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Applying a Heuristic Approach to Time Optimization in a Grid Schedule

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***Abstract*— With the development of information technology, the project management process across different sectors of the economy has changed. Very often, new approaches use combinations of familiar, established project management methods to meet the requirements.**

This article examines an approach to project management that combines the PERT method and evolutionary algorithms. The goal is to improve the estimate of the possible time required to complete the project. With the PERT method, you can identify the project's critical path and all critical activities. pessimistic, most likely, and optimistic. The project is represented as an acyclic graph, with tasks at the nodes and edges indicating connections between them. Each task is assessed with the three PERT assessments. Combining the two methods results in a shorter critical path, i.e., the time required to complete the project.

Keywords—PERT method, project management, evolutionary algorithm

I. Introduction

Project management needs adequate tools for planning and optimizing time schedules in the conditions of dynamically changing resources and deadlines. Network graphs provide a visual representation of the logic, sequence, and interdependencies among the project's individual activities. Classical methods for analyzing network schedules, such as the critical path method (CPM) and the program evaluation and review technique (PERT), provide the critical path, early and late deadlines, and time reserves. The methods are effective for relatively small and well-structured projects. They are used as an analysis tool, and additional methods are used to optimize time and resources. [1]

In today's dynamic, high-tech world, managing transport projects requires new methods and software to improve process efficiency and project sustainability. Solving current problems in the management of transport projects requires an integrated approach that combines methods of system management, the application of innovations and technologies, effective financial planning, and active cooperation among all stakeholders.

Network scheduling optimization tasks solve difficult problems by finding a real-time global optimum and reallocating resources. For this purpose, heuristic and metaheuristic approaches are used to find a good-enough solution for project optimization and resource allocation.

II. Intelligent Optimization – Evolutionary Algorithms

A. *Algorithms inspired by nature*

Bio-inspired algorithms are gaining great popularity due to their high efficiency and simplicity. There are at least 350 different algorithms of this type, based on over 100 different types and phenomena. Algorithms inspired by:

- Animals (terrestrial, aquatic, flying)
- Natural phenomena (rain, hurricanes, stars, water cycle)
- Music
- Sports
- Inspired by space (black holes), etc. [2]

Evolutionary algorithms (EAs) follow the principles of biological evolution. They are a subset of metaheuristic algorithms. Heuristic algorithms solve problems using readily available information and are based on experience and observation. They are used to support decision-making when exact methods are ineffective. Through them, a good enough solution with practical applicability is found. Metaheuristics are a combination of heuristic approaches to find better solutions. [3]

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A characteristic feature of evolutionary algorithms is that they operate not only on a single solution but on a population of solutions. The solutions themselves can be vectors, permutations, or real numbers. Traditional algorithms find local minimum. The evolutionary algorithm using mutation seeks global minimum to achieve better optimization.

Evolutionary algorithms simulate biological processes, making them a powerful tool for finding solutions in large data sets. They search for an optimal solution from a set of potential solutions. In the scientific literature, 5 main types of evolutionary algorithms are identified (Fig. 1).

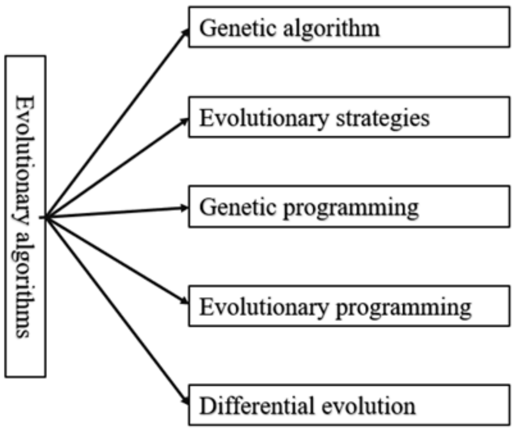

Fig. 1. *Types of evolutionary algorithms*

What the five main evolutionary algorithms have in common is the way they model processes using biological principles. They work with a population of decisions obtained through selection, mutation, and reproduction [4].

A disadvantage of evolutionary algorithms is the way they identify the optimal solution. The solution produced is the best available at the time. This method is also regarded as slow [5].

B. Program Evaluation and Review Technique /PERT/

The PERT method is a statistical project management tool for analyzing all project work and estimating project duration using three estimates: optimistic, pessimistic, and realistic.

In PERT, each activity is defined by four time estimates: Optimistic—the minimum completion time under ideal conditions;

Pessimistic – the maximum time it can take to complete a task when all anticipated and unforeseen incidents occur.

