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ВЕБ-СЕРВІС ПЛАНУВАННЯ РОБІТ З ВИКОРИСТАННЯМ МЕРЕЖЕВОГО ГРАФА

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АНОТАЦІЯ

Формулювання проблеми. *Масштабні проєкти сучасного суспільства включають велику кількість різноманітних видів робіт. Мережевий граф є основним документом для планування та управління такими проєктами. Це інформаційно-динамічна модель послідовності робіт і взаємозв'язків між ними. З математичної точки зору мережева модель являє собою скінченний орієнтований граф. Побудова такого графа починається з поділу проєкту на чітко визначені роботи, для яких вказується тривалість. Саме математичний підхід може і повинен замінити досі поширений механічний підхід до планування роботи науково обґрунтованим поділом виробничої програми між підрозділами. Більшість авторів розкривають сутність математичного моделювання через систему складних математичних формул або наголошують на застосуванні інформаційних систем і технологій. Проведені дослідження дозволили зробити висновок, що деякі питання управління дискретними процесами (а саме, тайм-менеджмент) потребує подальшого розгляду та дослідження.*

Матеріали і методи. *Під час дослідження застосовувався комплекс теоретичних, емпіричних та моделюючих методів, зокрема: систематичний аналіз науково-методичних джерел, результатів вітчизняного та зарубіжного досвіду вирішення проблеми, огляд існуючого програмного забезпечення для визначення стану вирішення проблеми та вибір засобів розробки веб-сервісу, аналіз методів і технологій побудови мережевих графів, узагальнення інформації з проблеми.*

WEB SERVICE OF WORKS PLANNING USING NETWORK GRAPH

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ABSTRACT

Formulation the problem. *Large-scale projects of the modern society include a large number of different types of work. The network graph is the main document for planning and managing such projects. This is an information-dynamic model of the sequence of works and the relationships between them. From a mathematical point of view, the network model is a finite-oriented graph. The construction of such a schedule begins with the division of the project into clearly defined works, for which the duration is specified. It is the mathematical approach that can and should replace the still widespread mechanical approach to work planning with a scientifically sound division of the production program between departments. Most authors reveal the essence of mathematical modeling through a system of complex mathematical formulas or emphasize the use of information systems and technologies. The conducted research allowed us to draw a conclusion that some discrete process management issues (namely time management) need further consideration and research.*

Materials and Methods. *During the study, a set of theoretical, empirical, and modeling methods were applied, in particular: systematic analysis of scientific and methodological sources, the results of domestic and foreign experience on the problem, review of existing software to determine the problem solution state and select development tools of web service, analysis of methods and technologies network graphs construction, generalization of information on the problem.*

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Результати. *Проведено огляд попередніх досліджень у цій галузі. Проаналізовано теоретико-методологічні основи побудови мережевих графів у задачах планування робіт. Обґрунтовано необхідність використання апарату теорії графів для вирішення задач оптимального планування робіт. На основі методичної стратегії розроблено веб-додаток, що дозволяє планувати хід робіт у складних проєктах шляхом побудови відповідного мережевого графа. Надано короткий опис функціональних можливостей та інтерфейсу користувача запропонованого веб-додатку.*

Висновки. *Особливістю створеного додатка є вирішення задачі планування виконання комплексних робіт, при цьому задіяні мережеві моделі, що спрощує розуміння моделі в цілому та забезпечує оптимізацію розробленого графа на основі математичних методів. Програма відображає результати планування у графічному та текстовому вигляді, що полегшує та робить очевидним вибір рішення, дозволяє стежити за перебігом подій і вносити в модель коригування з метою покращення оптимізації.*

Дослідження проведено в рамках Норвезько-українського проекту «Розвиток математичних компетенцій студентів за допомогою цифрового математичного моделювання» (DeDiMaMo) у партнерстві Тернопільського національного педагогічного університету імені Володимира Гнатюка та Університету Агдера (Норвегія), Київського університету імені Бориса Грінченка.

КЛЮЧОВІ СЛОВА: методологія управління проєктами; мережевий розклад; планування робіт; мережевий граф; мережева модель; Веб-сервіс.

