ИНФОРМАТИКА

Известия Саратовского университета. Новая серия. Серия: Математика. Механика. Информатика. 2023. Т. 23, вып. 3. С. 411–417
Izvestiya of Saratov University. Mathematics. Mechanics. Informatics, 2023, vol. 23, iss. 3, pp. 411–417
mmi.sgu.ru
https://doi.org/10.18500/1816-9791-2023-23-3-411-417
EDN: YLMFVF

Научный отдел

Article

Cloud service for interactive simulation of production location

A. S. Velichko

Far Eastern Federal University, 10 Ajax Bay, Russky Island, Vladivostok 690922, Russia
Institute of Automation and Control Processes FEB RAS, 5 Radio St., Vladivostok 690041, Russia

Andrei S. Velichko, vandre@dvo.ru, https://orcid.org/0000-0001-8760-316X, AuthorID: 228264

Abstract. The paper deals with a problem of decision-making support for production location problem. The paper describes the mathematical model of production location. Minimization of total cost of delivery of raw materials to the place of production is used as a criterion of potential production location. The problem belongs to the class of binary mathematical programming problems with linear constraints but could be reduced to a set of linear programming problems solved by sequential or parallel computing. Based on the mathematical model a software tool is implemented as a cloud service on heterogeneous computing architecture. The software architecture includes the simulation module and modules for control and visualization. The ontology and declarative model for information exchange between the modules are designed with JSON format. This declarative model includes the objects considered in the mathematical model which are "products", "areas" and "communications". The simulation module is implemented on a high-performance server platform. Visualization module allows us to present graphically the original and the resulting matrix data and to modify the input parameters of the model interactively. The control and visualization modules are produced within IACPaaS cloud platform. Communication between the modules is established via asynchronous http-queries. The paper demonstrates the use of the software tool for the simulation of production location for the Russian Far East regions based on input data provided by open statistics sources.

Keywords: digital economy, smart product-service systems, transportation, cloud platform
Acknowledgements: The paper was supported by Ministry of Science and Higher Education of Russia (project No. 0202-2021-0004, and "Advanced Engineering Schools" project No. 075-15-2022-1143).
For citation: Velichko A. S. Cloud service for interactive simulation of production location. *Izvestiya of Saratov University. Mathematics. Mechanics. Informatics*, 2023, vol. 23, iss. 3, pp. 411–417. https://doi.org/10.18500/1816-9791-2023-23-3-411-417, EDN: YLMFVF

Научная статья
УДК 519.87

Облачный сервис для задачи оптимизации местоположения

А. С. Величко

[1]Дальневосточный федеральный университет, Россия, 690922, г. Владивосток, о. Русский, п. Аякс, д. 10
[2]Институт автоматики и процессов управления Дальневосточного отделения РАН (ИАПУ ДВО РАН), Россия, 690041, г. Владивосток, ул. Радио, д. 5

Величко Андрей Сергеевич, кандидат физико-математических наук, [1]профессор Института математики и компьютерных технологий; [2]научный сотрудник, vandre@dvo.ru, https://orcid.org/0000-0001-8760-316X, AuthorID: 228264