Most likely, the time is the best estimate of task completion under normal conditions.

As expected, this is the average execution time, as ideal conditions do not exist. It is determined by repeated measurements over time. Formula (1) applies:

$$E = \frac{O+4*M+P}{6} \qquad (1)$$

where:

O – optimistic assessment;

M – most likely;

P – pessimistic assessment.

The use of these assessments for the project works leads to the development of three scenarios for the project, which can also be visualized in the Gantt chart: pessimistic, realistic, and optimistic. The three assessments provide a more realistic estimate of the project's duration and determine the probability of completion.

$$\text{Variance} = \left(\frac{O-P}{6}\right)^2 \qquad (2)$$

Variance calculation from formula (2) reveals risk concerning activity duration. This enables planning for delays in highly volatile tasks.

Defining the critical path enables you to prioritize tasks that could delay the project. Their duration can be reduced by optimizing resources. Identifying critical tasks strengthens risk management. These are the riskiest points requiring a response plan for observed deviations.

The PERT method is usually used in conjunction with the critical path method and in projects with time constraints. The critical path method uses a time and cost limit with one estimate each. In PERT, it does not use costs but three time estimates, and each activity is evaluated using the most likely, pessimistic, and optimistic times. In this way, the management team has information about hazards and the lack of time, based on comparisons of current results with planned results and targets, and on calculations of the probability of achieving the plan.

PERT is used to manage large, complex infrastructure projects. The sequence of application of PERT in the planning of a complex transport project is presented in Figure 2.

A disadvantage of PERT is its complexity in building and maintaining for projects with numerous tasks and connections. Another disadvantage is an excessive focus on deadlines, often at the expense of resources and budget [6].

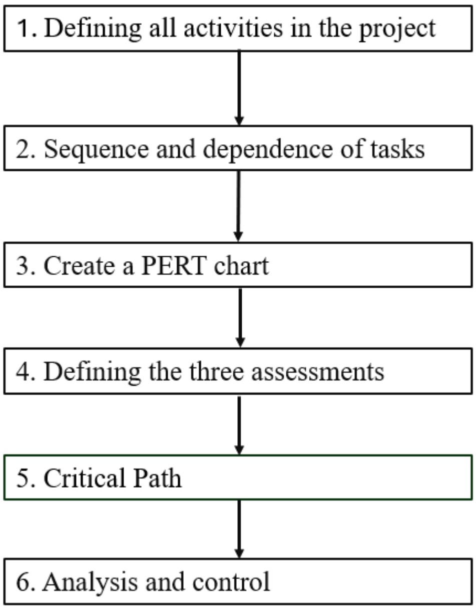

Fig. 2. *PERT Step Model*

The first step is carried out already at the project planning stage. Determining the sequence and dependencies of tasks is important for tracking them, their deadlines, and the overall duration of the project. Plotting the schedule is the third step. PERT charts visualize the critical path and help estimate task durations and the resources needed. In the fourth step, the three assessments are defined to estimate the most likely project duration. From the schedule and estimates, the project's critical path is determined. In the last step, the critical path is analyzed to determine which tasks can be manipulated to complete the project within the planned deadline.

The PERT diagram shows the sequence of activities that are set when the project is scheduled. Arrows indicate the direction and sequence of activities. The main components of the diagram are the elements: nodes, arrows, and paths. The nodes are depicted as circles or rectangles. They contain information about the duration, name, and resources for the specific task. The arrows illustrate the relationship between the tasks and the possible paths. At the beginning and end, dummy events with zero duration can be added [7].

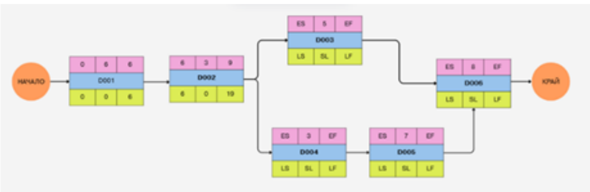

Fig. 3. *PERT chart*

One drawback of the PERT chart is its dependence on expert judgment, which, if inaccurate, may lead to significant project consequences. Fig. 3 presents a sample PERT chart created with canva.com. The diagram indicates that executing activity D002 will likely require 3 days. It is estimated to take 2 days or, in the event of issues, up to 4 days. The average duration of the activity, calculated using formula 2, is 3 days [8].