Results. *A review of previous research in this area has been conducted. The results of the pedagogical experiment and theoretical and methodological bases of construction of network graphs in works planning tasks are analyzed. The necessity of using the apparatus of graph theory to solve the problems of optimal work planning is substantiated. Based on the methodological strategy, a web application was developed that allows you to plan the progress of work in complex projects by building an appropriate network schedule. A brief description of the functionality and user interface of the proposed web application is provided.*

Conclusions. *A feature of the created application is the solution to the problem of planning the implementation of complex works, involving network models, which simplifies the understanding of the model as a whole and provides optimization of the developed graph-based on mathematical methods. The program displays the results of planning in graphical and textual representation, this facilitates and makes the choice of solution obvious, allows you to monitor the progress of events, and makes adjustments to the model to improve optimization.*

The study was conducted within the Norwegian-Ukrainian Project CPEA-ST-2019/10067 Development of students' mathematical competencies through Digital Mathematical Modelling (DeDiMaMo) in partnership between the Ternopil Volodymyr Hnatiuk National Pedagogical University and the University of Agder (Norway), Borys Grinchenko Kyiv University.

KEYWORDS: projects management methodology; network schedule; works planning; network graph; network model; Web service.

INTRODUCTION

Formulation of the problem. Large-scale projects of modern society, carried out by various departments and specialists, include a large number of different types of work. A *network graph* (or *network model*) is the basic planning document for network planning and management. It is an information-dynamic model of the sequence of work and the relationships between those works that must be fulfilled to complete a single project. From a mathematical point of view, the network model is a finite-oriented graph. The construction of such a graph (structural planning) begins with the breakdown of the project into clearly defined works for which the duration is specified. It is the mathematical approach that can and should replace the mechanical approach to works planning, which is still common, with a scientifically grounded division of the production program between units.

The purpose of the study is to evaluate the possibility of using the apparatus of mathematical modeling in management decisions, improving the theoretical and methodological tools, developing a suitable Web-service, providing practical advice on the possibility of planning the implementation of complex projects, monitoring the process of their implementation and making necessary adjustments.

Analysis of previous research and publications. The network models are exuded among a large number of information models. This is a relatively new way of presenting tasks for those subject areas that need to perform operations in a specific sequence (Batenko et al., 2003; Malsam, 2022; Verma, 2022).

In network models, targeted human activity is divided into a sequence of subtasks, the relationships between which are determined by the structure of the network. Each node in the network is a separate subtask that must be completed. The network structure determines the order of subtasks fulfillment. The use of mathematical graph theory made it possible to make a scientifically sound division of the production program between units (Aptekar et al., 2007; Siedykh & Chobanu, 2018; Kichor et al., 2007; Phillips & Garcia-Diaz, 1981). Any project is a list of works that can be managed to optimize the process, changing their duration, start, and end.

Aptekar et al. (2007), Batenko et al. (2003), Siedykh & Chobanu (2018), Trillenberg (2001), Fedorchak (2012) and others devoted their papers to the problems of the management of production processes, projects, and research of network models.

Projects can be repeated or modified, so each production organization sets different goals and positions its activities as work on specific projects (Evans, 2019; Phillips & Garcia-Diaz, 1981). The most well-known methods of network graphs are discussed in Jungnickel (2013).

In works (Balyk et al., 2021; Drushlyak et al., 2020; Proshkin et al., 2021) time sequences of works performed in the course of educational, scientific activity with the use of a projects method is considered.

Using network scheduling, you can optimize any process (Eddows & Stensfield, 1991; Evans, 2019; Zhang et al., 2019). Reducing the timing of some works can be done with a timely account of resource constraints (Phillips & Garcia-Diaz, 1981; Aptekar et al., 2007). The main stages of network planning (including justification of the execution time of each process in the network schedule) are discussed in (Watt, 2014; Tarasiuk, 2004; Taha, 2017). It is from network models that the development of project management methodology began (Eddows & Stensfield, 1991).

Improvement of organizational design methodology (determining the sequence of stages – phases, sections) is the subject of research by many scientists, among them (Mintzberg, 1979; Hatch, 2018).

Modern society, with its powerful growing information and techno-logical saturation, is placing ever greater demands on managers. The scope of the tasks requires the use of a wide range of information technologies and software packages. This applies to both the project management methodology as a whole and its elements, including network planning.

Most authors expose the essence of mathematical modeling through a system of complex mathematical formulas or emphasize the use of information systems and technologies. The use of the latter is only one element of management decision modeling. The conducted research has made it possible to conclude that the modeling of management processes as a complex process from the formulation of a management task to the implementation of the model in practice is still insufficiently studied and is relevant. Some discrete issues of process management (namely time management) need further consideration and research.

