Modeling of the oil transportation process through pipelines and its optimization according to the cost criterion

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Abstract. This article considers the problem of optimizing the process of oil transportation through oil pipelines from fields to oil collection and delivery points. The aim of the study is to build an effective logistics system for product transportation, which ensures the sustainable functioning of industrial production. The paper presents a mathematical model of the problem that takes into account the productivity of oil-producing enterprises and the needs of oil refineries, and represents a balanced transport problem. The optimization problem is solved on in the Python programming language, using imported libraries and modified program code. As a result of the software solution, the minimum cost of transportation and the optimal oil supply plan are determined, which allows providing all consumers with this energy resource with minimal costs. The proposed software product has a user-friendly and intuitive interface, which makes it accessible to a wide range of users when solving linear programming problems.

1 Introduction

The problems of optimizing transportation refer to extreme management and planning problems, which are solved numerically by linear programming. At the moment, the solution of the transport problem is considered by different methods using various tools. In [1,2], an overview of existing methods for searching for the initial reference plan of the transport problem was carried out, such as the northwest corner method, the potential method, the least element method, the Vogel's method, the distributive method for finding the optimal solution, the double preference method. In works [3-5], solutions to the transport problem are given in relation to the distribution of a homogeneous product, in [6] − to the distribution of cargo flows. In [7], a method for solving the transport problem is presented, which the authors called evolutionary population-based. In [8], a multi-criteria the transport problem with two objective functions was solved, optimization was carried out according to the criterion of transportation cost and the degree of priority of the transported product. A multi-criteria simplex method was used to solve the problem. The solution of the transport problem is presented in a network form [9]. Also check of the resulting initial basis for optimality in a network format is given. Mathematical formulations of optimization problems of logistics are considered in the article [10]. In [11] solutions to the problems of optimizing production

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processes according to the criterion of the cost of the manufactured product are presented. The possibilities of using the linear programming apparatus for developing strategies for the development of enterprises of various directions are shown. In [12], solutions to transport problem are presented using the "Solution Search" add-in of the MS Excel spreadsheet editor. In [13], an analysis of transport problem solutions was carried out using various tools, such as an online calculator, an MS Excel spreadsheet editor, a Matlab application package, a Mathcad computer-aided design system and built-in libraries of the Python programming language. It is indicated that the online calculator is convenient to use, but limited by the number of specified departure and destination points, the same disadvantage is also possessed by the MS Excel spreadsheet editor with its "Solution Search" add–in. It is noted that the advantage of using the Python programming language to solve technical problems using the simplex method using the cvxopt.modeling library is the ability to solve problems of any complexity, the disadvantage is the need to know the basics of programming in Python. In this work, to solve the technical specifications, the program code was modified in the Python programming language, which makes it easier to use the software product and make it available to a wide range of users.

2 Materials and Methods

As an example of the implementation of the proposed algorithm for solving transport problem, the Vostok Oil project is considered, which Rosneft Oil Company started implementing in 2020 in the Krasnoyarsk Territory. The main goal of the project is a direct exit along the Northern Sea Route, in order to reduce the political impact on oil transportation [14-15]. Currently, the Vankor cluster is already in operation, which includes such hydrocarbon deposits as Vankorskoye, Suzunskoye, Tagulskoye, and Lodochnoye [16]. As part of the Refining Unit, there are refineries: Komsomolsk Refinery, Angarsk Petrochemical Company, Achinsk Refinery, the oil refining complex of PJSC ANC Bashneft (Bashneft-Novoil, Bashneft-Ufaneftekhim, Bashneft oil refinery). Effective implementation of the project requires an integrated approach to the rational allocation of material, labor and financial resources, as well as to the optimization of logistics processes, based primarily on modern methods of mathematical modeling and planning.

Let's make up a mathematical model of the problem of optimizing oil delivery through main pipelines from fields to receiving and delivery points in relation to the Vankor cluster. Taking into account the known transportation distances and the tariff for oil delivery through the main pipelines of Transneft Company [12], a table of transportation costs has been compiled (Table 1).

Table 1. The initial data of the transport problem.

Oil fields	**Cost matrix. mln rub.**				
	Achinskiy oil refinery	**Angarskyi national chemical company**	**Komsomolsky oil refinery**	**PJSOC Bas hneft**	**Extraction. tons**
Vankorskoe	1721.36	1929.57	1889.14	1417.90	6000000
Suzunskoe	1802.28	1988.42	1918.57	1469.39	4500000
Tagulskoe	1805.96	1991.09	1919.91	1471.73	3000000
Lodochnoe	1733.62	1938.48	1893.60	1425.70	1500000
Demand. tons	5500000	4000000	2000000	3500000	

The formulated a transport problem is balanced, since the total volume of oil production at the Vankor cluster is equal to the total raw material needs of oil refineries indicated in the transportation matrix (Table 1). The cost of transporting the product is the criterion of optimality.