III. Materials and Methods

A. Mathematical Statement

The presented PERT-EA model addresses the management of a transport project by combining the well-known PERT approach with an evolutionary algorithm. The purpose of the model is to provide a more acceptable estimate of the project's possible duration. The PERT method provides an expected time range for completing the project, using three types of assessments: pessimistic, optimistic, and most likely. With it, the critical path can be found. When constructing a project graph, the work is placed in the nodes.

The transport infrastructure project is presented as a network of activities.

Let project W be a set of activities:

$$W = \{A, B, C, \ldots\ldots\} \tag{3}$$

As with A, B, C..., the activities are indicated in the column for clearer writing.

Each activity is characterized by three times:

mi – average duration of the activity

AI – Optimistic assessment of the duration of the activity

BI – pessimistic assessment of the duration of the activity

The average duration is the constant element. Optimistic and pessimistic estimates can vary. It is unwise to alter the average estimate, as it is typically derived from empirical experience and precise measurements.

The expected estimate shall be calculated according to the known formula (4).

$$t_i = \frac{a_i + 4 * m_i + b_i}{6} \tag{4}$$

where i is the project's activity number.

The network schedule for the AON-type project is drawn. In the vertices of the column are the names of the works, and the weights along the arcs are time estimates. Two auxiliary (service) vertices are entered, corresponding to the project's beginning and end. The graph is necessary to describe all possible paths for the project and all connections between the individual activities.

When creating the network schedule, Table I is used. Timely completion of the project depends on the resource management approach, one of which is time itself. 6 (six) main parameters are used for time management:

- RS – Early start
- RK – Early End
- CS – Late start
- CC – Late End
- P – Duration

- P – reserve.

Reserves are calculated for each activity. Critical activities with zero reserve are flagged. Optimization can assess activities along possible paths in the network schedule by adding resources such as equipment, funding, or personnel.

When creating a PERT graph, Table I is filled in two passes: a straight pass and a reverse pass. The duration column receives the weighted estimate for activity ti from formula 4. The early-start cell records the result from formula (5).

$$PC = \max \text{ (RC of previous activities)} \quad (5)$$

Record the early end using formula (6).

$$RK = P + RS \quad (6)$$

In the reverse pass, the column is traversed from the end to the beginning, and the third row of Table I is filled in. In the last cell, the result of formula (7) is filled in.

$$CC = \min \text{ (CC of previous works)} \quad (7)$$

In the Late start cell, enter the value obtained from formula (8).

$$KS = KK - P \quad (8)$$

In cell Reserve, enter the difference between late end and early end using formula (9).

$$P = CC - RK \quad (9)$$

TABLE I. PERT SCHEDULE PRINCIPAL TIME

Early start	**Duration**	**Early End**
Name of activity		
Late start	**Reserve**	**Late end**

The target function takes the form of equation (10).

$$\min Tj = f(a_i, b_i) \quad (10)$$

such as:

ai is a vector of optimistic assessments

bi is a vector of pessimistic assessments.

One disadvantage of the PERT method is the reliance on expert assessments. In this case, this disadvantage is used as the average score (mi) is taken from the MS Project, and conditions and limits are set for the optimistic and pessimistic ones.

Several types of target function models are tested to find the most acceptable one that minimizes the objective, with the Solver adjusting the optimistic and pessimistic estimates.

To find the minimum total time, the Solver tool in MS Excel is applied. Each solution represents a distinct scenario, and the decision-maker selects the preferred option.

The restrictions are:

1. $a_i > 0$
2. $a_i <= m_i$
3. $b_i >= m_i$
4. $a_i >= k_a * m_i$
5. $b_i <= k_b * m_i$

B. Algorithm for the implementation of PERT – EA

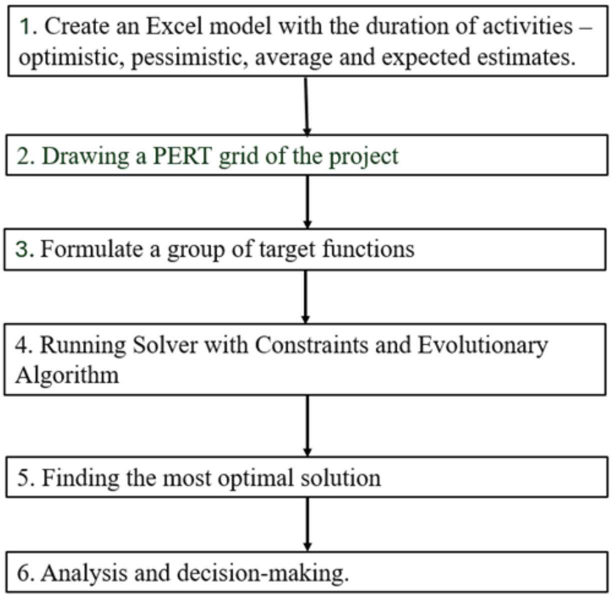

Fig. 4. *PERT-EA application algorithm*

Fig.4 shows the sequence and specific steps in applying the PERT-EA method.

