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Model for determining optimal routes in complex transport systems

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Abstract

The paper analyzes standard algorithms and software based on them to determine the optimal routes for cargo transfer in road transport systems. It was found that one of the urgent issues related to routing is to find a solution to the optimization problem by several efficiency criteria, including the reduction of computational procedures. As a result of the study, we propose an original solution to this problem.

Keywords: routing; road transport system; optimization algorithm; multi-criteria problem; software.

1. Introduction

Despite the active development of routing methods in road transport systems (RTS) and their implementation in software, applications, etc., we still do not have the best solution to the problem of objective route selection due to the constant increase in the number of efficiency criteria. Moreover, recently, the criterion associated with the required number of computational procedures has been considered as the main efficiency criterion in relation to routing algorithms in RTS. This criterion determines trade-offs in terms of the time of passing inquiries, data preprocessing, disk space usage, frequency of inquiries, and, among other factors, stability when making changes in the RTS routes. In other words, if in the case of the previous algorithms the route selection was determined by the factor of distance, it is not a problem anymore because modern algorithms find the shortest routes in the RTS reliably. Today, the relevant issues are the following:

1) how reasonable is it to use a single criterion of the shortest distance and its projection on a complex indicator (costs) as an objective function?

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2) how rational are the used route optimization algorithms in terms of the volume of computational procedures?

2. Theoretical studies

Many researchers addressed the issues of transport planning, traffic management, the improvement of transport and environmental safety, as well as the quality of roads and transport system operation (Boryaev et al. 2020, Chernyaev et al. 2020, Dygalo et al. 2020, Evtiukov et al. 2020, Grayevskiy et al. 2020, Ivanov et al. 2020, Kerimov et al. 2020a, 2020b, Kurakina and Evtiukov 2020, Kurakina et al. 2020a, 2020b, Lobanova and Evtiukov 2020, Marusin et al. 2020, Mavrin et al. 2020, Petrov et al. 2018, 2019, Rakov et al. 2020, Repin and Evtjukov 2013, Safiullin et al. 2019, 2020, Vasiliev et al. 2017, Voitko et al. 2020). The most common standard solution to the routing problem is Dijkstra's algorithm, proposed by Dutch scientist Dijkstra in 1959 and widely used in software for the creation of route transport networks (Cherkassky et al. 1996, 1997, Dijkstra 1959). This algorithm finds the shortest distance from one of the vertices of the distance graph to all the others. A large number of studies abroad dealt with the development of this algorithm and its effective application in practice (Abraham et al. 2013, Dantzig 1963, Denardo and Fox 1979, Fredman and Tarjan 1987, Goldberg 2008, Meyer 2001, Thorup 2003). This algorithm is easily implemented in software. A standard matrix is used to store the "weights" of the graph under study (Fig. 1), where the vertices of the graph are in the row and column headers, and the weights of the graph arcs are placed in the internal cells of the table.

Along with the development of Dijkstra's algorithm, the search for alternative methods of computation was carried out. One of them is the Bellman–Ford algorithm (Bellman 1958). The main advantage of this method is that it works in cycles (by improving the current state of the RTS dynamically), by scanning all the vertices, the distances of which were improved, in each cycle. The Bellman–Ford algorithm implements control in the RTS (Ω) step-by-step (discretely) after determining the effective solution and applying it as one of a finite number of potential actions. In general terms, a discrete controlled RTS for a single-criterion model can be determined as follows:

$$\Omega = \{D; x_0; F; V(x), f(x,v), s(x,v)\} \tag{1}$$

where D — the set of potential states of the RTS; F — the set of states of the RTS parameters; $V(x)$ — the set of controls when choosing the travel direction (options in the system) — $(x \in D|F)$; $f(x,v)$ — the function of transitions from the x state during control v; $s(x,v)$ — the function of "losses" due to travel.

Making a route based on the Bellman principle can be represented as follows:

$$Б(x) = \min_{v \in V(x)} \{ s(x,v) + B\big(f(x,v)\big)\} \tag{2}$$

where $B(x)$ — the $Б(x)$ function in the previous discrete state.

3. Calculations

The calculation of the Bellman function values according to Eq. (2) is performed in stages and makes it possible to order and significantly reduce the search for potential route options.