THEORETICAL AND METHODOLOGICAL BASICS

Let us consider network graphs as an object of mathematical graph theory. Suppose that there is some work to be done and that many, many employees – individual employees, groups, teams, or entire businesses – have to take part in this common, "big" job, so that individual tasks will be assigned to different people, groups, teams, and so on. Questions arise:

- How best to distribute employees to do all the "big" work in the shortest possible time?
- How to distribute resources (labor, materials, finances, equipment) so that all the "big" work is the cheapest?
- What to do if, in the course of the work, it turns out that individual employees do not meet the deadline set by the plan?
- Where to throw reinforcements (tools, equipment, people)?
- How to find out what is currently the most important, where is the most responsible area, on the results of which depends on the success of the whole case (Phillips & Garcia-Diaz, 1981)?

Such issues are considered by many authors (Aptekar et al., 2007; Batenko et al., 2003; Evans, 2019).

The very process of ordering the network graph leads to the need to take into account all the links of "big" work. The main characteristic of each work – its expected duration of execution – in graph theory is called arc length. The presence of this numerical estimate makes it possible to perform a mathematical analysis of the network graph.

As a result of such analysis, it is possible to determine, first of all, its parameters:

- the earliest possible start time for each job or the occurrence of each event;
- the latest permissible time of completion of each job or the occurrence of each event, which will not cause a delay in the deadline for completing all the "big" work;
- time reserves for each job (and the time of occurrence of each event) – how many units of time can be delayed for the execution of this work without delaying the termination of "big" work (this is the so-called full-time reserve), or even without to change the timing of other jobs of the graph (this is the so-called free time reserve);
- a so-called critical path can be found – the longest path leading from the initial event of the schedule to its final event. It has the important property that delays in the execution of any work and the occurrence of any event lying on this path inevitably causes a delay of the same term in the occurrence of the final event, that is, in the termination of the entire "big" work, unless the management of the work does not take timely measures – the transfer of resources from the works, which have time reserves, to the work that lies on the critical path;
- the most important at any given moment of work can be found – these are the works in which time reserves are minimal. They are either already on a critical path, or maybe coming to it shortly.

If necessary, the network model can be calculated by sector method. Then the calculations are performed directly on the graph and for this purpose, each event is divided into 4 sectors, which list all the necessary data for the calculation of the work.

The calculation of the network model begins with the timing of events that fit directly into the vertices of the network graph (see Fig. 1).

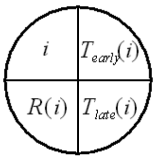

Fig. 1. Displaying temporary parameters of the events on a network graph

$T_{early}(i)$ – early term of event start, minimum required to complete all work preceding the event;

$T_{late}(i)$ – late term of event start, exceeding which will cause a similar delay for the start of the finishing event on network graph;

$R(i) = T_{early}(i) - T_{late}(i)$ – an event reserve, that is, a time that can delay the start of an event without violating the deadline for the project as a whole.

Early terms of the events fulfilment $T_{early}(i)$ are calculated from the original (*S*) to the final (*F*) event as follows:

- for original event S $T_{early}(S) = 0$;
- for all other events i: $T_{early}(i) = \max\limits_{\forall(k,i)}\left[T_{early}(k) + t(k,i)\right]$, where the maximum is taken for all the works (k,i) that are part of the event i and $t(k,i)$ – the duration of work (k,i) (see Fig. 2).

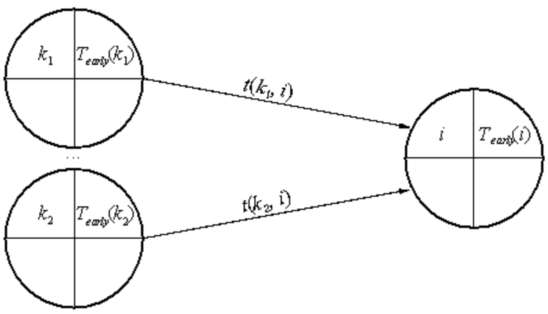

Fig. 2. Calculation of early terms of the event fulfilment i

Late terms of event occurrence $T_{late}(i)$ are calculated from the final event to the initial event:

• for final event F: $T_{late}(F) = T_{early}(F)$;

• for all other events i: $T_{late}(i) = \min_{\forall(i,j)}[T_{late}(j) + t(i,j)]$, where the minimum is taken for all the works (i,j) coming out of the event *i* and $t(i,j)$ – the duration of work (i,j) (see Fig. 3).

