid excessive influence from other projects. The normalisation formula is written for each i-th row of the matrix A:

$$A'_{ij} = \frac{A_{ij}}{\sum_{k=1}^{n} A_{ik}}, \text{ subject to } j \neq i. \tag{12}$$

If the sum is $\sum_{k=1}^{n} A_{ik} = 0$, then the value is $A_{ij}' = 0$. As a result, a matrix A'_{ij} is formed, which is used to determine the degree of influence of the i-th project on the j-th project.

L. Chernova *et al*. (2022) substantiate the external factors $S_i(t)$ that play an important role in modelling the implementation of medical projects in their portfolios. They reflect influences that do not directly depend on the internal processes of projects, but significantly affect their implementation and efficiency. In the model of synergistic management of a medical project portfolio, $S_i(t)$ they are time functions that describe external influences on each individual i-th project. External factors are mathematically described as functions of time for each i-th project:

$$S_i(t) \text{ for projects } i = 1,2, \dots ,n, \tag{13}$$

where $S_i(t)$ – is an external factor that affects the i-th project at a given time t; t – time, which is displayed in months, years, etc.

In order to model external factors, it is proposed to consider their values in a combined manner, both deterministic (predictable trends) and stochastic (presence of random fluctuations):

$$S_i(t) = A_i sin(\omega_i t + \phi_i) + \sigma_i \in(t), \tag{14}$$

where A_i – is the amplitude of the impact; ω_i – is the frequency of oscillations; ϕ_i – is the phase shift.

External factors are integrated into the telegraphic equation (2) for each i-th project, affecting the dynamics of its state. For projects affected by seasonal factors (e.g., changes in demand for medical services, etc.), they are described:

$$S_i(t) = A_i \, sin\left(\frac{2\pi t}{T}\right), \tag{15}$$

where T – is the period of fluctuations (usually set during the calendar year – 12 months for seasonal changes).

It is important in the synergistic management of healthcare project portfolios to take into account the impact of seasonal changes on resource requirements or demand for certain services. Conditionalities are used to model sudden changes, such as the introduction of new regulations:

$$S_i(t) = \begin{cases} S_{i0}, & t < t_0 \\ S_{i1}, & t \geq t_0, \end{cases} \tag{16}$$

where t_0 – is the point in time in the life cycle of the i-th medical project when the change occurs.

The following expression is used to model unpredictable economic changes:

$$S_i(t)=\sigma_i \varepsilon(t), \quad (17)$$

where $\varepsilon(t)$ – is white noise with mean 0 and correlation $\delta(t-t')$.

For the complex modelling of the project environment components, taking into account expressions (14) and (16), which describe both predictable trends and random influences, the expression is used:

$$S_i(t) = A_i \sin\left(\frac{2\pi t}{T}\right) + \sigma_i \varepsilon(t). \quad (18)$$

The choice of a specific form for definition $S_i(t)$ depends on the characteristics of medical projects and their external project environment. If there are predictable and cyclical components of the project environment, then deterministic functions are used. If there are random and unpredictable components of the project environment, stochastic functions are used.

Taking into account external factors of the project environment $S_i(t)$ is an important component of the proposed model of synergistic management of a portfolio of medical projects. It reflects the influence of project environment components that do not depend on the internal components of medical projects but significantly affect their effectiveness. Mathematical modelling of these factors allows to create an adaptive model that takes into account both predictable and random influences of the external project environment. The choice of a specific formula for determining $S_i(t)$ depends on the characteristics of medical projects and their project environment. For the study, were selected the data officially published as of year 2021.

Results and Discussion

In the course of the study, a model of synergistic management of a medical project portfolio based on the telegraphic equation was built. It involves the systematic implementation of 6 stages, each of which reflects the main steps in data generation, analysis, numerical calculations, and project portfolio optimisation (Fig. 1).