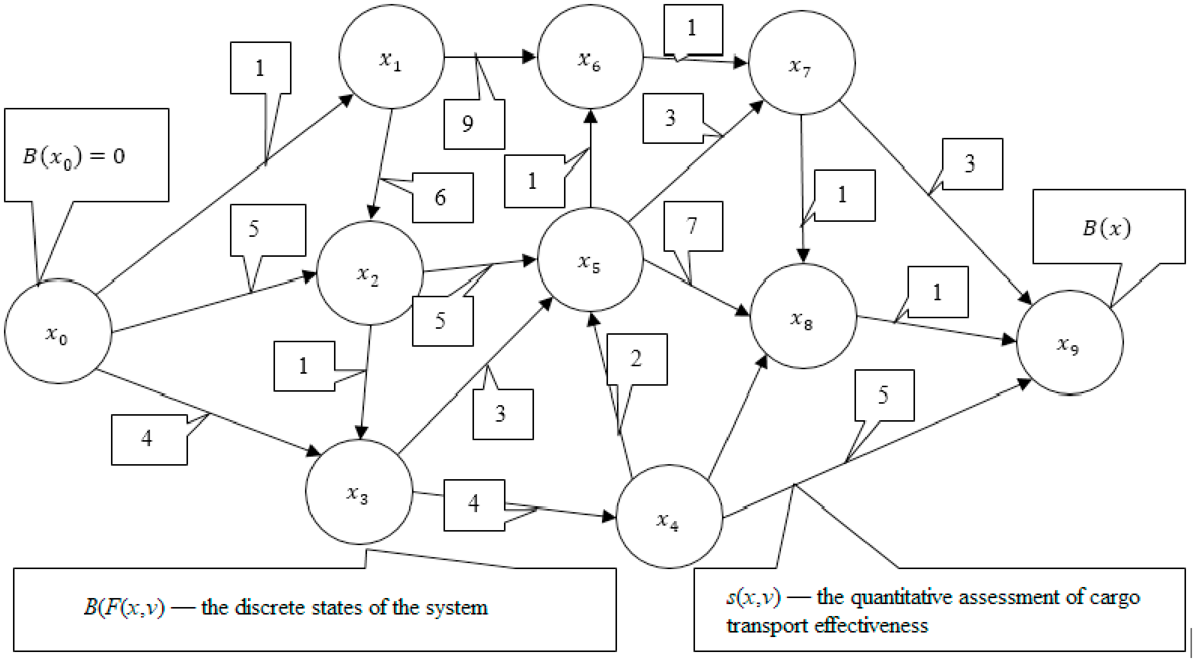
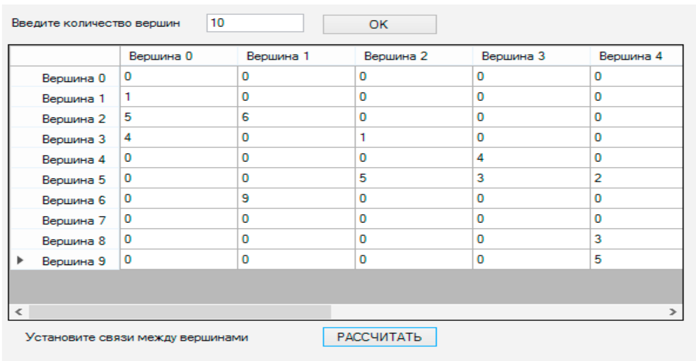


Fig. 1. Conditional graph of potential routes in the RTS with discrete states — (Ω).

It is not difficult to develop algorithms and software for the optimization problem of dynamic programming based on the Bellman principle. Figs. 2 and 3 provide the interfaces of the software developed using the algorithmic language C++. Fig. 3 presents the results of the calculation in the developed software. The algorithm for solving the dynamic programming problem is shown in Fig. 4.



	Вершина 0	Вершина 1	Вершина 2	Вершина 3	Вершина 4
Вершина 0	0	0	0	0	0
Вершина 1	1	0	0	0	0
Вершина 2	5	6	0	0	0
Вершина 3	4	0	1	0	0
Вершина 4	0	0	0	4	0
Вершина 5	0	0	5	3	2
Вершина 6	0	9	0	0	0
Вершина 7	0	0	0	0	0
Вершина 8	0	0	0	0	3
Вершина 9	0	0	0	0	5

Fig. 2. Problem initialization and initial data input.

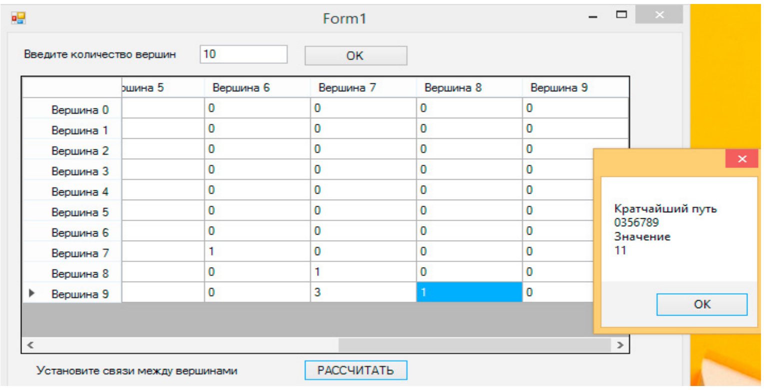


Fig. 3. Results of the automated calculation in the developed software for the example in Fig. 1.