The formulation of an economic and mathematical problem involves determining the minimum value of the objective function:

$$F_{min} = \sum_{i=1}^{m} \sum_{j=1}^{n} c_{ij} x_{ij} \quad (1)$$

with restrictions determined by the terms of delivery of raw materials:

$$\begin{cases} \sum_{j=1}^{n} x_{ij} = a_i, (i = \overline{1,m}); \\ \sum_{i=1}^{m} x_{ij} = b_j, (j = \overline{1,n}); \\ x_{ij} \geq 0 \ (i = \overline{1,m};\ j = \overline{1,n}). \end{cases} \quad (2)$$

where c_{ij} are the tariffs for cargo transportation from the point of departure *i* to the destination *j*.

Let's make up the objective function (1):

$$\begin{gathered} F_{min} = 1721.36\,x_{11} + 1929.57\,x_{12} + 1889.14\,x_{13} + 1417.90\,x_{14} + \cdots \\ +1802.28\,x_{21} + 1988.42\,x_{22} + 1918.57\,x_{23} + 1469.39\,x_{24} + \cdots \\ +1805.96\,x_{31} + 1991.09\,x_{32} + 1919.91\,x_{33} + 1471.73\,x_{34} + \cdots \\ +1733.62\,x_{41} + 1938.48\,x_{42} + 1893.60\,x_{43} + 1425.70\,x_{44} \end{gathered} \quad (3)$$

And the limitations of the task (2):
according to reserves, the entire volume of oil supply should be sold at the refinery:

$$\begin{cases} x_{11} + x_{12} + x_{13} + x_{14} = 6000000 \\ x_{21} + x_{22} + x_{23} + x_{24} = 4500000 \\ x_{31} + x_{32} + x_{33} + x_{34} = 3000000 \\ x_{41} + x_{42} + x_{43} + x_{44} = 1500000 \end{cases} \quad (4)$$

according to the needs − all consumers must be satisfied:

$$\begin{cases} x_{11} + x_{12} + x_{13} + x_{14} = 5500000 \\ x_{21} + x_{22} + x_{23} + x_{24} = 4000000 \\ x_{31} + x_{32} + x_{33} + x_{34} = 2000000 \\ x_{41} + x_{42} + x_{43} + x_{44} = 3500000 \end{cases} \quad (5)$$

non-negativity conditions:

$$x_{ij} \geq 0 \ (i = \overline{1,4};\ j = \overline{1,4}) \quad (6)$$

3 Results

For accessibility of the software product interface, the source data and calculated values are written to a file format (.xlsx). The solution to the problem is implemented using the openpyxl and cvxopt.modeling libraries, the source code is written in the Python programming language.

The solution algorithm:

1. According to the initial data of the task. in the MS Excel spreadsheet editor, the transportation matrix is filled in, restrictions (4) – (6) are introduced (Table 1).
2. Python libraries necessary for solving transport problem are imported, a file with the source data is read:

```
import openpyxl
wb = openpyxl.reader.excel.load_workbook(filename = 'T3.xlsx', data_only=True)
wb.active = 0
from cvxopt.modeling import variable, op
sheet = wb.active
print(sheet['A1'].value)
for i in range (2,7):
   print(sheet['A'+str(i)].value,'      ',      sheet['B'+str(i)].value,'      ',sheet['C'+str(i)].value,'
',sheet['D'+str(i)].value,' ',sheet['E'+str(i)].value,)
```

3. The task is checked for balance:

```
s_p = sheet['B7'].value + sheet['C7'].value + sheet['D7'].value + sheet['E7'].value
s_o = sheet['F3'].value + sheet['F4'].value + sheet['F5'].value + sheet['F6'].value
if s_o == s_p:
   print('The transport task is balanced', s_p, '=', s_o)
   sheet['B18'].value = s_p
   sheet['B19'].value = s_o
```