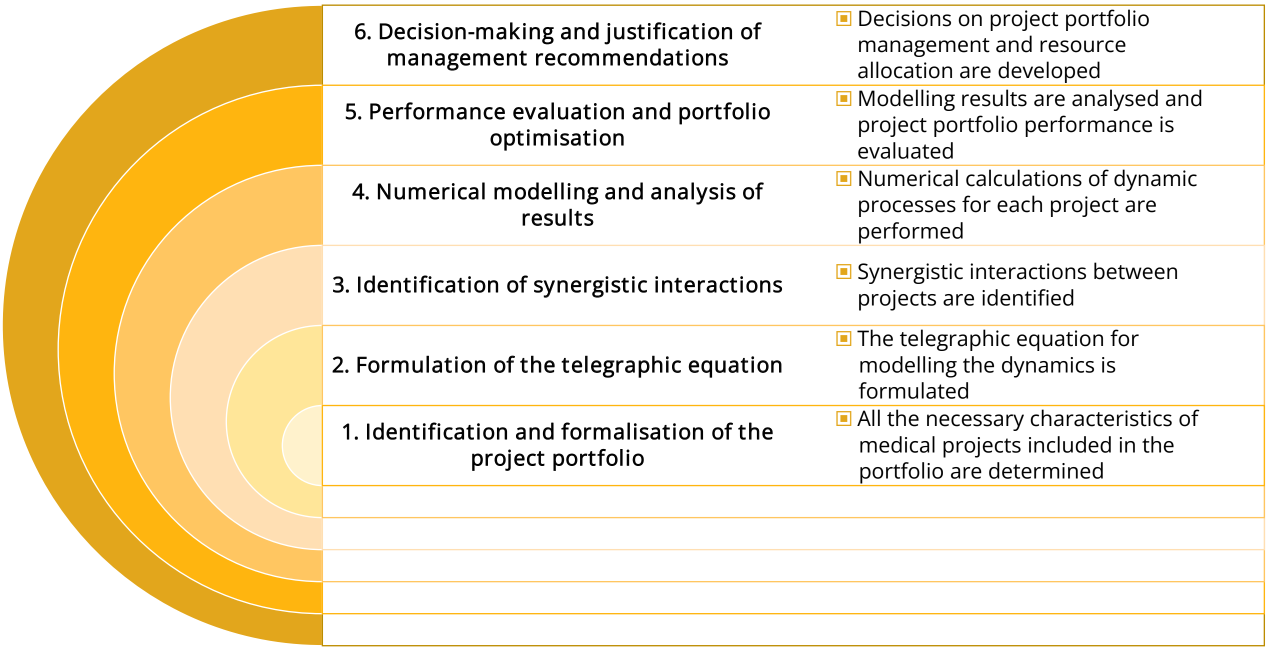

Figure 1. *Schematic of the model of synergistic management of a medical project portfolio based on the telegraphic equation*
Source*: developed by the authors*

At the first stage of the proposed model, the medical projects included in the hospital district development portfolio are identified. At the same time, their respective characteristics are recorded: resources, budget, deadlines, expected results, risks, and interrelationships between projects. Based on this, the main factors describing the status of each healthcare project (health status of the population, amount of resources used, implementation status, etc.)

Stage 2 of the proposed model involves the formulation of the telegraphic equation (1-2), which describes dynamic changes in the state of projects and the interaction between them. The telegraphic equation is a second-order differential equation used to model changing processes and dynamic changes in the project environment. The equation provides adaptation to a changing project environment and describes the dynamics of changes in the state of medical projects and the interdependencies between them in space and time.

Stage 3 of the model analyses the interrelationships between the medical projects included in the hospital district's development portfolio. It takes into account such components as the exchange of resources between projects, the impact of changes in one project on the effectiveness of others. This makes it possible to identify positive and negative synergies. For example, if two projects share resources or complement each other, this increases the overall efficiency of the healthcare project portfolio.