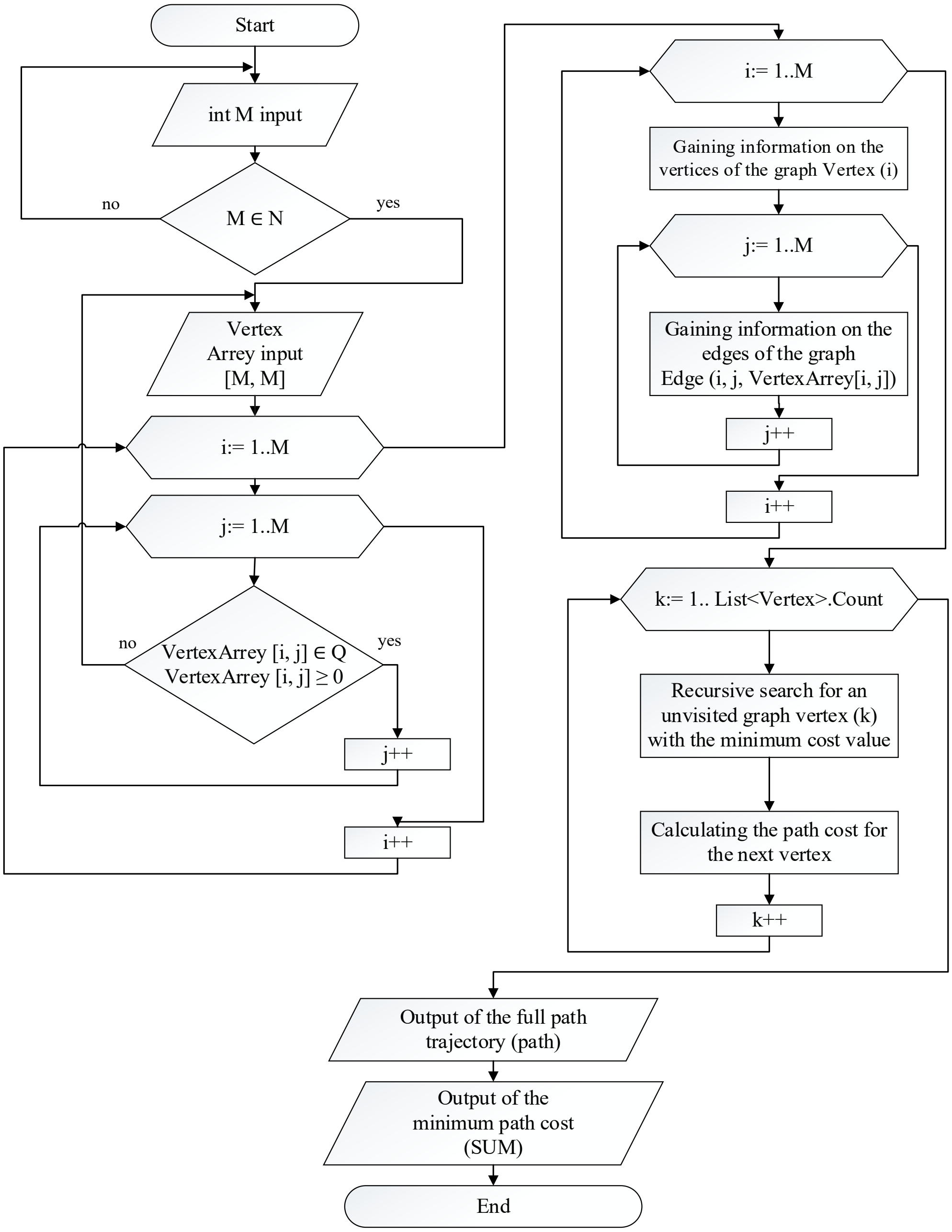


Fig. 4. Algorithm for automated calculation of the dynamic programming problem.

The main disadvantage of using dynamic programming methods to implement routing in the RTS is that only one criterion is accepted as a controlled parameter. A real RTS usually requires calculations based on several efficiency criteria. The technology for the synthesis of complete sets of efficiency estimates should be provided by determining the partial efficiency estimates of the Pareto optimal, which inevitably leads to an increase in the number of computational procedures (Sommer 2014).