C. Solver module

A Solver module is available in MS Excel, which has a built-in Evolutionary optimizer. This optimizer uses evolutionary algorithms without guaranteeing reaching a global optimum, but gives good chances for reaching sub-optimal solutions. Parameters (settings) are set in advance, and the resulting solution is returned.

In order for the Solver to stop working and give a solution, one of the conditions must be met:

- The set heuristic rules state that no significant improvement is expected in the next iteration.
- The set time limits have been exceeded. The number of trial solutions has been reached.

From the Solver Parameters – Options dialog box, additional settings can be made to the Evolutionary Solving Method. The correct selection of parameters is an essential decision on the effectiveness of the optimization.

Convergence – a maximum allowable percentage difference in the values of the target function is introduced for the best 99% of the solutions. Lower convention values lead to more precise results, but increase the calculation time.

Mutation Rate – enter a number in this field – relative frequency in the range [0; 1]. The number indicates how a member of the population will mutate to create a new trial solution. A higher frequency value increases the diversity of the population and improves the likelihood of finding a better solution.

Population Size – enters the number of solutions viewed at the same time. The minimum value is 10. If no value is set, Solver automatically sets the size to a value between 10 and 200.

Random Seed – A positive integer is entered. This parameter gives the starting value for generating random numbers. If the field is empty, random values are used, which can lead to different decisions on each start.

Maximum Time without Improvement – the maximum time during which the algorithm can work without a significant improvement to the best solution is introduced.

Require Bounds on Variables – checking this box sets the lower and upper execution limits [9].

IV. Results and discussion

In the created model, five target functions are considered and tested to find a solution that best meets the decision-maker's needs. The model allows decision-makers to better navigate the optimistic and pessimistic phases of implementing project activities.

The input data is taken from Solver and used in the solution. They are the basis for calculations of the expected time. They compare durations and identify nd identify bottlenecks [10].

Target function T1 is linear, calculated using formula (10), and serves as a reference function. Table II contains the solution obtained with Solver for the target function T1. The PERT graph (Fig. 5) gives the dependencies between the project activities. For target function T1, the critical path includes the activities S→B→E→G→K→O→Z. The longest activities are K (8.67), H (7.80) and I (6.94). The shortest activities are A (2.60) and M (2.60). The expected time to complete the project is 26.87. All activities on the critical path have zero reserve. Non-critical activities have a positive reserve and can be shifted without changing the deadline, for example, activity I can be shifted by about 6.06 and activity N by about 4.34.

The evolutionary algorithm represents each solution as a chromosome, where genes encode estimates of the pessimistic and optimistic times for activities within the defined limits. When starting the Solver, the target function values for time, reserves, and load are determined. The algorithm uses the initial population to evaluate solutions, selects the better ones, combines them, and introduces mutations in the form of random values.

TABLE II. Table Type Styles

Work	***Optimistic***	***Ka*m***	***Realistic***	***Kb*m***	***Pessimistic***	***Expected***
	a	***0,8*m***	***m***	***1,2*m***	***b***	
A	2.40	2.4	3	3.6	3.00	2.90
B	3.20	3.2	4	4.8	4.00	3.87
C	4.00	4	5	6	5.00	4.83
D	5.62	5.6	7	8.4	7.03	6.77
E	4.81	4.8	6	7.2	6.01	5.80
F	4.02	4	5	6	5.01	4.84
G	4.01	4	5	6	5.00	4.84
H	7.21	7.2	9	10.8	9.00	8.70
I	6.44	6.4	8	9.6	8.01	7.74
J	3.21	3.2	4	4.8	4.01	3.87
K	8.01	8	10	12	10.01	9.67
L	6.40	6.4	8	9.6	8.04	7.74
M	2.41	2.4	3	3.6	3.01	2.90
N	5.61	5.6	7	8.4	7.01	6.77
O	4.80	4.8	6	7.2	6.00	5.80

With each generation of a new chromosome, there is a change in times. In the critical pathway, a new total duration is obtained.