At the fourth stage of the presented model, numerical calculations are carried out to simulate the dynamics of changes in the project portfolio, taking into account the telegraphic equation. The paper assumes that the coefficient characterises a low level of dissipation. At the same time, projects, when implemented together in a portfolio, lose efficiency slowly, which is typical for stable and well-managed projects. If the coefficient has a medium level of dissipation, it indicates a moderate level of efficiency losses in the healthcare project portfolio, which is a result of risks and delays. If the coefficient has a high level of dissipation, portfolios with medical projects quickly lose efficiency due to high risks or inefficient use of resources.

At stage 5 of the presented model, the efficiency and optimisation of the portfolio of hospital district development projects is assessed. Calculations are made to assess the overall efficiency of the project portfolio, taking into account synergies. In addition, the project portfolio management strategy is justified in order to maximise synergies and minimise resource costs.

At stage 6 of the proposed model, decisions are made and management recommendations are substantiated. Based on the results obtained, recommendations for the effective management of the portfolio of hospital district development projects are developed. The optimal strategies for resource allocation and interaction between projects are determined.

On the basis of the proposed model of synergistic management of a portfolio of medical projects using the telegraphic equation, a computer programme has been created. It allows the user to enter initial data, perform calculations and obtain visual results to support decision-making. To ensure that the computer programme implementing the model of synergistic management of a medical project portfolio based on the telegraphic equation is working correctly, were tested its adequacy. Such verification involves comparing the results obtained with the help of a computer program with analytical solutions of the telegraphic equation and real data. For this purpose, the telegraphic equation has the form:

$$\frac{\partial^2 P(x,t)}{\partial t^2} - c^2 \frac{\partial^2 P(x,t)}{\partial x^2} = f(x,t), \qquad (19)$$

where $P(x, t)$ – is the degree of project completion at a given time t at a distance x; c – is the rate of spread of influence or resources; $f(x, t)$ – is a function of external influences and synergies.

For the given initial data with the characteristics of the design environment, equation (18) has an analytical solution, the results of which can be used to compare with the results obtained by using a computer program. It is tested on data sets for which the analytical solution of the equation is known. For each of the datasets, the results of the programme (the value of the project completion rate) were compared with the analytical solution (Table 1). In addition, a formula was used to calculate the error:

$$\Delta P = \frac{|P_{\text{num}}(x,t) - P_{\text{an}}(x,t)|}{P_{\text{an}}(x,t)} \times 100\%. \qquad (20)$$

Table 1. *Results of the adequacy test of a computer program that implements a model of synergistic management of a portfolio of medical projects based on the telegraphic equation (data for 2021)*

Project name	Duration, *t*, months	Degree of project completion		Error, *ΔP*, %
		$P_{num}(x, t)$ %	$P_{an}(x, t)$ %	
Hospital A	3	35.2	34.8	1.15
Hospital A	6	57.3	56.9	0.70
Hospital A	9	76.4	75.8	0.79
Polyclinic B	3	42.1	41.6	1.20
Polyclinic B	6	63.5	62.9	0.95
Polyclinic B	9	82.8	81.9	1.10
Diagnostic centre	3	29.7	29.3	1.37
Diagnostic centre	6	49.8	49.1	1.43
Diagnostic centre	9	67.4	66.5	1.35
Surgical centre	3	33.4	32.7	2.14
Surgical centre	6	55.6	54.8	1.46
Surgical centre	9	73.5	72.3	1.66
Rehabilitation centre	3	21.7	21.3	1.88
Rehabilitation centre	6	41.5	40.9	1.47
Rehabilitation centre	9	58.2	57.3	1.57

Source*: calculated by the authors*

Verification of the adequacy of the computer programme developed on the basis of the telegraphic equation showed that the created decision support tool provides accurate results in solving the tasks of managing a portfolio of medical projects. The difference between numerical and analytical solutions did not exceed 5%, which meets the requirements for such models.

To use the developed computer program based on the model of synergistic management of a medical project portfolio, the indicators for each project are presented in Table 2.