The analysis of various routing methods containing Pareto set-based solution search in RTS — two hierarchical methods based on Dijkstra's algorithm (CRP and CH) (Delling et al. 2013a, 2013b), three non-graph-based algorithms (TNR, HL, HLC), two combined ones (CHASE and TNR+AF) (Abraham et al. 2012, Bauer et al. 2010, Delling et al.

2013, Geisberger and Vetter 2011) and others — showed the necessity for a significant number of computational procedures. It is possible to reduce the number of computational procedures significantly by creating algorithms for obtaining a Pareto set based on mathematical models of linear programming (Karelina et al. 2018, Prudovskiy 2015, Prudovsky and Terentyev 2014, Terentiev and Prudovskiy 2014, Terentyev et al. 2019). Fig. 5 shows an algorithm for optimizing the multi-criteria problem of finding Pareto-optimal solutions, which makes it possible to accelerate the processing of large data volumes.

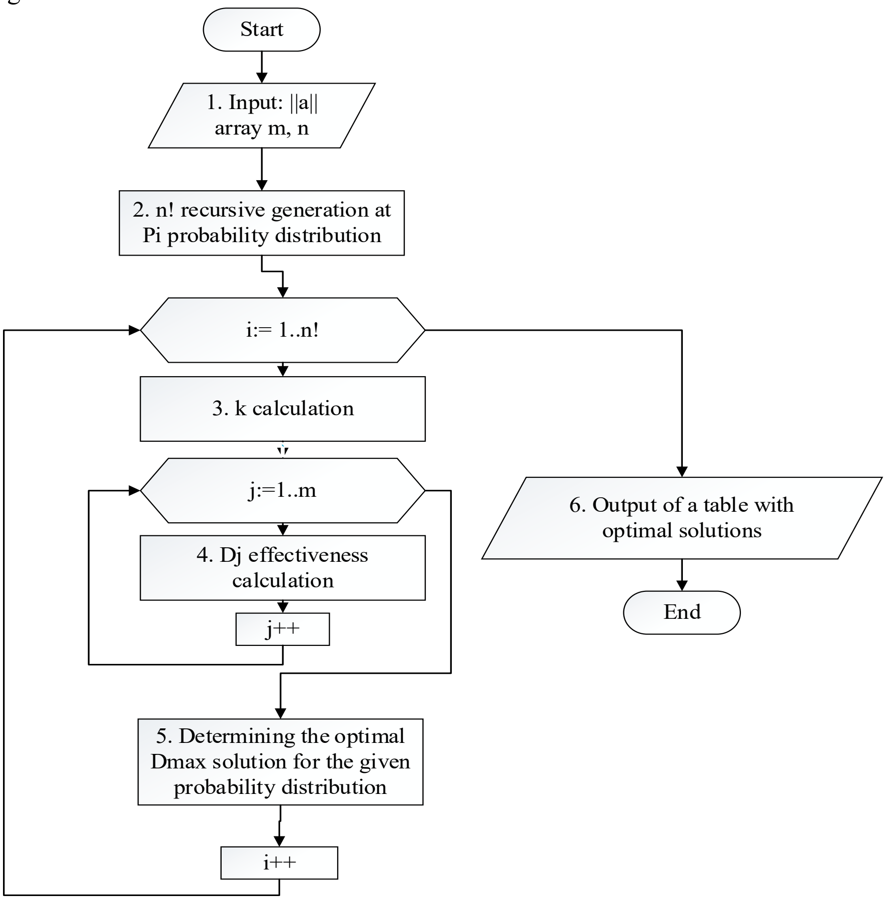


Fig. 5. Algorithm for optimizing the multi-criteria problem of finding Pareto-optimal solutions.

The interfaces for obtaining Pareto-efficient solutions in the developed software are shown in Figs. 6, 7, and 8.

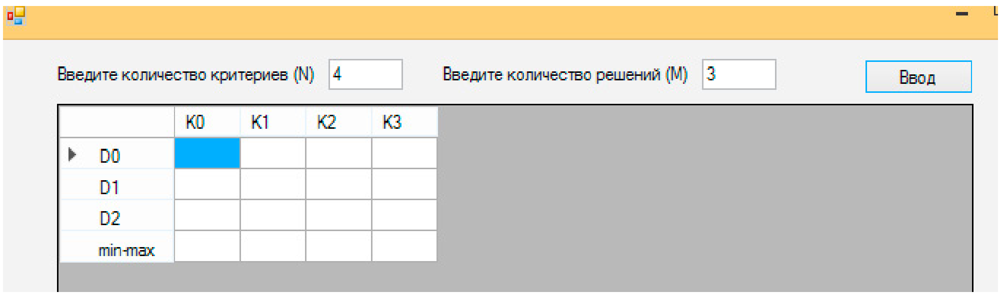


Fig. 6. Program initialization.