The algorithm stops when it has found a stable optimal solution, meaning a well-balanced schedule, a minimum critical path, and optimal use of reserves.

A Solver is applied to each target function, resulting in changes to the input data and the network schedule's critical path.

The solution obtained with Solver for target function T2 yields a highly modified network graph. The critical path of the project is: S → B → E → H → N → Z, with a duration of 59.82. The optimization has led to a large increase in time. The longest activities are N (25.04) and E (22.98), and the shortest B (4.00) and H (7.80).

The solver receives upper and lower bounds on the ratings ai and bi, which we set in the coefficients ka and kb. The coefficient ka determines the lower limit of the assessment ai, and kb determines the upper limit of bi. The assessment of AI should not be negative..

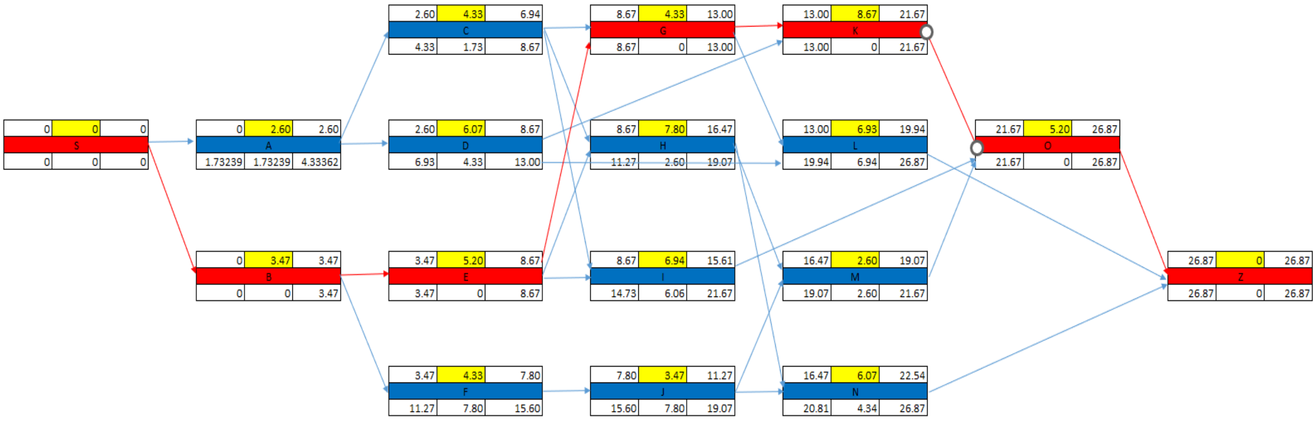

Fig. 5. *PERT charter of Target function T1*

The critical pathway for target function T3 is S → A → D → K→ O → Z, with a duration of 58.51. There is a slight decrease in the critical pathway compared to that of T2. The longest critical activities are D (22.89) and K (22.76). The shortest activities are O (5, 20) and A (7.66).

The critical path for target heading T4 includes the activities: S → A → C → G → K → O → Z. The project is expected to be completed in a possibly shorter period compared to target headings T2 and T3 with an output of 34,31. The longest activity for heading T4 is A (11, 75) and the shortest duration is C (4,34) and G (4,34).

For target function T5, the critical path includes the following activities S → B → F → J → M → O → Z with a duration of 33,41. This is the second most preferred estimate of time after the decision obtained under target function T1. The longest critical activity is F (18,63) and the shortest activity is M (2,61).

TABLE III. SUMMARY DATA

Target function	**Table Column Head**		
	Critical Path	***Longest critical activity***	***Shortest critical activity***
T1	S→B→E→G→K→O→Z	K (8.67)	A (2,60) M(2,60)
T2	S → B → E → H → N → Z	N (25,04)	B (4,00)
T3	S→A→D→K→ O →Z	D (22,89)	O (5, 20)
T4	S → A → C → G → K→ O → Z	A (11, 75)	C (4.34) G (4.34)
T5	S → B → F → J → M → O → Z	F (18,63)	M (2,61)

Table III presents the aggregated data on critical pathways after a solution with Solver.

The proposed approach to pessimistic and optimistic assessment provides different scenarios for the project's course, especially regarding the formation of activities on the critical path. This variety of scenarios provides additional opportunities for making well-reasoned decisions.

V. CONCLUSIONS

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VI. ACKNOWLEDGMENT

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