Table 2. *Initial data for the synergistic management of a medical project portfolio (data for 2021)*

No.	Project	Degree of completion, *P*(*x*, *t*)%	Budget, *B*(*x*), UAH million	Resources *R*(*x*), %	Risks *p*(*x*, *t*)%
1	Hospital A	40	50	80	30
2	Polyclinic B	60	30	70	25
3	Diagnostic centre	30	70	60	40
4	Surgical centre	50	40	75	35
5	Rehabilitation centre	20	60	65	50

Source: *compiled by the authors*

Table 2 shows the degree of project completion as a percentage of the project's start to the point in time . For example, for the Hospital A project , this indicates that the project is 40% complete from the set goals. The project budget describes the amount of funding allocated to the project. Resources reflect the proportion of available material and human resources used to implement the project. For example, for the Hospital A project, only 80% of the available resources are used. Risks characterise the quantitative value of risks that may affect the success of the healthcare project. This indicator is presented as a percentage, where 100% means maximum risks.

Based on the initial data in Table 2 and using the developed computer program that implements the model of synergistic management of a portfolio of medical projects based on the telegraphic equation, were modelled and forecasted the results of medical projects, taking into account synergistic interactions and their impact on the overall state of the portfolio of medical projects (Fig. 2).

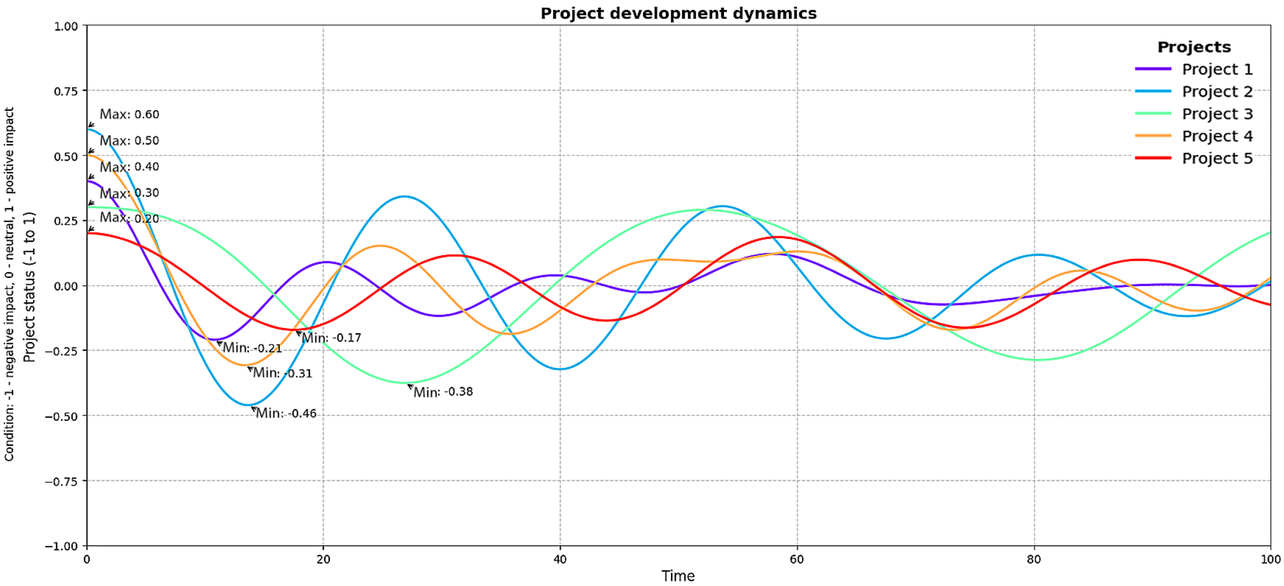

Figure 2. *Trends in the status of medical projects included in the hospital district development portfolio (data for 2021)*
Source: *developed by the authors*