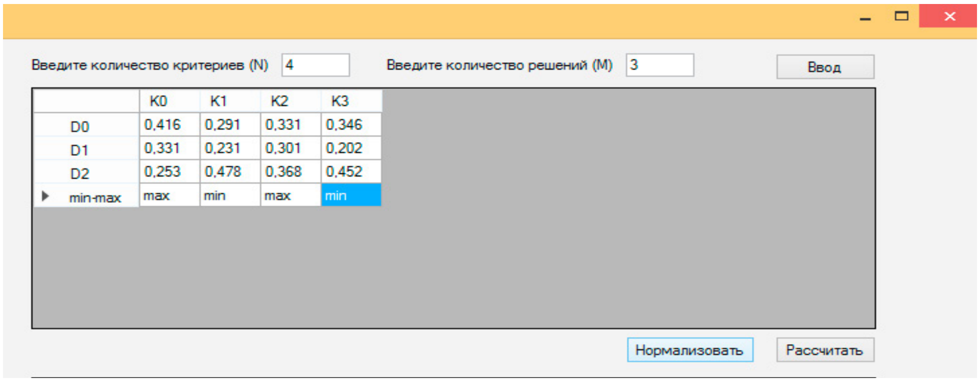


Fig. 7. Standardization of the initial values, taking into account the definition of objectives for particular efficiency criteria.

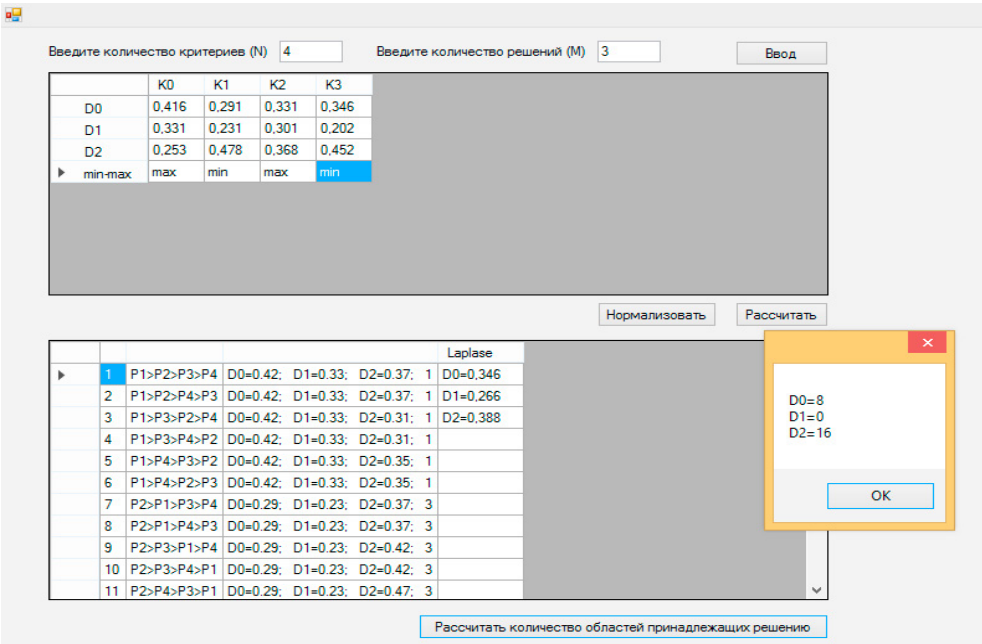


Fig. 8. Automated calculation of the optimal option in the RTS.

4. Conclusions

At this stage of studying routing models and algorithms in the RTS, an optimization analytical model of object-oriented control and algorithms based on it were developed (Nitsevich et al. 2017, Terentyev 2019, Terent'ev et al. 2017). The following two main algorithms and software based on them were developed as well.

1. The algorithm and software for solving the dynamic programming problem, implementing the Bellman principle, and making it possible to determine the optimal trajectory (route) of cargo transfer in the RTS.
2. The algorithm and software for determining the Pareto-optimal options in the case of multicriteriality in the studied RTS.

The main tasks of further research were determined:

1. Integration of the developed algorithms and software into a single software package.
2. Testing of the developed software package using a local data sample on the transfer of a given number of cargo lots in the RTS given several transshipment complexes and with account for several efficiency criteria.

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