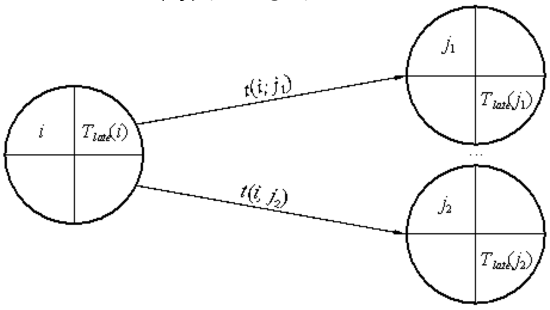

Fig. 3. Calculation of late terms of the event fulfilment i

The temporal parameters of the work are determined on the basis of early and late terms of the events:

• $T_{early-start}(i,j) = T_{early}(i)$ – early term of the work start;

• $T_{early-finish}(i,j) = T_{early}(i) + t(i,j)$ – early term of the work finish;

• $T_{late-finish}(i,j) = T_{late}(i)$ – late term of the work finish;

• $T_{late-start}(i,j) = T_{late}(i) - t(i,j)$ – late term of the work start;

• $R_{full}(i,j) = T_{late}(j) - T_{early}(i) - t(i,j)$ – the full work reserve shows the maximum time that can be increased work fulfilment (i,j) or delayed its start in order not to change the project completion time as a whole;

• $R_{free}(i,j) = T_{early}(j) - T_{early}(i) - t(i,j)$ – free work reserve shows the maximum amount of time that can be extended the term of work fulfilment or delayed its start without changing the early start time of subsequent work.

STUDY RESULTS

Let us consider the problem of constructing a network model, which includes the works *A*, *B*, *C*, ..., *G* and reflects the following ordering of works: *A*, B, *C* – the original works of the project; *A* precedes *D*; *B* precedes *E*; *C* precedes *F*; *D*, *E* preceded *G*. The duration of its execution is specified for each work: *A* = 1; *B* = 4; *C* = 3; *D* = 2; *E* = 6; *F* = 6; *G* = 4.

We can calculate the network model of this problem by the *sector method* (see Fig. 4).

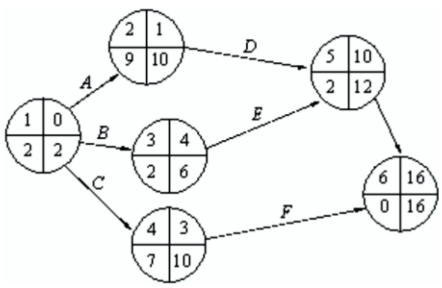

Fig. 4. Sectoral method of network model calculation

Based on the above material, we created a program in the form of a Web application, which has both advantages and disadvantages:

advantages:

• no need to install and update the application;

• access via internet;

• the data is stored remotely;

• no need for powerful computers and disk space;

• cross-platforms (possibility to work on different systems of Windows, Linux, etc.);

• disadvantages:

• needs internet access;

• the server may be attacked, which can lead to leakage of private information;

• users have more experience with Desktop applications;

• The basic idea of the web application is to enable users to plan the implementation of complex projects, follow the process of executing long-lived projects, to make adjustments to their projects.

A brief description of the Web service. The project data entry process is broken down into several steps:

• input of individual project works (see Fig. 5);

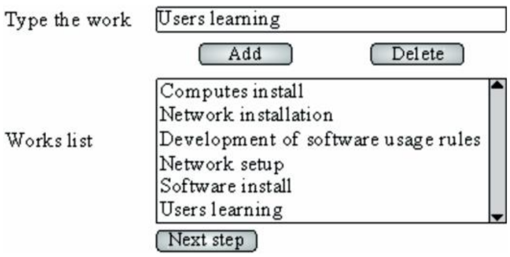

Fig. 5. The form for input of the works of the project

- definition of the initial works of the project;
- description of the parameters of each work (the order of execution, the resources expended, the duration of execution) (see Fig. 6);

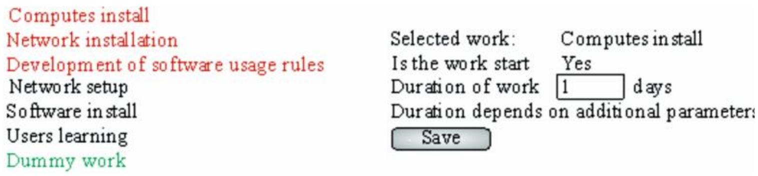

Fig. 6. List of project works (the original project works are indicated in red, the dummy ones are green). Enter time parameters for a specific job

- description of project parameters (days off (days that will not be included in the project scheduling), project start date) (see Fig. 7).

Fig. 7. Enter project parameters (start date, weekends)

At each step, all data is subject to mandatory validation (check the uniqueness of the name of each job, check for the original works of the project). At the step of introducing interdependencies between works, a network graph is constructed. The network graph constructing method reflects the dependencies of all jobs and greatly simplifies the input of dependencies between works. Building a network schedule involves: adding and deleting events, and adding and deleting jobs (see Fig. 8).