Figure 2 shows the trends in the status of medical projects included in the hospital district's development portfolio over time as a result of the impact of project environment factors. The ordinate axis shows the status of medical projects (-1 means negative impact (due to delays, insufficient resources and high risks), 0 means neutral (no significant positive or negative changes), +1 means positive impact (effective implementation, improved use of resources, reduced risks)). At the beginning of the monitoring of the Hospital District Development Portfolio, all of its projects are in the positive zone with the maximum value of their positive status, except for project 5 'Rehabilitation Centre'. This project reaches the maximum value of +0.34 approximately one month after the start of the monitoring. At the same time, due to the negative impact of external project environment factors, all projects move to the negative zone. Project 2, Polyclinic B, acquires the highest negative value with an indicator of -0.52, which indicates a lack of resources or problems with financing. Most of the projects (project 1, project 2, project 4) demonstrate positive dynamics of implementation after two months of implementation due to the right management decisions, even with initial difficulties, which confirms the effectiveness of synergistic project portfolio management.

The study quantified the synergistic effects of the systematic management of medical projects included in the hospital district's development portfolio (Fig. 3).

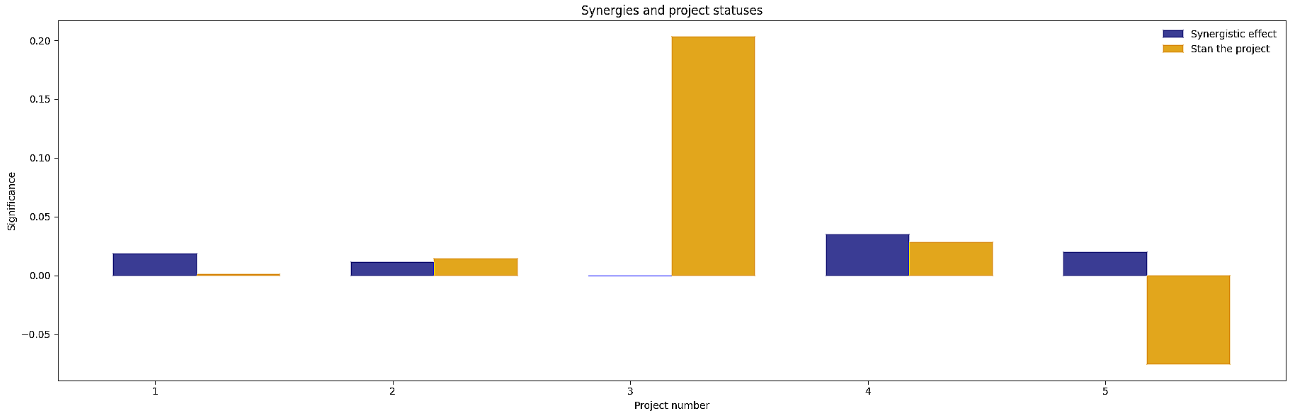

Figure 3. *Histogram of the status and synergies of medical projects included in the hospital district development portfolio*
Source*: developed by the authors*

Also were analysed the results (Fig. 3) regarding the status and synergies of the medical projects included in the hospital district development portfolio. It was found that projects 1 and 5 have a negative impact (-0.025 and -0.08) on the portfolio. This indicates that there are problems in the management or implementation of these projects. This situation is caused by a lack of resources, budgetary constraints or a high level of risk. At the same time, projects 2, 3 and 4 have a positive impact (+0.025, +0.12 and +0.015) on the portfolio. The synergistic effect reflects the extent to which one project affects the others during their systematic implementation in the portfolio. It was found that project 1 has a zero synergistic effect, which does not contribute to the improvement of other projects. However, the impact on other projects is significant. In particular, on project 2 – 0.68, project 3 – 0.24, project 4 – 0.78, project 5 – 0.71. Project managers should reconsider the approach to managing Project 1. It has a negative impact on its own status, its impact on other projects is important, but it requires additional resources or management interventions. Project 2 has a synergistic effect of +0.01, which indicates a slight positive impact on other projects. At the same time, its impact on other projects is also significant. In particular, on project 1 – 0.91, project 3 – 0.84, project 4 – 0.78, project 5 – 0.13. At the same time, project 2 has the greatest impact on project 1, which helps to improve its condition. Support from other projects should also be increased. Project 3 has an insignificant synergistic effect of -0.01, which indicates a slight negative impact, but it does have an impact on other projects. In particular, on project 1 – 0.83, project 2 – 0.38, project 4 – 0.09, project 5 – 0.63. Project 3 requires additional efforts to eliminate the negative effects that affect its status and potentially interfere with other projects. Project managers should pay special attention to resource management. Project 4 has a positive synergy effect of +0.01 and a positive impact on other projects. In particular, on project 1 – 0.63, project 2 - 0.88, project 3 – 0.77, project 5 – 0.39. Project 4 is stable and contributes to the development of other projects, in particular project 2. It is recommended to continue to actively support it. Project 5, despite its negative status of -0.8, has a positive synergistic effect of +0.01. However, the impact on other projects is significant. In particular, on project 1 – 0.94, project 2 – 0.79, project 3 – 0.42, project 4 – 0.67. Project 5 has great potential for recovery if supported by other projects. It has a significant impact on project 1, and coordination between the two projects should be strengthened.