4. The objective function of the transport problem (3) is compiled, constraints (4) – (6) are read:

```
x = variable(16, 'x')
z=(sheet['B3'].value * x[0] + sheet['C3'].value * x[1] + sheet['D3'].value * x[2] +
sheet['E3'].value * x[3] + sheet['B4'].value * x[4] + sheet['C4'].value * x[5] +
sheet['D4'].value * x[6] + sheet['E4'].value * x[7] + sheet['B5'].value * x[8] +
sheet['C5'].value * x[9] + sheet['D5'].value * x[10] + sheet['E5'].value * x[11] +
sheet['B6'].value * x[12] + sheet['C6'].value * x[13] + sheet['D6'].value * x[14] +
sheet['E6'].value * x[15])
us1 = (x[0] + x[1] + x[2] + x[3] == (sheet['F3'].value))
us2 = (x[4] + x[5] + x[6] + x[7] == (sheet['F4'].value))
us3 = (x[8] + x[9] + x[10] + x[11] == (sheet['F5'].value))
us4 = (x[12] + x[13] + x[14] + x[15] == (sheet['F6'].value))
us5 = (x[0] + x[4] +x[8]+ x[12] == (sheet['B7'].value))
us6 = (x[1] + x[5] +x[9]+x[13] == (sheet['C7'].value))
us7 = (x[2] + x[6] +x[10]+x[14] == (sheet['D7'].value))
us8 = (x[3] + x[7] + x[11]+ x[15] == (sheet['E7'].value))
x_non_negative = (x >= 0)
```

5. The optimal value of the objective function and the corresponding transportation plan are determined using the built-in function of the cvxopt.modeling library, the results are saved to the source file:

```
 problem = op(z,[us1,us2,us3,us4,us5,us6,us7,us8,x_non_negative])
problem.solve(solver='glpk')
sheet['B11'].value = x.value[0]
```

```
sheet['C11'].value = x.value[1]
sheet['D11'].value = x.value[2]
sheet['E11'].value = x.value[3]
sheet['B12'].value = x.value[4]
sheet['C12'].value = x.value[5]
sheet['D12'].value = x.value[6]
sheet['E12'].value = x.value[7]
sheet['B13'].value = x.value[8]
sheet['C13'].value = x.value[9]
sheet['D13'].value = x.value[10]
sheet['E13'].value = x.value[11]
sheet['B14'].value = x.value[12]
sheet['C14'].value = x.value[13]
sheet['D14'].value = x.value[14]
sheet['E14'].value = x.value[15]
sheet['F11'].value = sheet['B11'].value + sheet['C11'].value + sheet['D11'].value + sheet['E11'].value
sheet['F12'].value = sheet['B12'].value + sheet['C12'].value + sheet['D12'].value + sheet['E12'].value
sheet['F13'].value = sheet['B13'].value + sheet['C13'].value + sheet['D13'].value + sheet['E13'].value
sheet['F14'].value = sheet['B14'].value + sheet['C14'].value + sheet['D14'].value + sheet['E14'].value
sheet['B15'].value = sheet['B11'].value + sheet['B12'].value + sheet['B13'].value + sheet['B14'].value
sheet['C15'].value = sheet['C11'].value + sheet['C12'].value + sheet['C13'].value + sheet['C14'].value
sheet['D15'].value = sheet['D11'].value + sheet['D12'].value + sheet['D13'].value + sheet['D14'].value
sheet['E15'].value = sheet['E11'].value + sheet['E12'].value + sheet['E13'].value + sheet['E14'].value
sheet['B23'].value = problem.objective.value()[0]
wb.save('T3.xlsx')
```

6. The optimal product delivery plan and the corresponding minimum cost of raw material delivery, taking into account all the needs of the considered refineries, are displayed on an Excel sheet in the form of a transportation matrix (Fig. 1).

Oil fields	Cost matrix, mln rub					
	Achinskiy oil refinery	Angarskyi national chemical company	Komsomolsky oil refinery	PJSOC Bashneft	Extraction, tons	Stocks, tons
Vankorskoe	5500000	500000	0	0	6000000	6000000
Suzunskoe	0	2000000	0	2500000	4500000	4500000
Tagulskoe	0	0	2000000	1000000	3000000	3000000
Lodochnoe	0	1500000	0	0	1500000	1500000
Demand, tons	5500000	4000000	2000000	3500000		
Delivered, tons	5500000	4000000	2000000	3500000		
Total requirements, tons	15000000					
Total reserves, tons	15000000					
Target function	26 301 843 529,50 ₽					

Fig. 1. The result of solving the transport problem.

4 Conclusions

The paper considers a specific logistic process, on the basis of which an optimization model is built. It is shown that the use of mathematical apparatus allows us to obtain quantitative estimates that can be used to make rational management decisions.

A solution to the transport problem in Python using imported libraries and modified program code is presented. The advantage of the proposed software product is the simplicity of its application, the ability to read the source data and output the results of the solution to a file format (.xlsx), which simplifies the solution of optimization problems and allows you to use the proposed product for a wide class of linear programming problems.

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