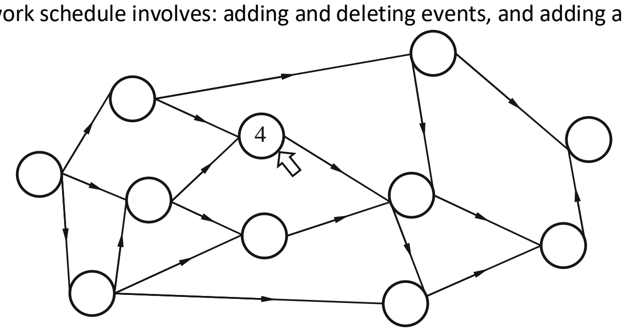

Fig. 8. Network graph modeled by program

If you move the mouse over an event (a circle), its number appears. When building a network graph, the data is also validated. The procedure for validation of the network schedule provides creation of dummy works, the impossibility of the formation of cycles, use of all works of the project.

After the project data entry procedure, the program allows you to view the results: total project duration, approximate date of completion, including days off, duration of each work separately, early and late start and end terms of each work, resources spent on each work (see Fig. 9).

To analyze time parameters of the network model, the program builds a timeline of the project that shows the percentage of tasks completed (see Fig. 10).

You can optionally view an event calendar that displays the availability of work at a specific time.

Project duration, days: 8
The critical path: Network setup → Software install → Users learning
Project finish date: 15-04-2020

Work	Duration	Start	Finish	Early start	Late start	Early finish	Late finish	Full reserve	Free reserve
Computes install	1	05-04-2020	06-04-2020	05-04-2020	05-04-2020	06-04-2020	06-04-2020	0	0
Software install	1	11-04-2020	12-04-2020	11-04-2020	11-04-2020	12-04-2020	12-04-2020	0	0
Users learning	3	12-04-2020	15-04-2020	12-04-2020	12-04-2020	15-04-2020	15-04-2020	0	0
Network setup	3	06-04-2020	11-04-2020	06-04-2020	06-04-2020	11-04-2020	11-04-2020	0	0
Network installation	2	05-04-2020	07-04-2020	05-04-2020	05-04-2020	07-04-2020	05-04-2020	-2	0
Development of software usage rules	4	05-04-2020	11-04-2020	05-04-2020	06-04-2020	11-04-2020	12-04-2020	1	1

Fig. 9. The results of the program

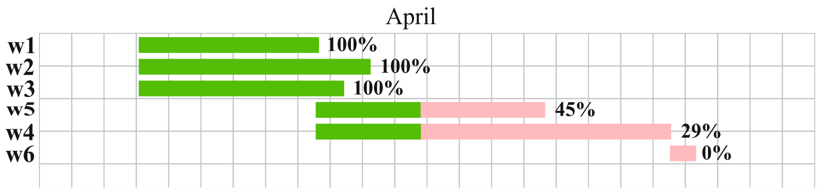

Fig. 10. Timeline of the project

After logging in to the system, each user receives additional features:

- save the projects, with the possibility of their further editing, to view the list of their projects;
- keep track of project work using an event calendar and timeline of the project;
- add to project managers (ability to manage a project by several persons at a time).

Web applications created using such tools and technologies as PHP, Perl, and MySQL. For debugging and testing, we used the XAMPP Web server, which has most of the required programs and utility tools.

CONCLUSIONS

The use of a network planning system helps to develop the optimal variant, which is the basis for the operational management of a complex of works during the implementation of a particular project. The main planning document in this system is a network graph that represents an information-dynamic model that reflects all the logical relationships and results of the work required to achieve the ultimate strategic planning goal.

Features of the program:

- submit the total number of works;
- determine input works;
- describe the parameters of each work (the order of execution, the resources consumed, their number, and cost);
- build a network schedule as a graph that allows you to see the relationship of all the links;
- describe project parameters (project start date, weekends, days not included in the scheduling);
- additional functionality: registering of the users, users' management, and monitoring for the process of own project.

The main feature of the program is the solution of the problem of planning the implementation of complex works, which in turn provides network models and network graphs, which simplify the understanding of the whole model, provide optimization of the developed schedule based on mathematical methods. The program outputs scheduling results in a graphical and textual presentation that makes it easy or obvious to decide for the manager while saving the project allows you to watch the events and make adjustments to the model to improve optimization.

When analyzing network graphs, it is considered that the duration of each job does not depend on the moment of its beginning, which is not always true in reality. It should be noted that further extension of the problem by introducing additional dependencies seems appropriate and creates the basis for further research.

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