In general, project managers should pay attention to project 5, which requires immediate intervention to overcome the negative factors of the project environment, given its strong impact on other projects. Projects 2 and 4 demonstrate stable positive development and can serve as models for implementing management decisions in other projects. Project 1 is also worthy of note, as it has a significant impact on other projects despite its poor condition. Additional resources and improved management will have a positive effect on the entire portfolio. It is important to strengthen coordination between projects, as synergies contribute to the overall success of the portfolio.

Based on the analysis of the results and indicators of the mutual impact of healthcare projects in the hospital district development portfolio, recommendations for project managers were substantiated, as shown in Table 3.

Table 3. *Recommendations for project managers on the synergistic management of portfolios of medical projects for the development of hospital districts*

Recommendations	Project 1	Project 2	Project 3	Project 4	Project 5
Manage the relationships between projects	Interaction with projects 2, 4, 5	Interaction with projects 1, 3, 4	Interaction with projects 1, 5	Interaction with projects 1, 2, 3	Interaction with projects 1, 2, 4
Prioritisation of resources	–	Important	–	Important	Important
Planning flexibility	Yes	Yes	Yes	Yes	Yes
Control and monitoring of risks	Yes	Yes	Yes	Yes	Yes
Timing of implementation	Speed up	Speed up	Speed up	Speed up	Speed up

Source*: compiled by the authors*

The article analyses the recommendations provided for project managers who manage portfolios of medical projects. The interrelationships between medical projects that influence each other are important and can be assessed by synergistic effects. The most influential are projects 1, 2, and 4, which have a strong mutual impact. This means that coordination between these projects is fundamental to the successful completion of the Hospital District Health Project Portfolio. For example, strengthening the interaction between projects 1 and 4 improves the effectiveness of the portfolio. The greatest attention should be paid to projects 2, 4 and 5 as they lack resources. This may reduce their effectiveness and increase risks, so it is recommended to increase funding or reallocate existing resources. It is important for project managers to constantly review the plans of all healthcare projects, as the dynamics of changes affect the effectiveness of their implementation. A mechanism should be put in place to regularly adapt strategies in line with current data and the results of monitoring the project environment. All healthcare projects require ongoing risk monitoring. It is especially important to monitor risks in projects with high negative impact (e.g. project 5) to ensure timely response to them. For all projects, consider accelerating their implementation to reduce risks and increase positive synergies.

Project managers are advised to focus on increasing the interaction between core projects that have strong synergies with each other. This will help improve the overall success of the portfolio. In addition, it is important to ensure that sufficient resources are allocated to the most challenging projects and to continue to plan and control risks flexibly to avoid potential threats.

The model of synergistic management of a medical project portfolio based on the telegraphic equation has significant potential to improve the efficiency of medical project management. This is especially true in a dynamic and complex project environment in which medical projects are implemented. The analysis shows that the use of the telegraphic equation allows taking into account the temporal and spatial aspects of interaction between projects, which contributes to more accurate risk prediction and assessment of results. The results of the study were analysed in comparison with the existing scientific approaches and studies conducted by other researchers. One of the basic aspects confirmed in the study by A. Alothman *et al.* (2023) is the complexity of implementing the latest technologies in project management, particularly in infrastructure projects in India. This study highlights the need to adapt management models to specific project conditions, which is also relevant to this model of the telegraphic equation in healthcare projects. Synergistic project portfolio management should take into account the specifics of the healthcare sector, where resources, technology and changes in the external environment have a significant impact on project success.

The authors G. Bilgin *et al*. (2023) in their study developed a decision support system for project portfolio management in construction companies. Although the construction industry and medical projects are different, the principles of portfolio management, such as prioritisation and resource optimisation, have common features. This demonstrates the versatility of project management models based on the telegraphic equation, which can be adapted to different industries.

Researchers E. da Costa Carvalho & S.R.B. Oliveira (2022) explore the variety of approaches to supporting software project management using Agile, which focuses on the flexibility and adaptability of the methods. Although Agile is mostly used in the IT industry, its principles are also useful for healthcare projects, where rapid adaptation to changes in the external project environment is also important. For example, in the context of pandemics or crises, when project priorities change rapidly, applying Agile approaches such as incremental updates and frequent progress reviews is useful for a synergistic healthcare project portfolio management model.

R. Ghule *et al*. (2015) discuss in detail the modelling of the telegraphic equation for system stabilisation in the energy context, which has direct parallels with model, analysed in this research. Their approach to controlling dynamic systems through telegraphic equations shows that such methods are effective in predicting the behaviour of complex systems, including medical projects with many interconnected elements.

Another important aspect was investigated by A. Kock *et al*. (2020) and D. Silva *et al*. (2021), who studied the impact of information systems on the success of project portfolio management. Their results showed that the level of use of management processes is quite important for ensuring project efficiency. In the context of model, outlined in this paper, this means that the use of the telegraphic equation is only successful if there is a high level of use of management processes in healthcare project management.

Finally, Y. Zhang *et al*. (2020) investigated dynamic modelling of financing strategies for infrastructure projects, which is also useful in the context of healthcare projects where funding is often limited and requires careful planning. Their simulation approach confirms the importance of dynamic models for evaluating financing strategies, which is another confirmation of the effectiveness of the telegraphic equation in project portfolio management.

Thus, the results of model of synergistic management of a medical project portfolio based on the telegraphic equation are consistent with existing research and approaches to project management, which confirms its practical value for improving efficiency in the complex and dynamic conditions of a given project environment. Proposed model of synergistic management of a portfolio of medical projects based on the telegraphic equation and the developed computer programme based on it allow to effectively assess the status of each project in the portfolio, taking into account both individual characteristics and mutual influence between projects. This toolkit allows to identification of negative trends at the early stages of changes in the project environment, which makes it possible to analyse synergies arising from the interaction between projects and to substantiate recommendations for improving the efficiency of project management.

Testing of the model has shown that synergistic effects play an important role in stabilising or deteriorating the state of individual projects, which underlines the expediency of using a synergistic approach to managing portfolios of such projects. The use of the telegraphic equation provides an accurate description of project dynamics, allow to track trends in their development over time.

The average error of the computer program test results, which does not exceed 5%, confirms the adequacy and accuracy of the numerical solutions made by it, which is acceptable for use by project managers for practical purposes. Recommendations based on the model are used by project managers to improve the efficiency of project implementation, optimise resource allocation, and reduce risks. Implementation of this model in real-world conditions will allow for more flexible and efficient management of the development of hospital districts and their medical facilities, improve the quality of medical services, and promote the rational use of limited financial and human resources within the hospital district.

Conclusions

Based on the analysis of scientific papers on the developed tools for managing medical projects, it has been found that scientists have paid considerable attention to both models and methods of managing individual medical projects and their portfolios. However, due to the lack of management tools that provide modelling of dynamic processes in systems with spatio-temporal interactions, there is a need to develop a model of synergistic management of a portfolio of medical projects using the telegraph equation.

The developed model of synergistic management of a portfolio of medical projects is built based on the telegraphic equation and includes 6 stages. It is based on the construction of a system of interrelated ordinary differential equations that represent a discrete analogy of the telegraphic equation. The proposed model in the form of a system of differential equations allows for taking into account both the use of resources and their distribution between projects and synergistic effects arising from the interaction of medical projects.

Based on the developed model of synergistic management of a medical project portfolio, a computer program was created that significantly accelerates the process of making managerial decisions on the implementation of project portfolios in a changing environment. Verification of the adequacy of the program, based on the telegraphic equation, has shown that this decision support tool provides high accuracy in solving the problems of managing a portfolio of medical projects. The deviation between the numerical and analytical solutions did not exceed 5%, which is in line with the standards for such models.

Based on the initial data on the implementation of projects in the hospital district (Ukraine) for 2021, using the developed computer program that implements the model of synergistic management of a portfolio of medical projects based on the telegraphic equation, the results of the implementation of medical projects were modelled and forecasted, taking into account synergistic interactions and their impact on the overall state of the portfolio of medical projects. The obtained results made it possible to quantify the status and synergistic effects of medical projects included in the hospital district development portfolio, as well as to develop recommendations for project managers.

Further research should be conducted to adapt the model of synergistic management of a healthcare project portfolio based on the telegraphic equation to the conditions of different hospital districts. In particular, additional factors of the project environment, such as changes in the sources and amounts of project funding, should be taken into account. Particular attention should be paid to developing methods for forecasting long-term synergies, which will improve resource management and increase the efficiency of project implementation. It is also worth integrating more flexible algorithms for adapting to the rapidly changing components of the project environment of hospital districts.

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Conflict of Interest

None.

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Модель синергетичного управління портфелем медичних проєктів на основі телеграфного рівняння

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Анотація. Актуальність дослідження полягає у потребі підвищення ефективності управління портфелем медичних проєктів розвитку госпітальних округів. Метою статті була розробка та використання моделі синергетичного управління портфелем медичних проєктів розвитку госпітальних округів на основі телеграфного рівняння, що враховує синергетичні взаємозв'язки між проєктами та забезпечує отримання максимальної цінності від їх реалізації. У роботі використано метод критичного аналізу наукової літератури із проєктного менеджменту, інформаційних технологій, синергетичного управління та управління медичними проєктами, модель синергетичного управління портфелем медичних проєктів на основі телеграфного рівняння, чисельні методи, метод аналізу ієрархій. Було виконано аналіз наукових праць щодо наявного інструментарію для управління медичними проєктами. Встановлено, що у 2024 році відсутній управлінський інструментарій, що забезпечує моделювання динамічних процесів в системах з просторово-часовими взаємодіями. Обґрунтована доцільність розробки моделі синергетичного управління портфелем медичних проєктів з використанням телеграфного рівняння. Запропонована модель синергетичного управління портфелем медичних проєктів на основі телеграфного рівняння. Вона передбачала виконання 6-х етапів, які базуються на формуванні системи взаємопов'язаних звичайних диференціальних рівнянь, які є дискретною аналогією телеграфного рівняння. На основі розробленої моделі було створено комп'ютерну програму, яка значно пришвидшує процес прийняття управлінських рішень щодо реалізації портфелів проєктів за зміни їх проєктного середовища. Виконана перевірка адекватності комп'ютерної програми. Встановлено, що створений інструмент для підтримки прийняття рішень дає точні результати під час вирішення завдань управління портфелем медичних проєктів. Похибка між чисельними та аналітичними рішеннями не перевищувала 5 %, що відповідає вимогам для таких моделей. На підставі проведених досліджень кількісно оцінено стан та синергетичні ефекти медичних проєктів, включених у портфель розвитку госпітального округу, а також розроблено рекомендації для проєктних менеджерів

Ключові слова: портфельне управління; синергетичний ефект; моделювання; диференціальні рівняння; частинні похідні