Аннотация. В статье рассматривается система поддержки принятия решений по проблеме размещения производства. Описана математическая модель, в которой в качестве критерия потенциального размещения производства используется минимизация общей стоимости доставки сырья к месту производства. Задача относится к классу бинарных задач математического программирования с линейными ограничениями, но может быть сведена к набору задач линейного программирования, решаемых с помощью последовательных или параллельных вычислений. На основе математической модели и программного инструмента реализован облачный сервис на гетерогенной вычислительной архитектуре. Архитектура программного обеспечения включает модуль моделирования и модули управления и визуализации. Онтология и декларативная модель обмена информацией между модулями разработаны в формате JSON. Эта декларативная модель включает в себя объекты, рассматриваемые в математической модели: «продукты», «места размещения» и «коммуникации». Модуль моделирования реализован на высокопроизводительной серверной платформе. Модуль визуализации позволяет графически представить исходные и результирующие матричные данные, а также интерактивно изменять входные параметры модели. Модули управления и визуализации созданы на облачной платформе IACPaaS. Связь между модулями устанавливается посредством асинхронных http-запросов. В статье показано использование разработанного программного инструментария для моделирования размещения производства в регионах Дальнего Востока России на основе статистических данных из открытых источников.
Ключевые слова: цифровая экономика, умные товарно-сервисные системы, транспорт, облачная платформа
Благодарности: Работа выполнена при поддержке Минобрнауки России (проект № 0202-2021-0004 и проект «Передовые инженерные школы» № 075-15-2022-1143).
Для цитирования: *Velichko A. S.* Cloud service for interactive simulation of production location [*Величко А. С.* Облачный сервис для задачи оптимизации местоположения] // Известия

Саратовского университета. Новая серия. Серия: Математика. Механика. Информатика. 2023. Т. 23, вып. 3. С. 411–417. https://doi.org/10.18500/1816-9791-2023-23-3-411-417, EDN: YLMFVF

Introduction

Modern business is largely based on digital technologies that affect market competition by giving such advantages like reducing costs, expanding the geography of supply, and increasing the market share. Digital technologies provide broad opportunities to automate production processes. Digital platforms as complex software solutions help for digitalizing business processes such as logistics, production, supply management, and others.

In papers [1–3] authors analyze different types of software systems and platforms and reveal their advantages and disadvantages focusing on comparing software solutions in terms of the business problems they solve. The results of this analysis show that not all the actual business problems are covered by modern software solutions despite a wide range of Russian and foreign software platforms. At the stage of organization and production planning such business problems and other related issues are to choose the optimal location, to analyze demand for products, and to select reliable suppliers. That is why the development of new software solutions that use modern information technologies to support various stages of digital production is an important problem and it is aimed at the economic development of a country overall.

1. Mathematics of production location problem

This section sketches the mathematical model of production location. It is based on a broader problem of interregional trade flow models [4].

Companies produce their products that are called "final products" if they use other products or "raw materials" which are delivered from different suppliers. The suppliers of these raw materials are located at the nodes of the transportation network. A company can deliver raw materials from different suppliers and a single supplier might not always provide a shipment to any node. Also, for this simple model, we consider that only one supplier is located at each node.

Let us consider the model of N-nodes transportation network among N regions each of them is producing and consuming different M products. Let z_{ij}^k be an unknown volume of a product type $k = 1, \dots, N$ delivered from region i to the region j, $i, j = 1, \dots, N$. The flow z_{ii}^k is not necessarily assumed to be zero and is interpreted as a self-produced product consumption in this region that is not transported outside.

The price p_j^k and the amount v_j^k of delivered product that can be provided from supplier j are given. We also consider transportation unit costs among nodes as t_{ij}. Let us aggregate all the external regions to the region $N + 1$ and let us consider additional unknown flows $z_{N+1,j}^k$.

Denoting D_j^k as the demand at node j for product k in a case of the closed economy of N-nodes, the first group of constraints of a location problem is

$$\sum_{i=1}^{N+1} z_{ij}^k = D_j^k. \tag{1}$$

For each node $j = 1, \dots, N$ and product $k = 1, \dots, M$ we need to consider the constraints for the supply at node $i = 1, \dots, N$

$$0 \leqslant z_{ij}^k \leqslant v_i^k. \tag{2}$$

For each node j as a potential place for production location the total cost of products delivery from all the nodes is $W(j) = \sum_{k=1}^{M} \sum_{i=1}^{N+1} (p_i^k + t_{ij}) z_{ij}^k$.

Let y_j be a binary variable that equals 1 if the region j is chosen as a place for production or equals zero otherwise. We should consider the constraint

$$\sum_{j}^{N} y_j \geqslant 1 \tag{3}$$

which means that we locate the production at least at one node.

The criteria of potential production location for a company at the node can be formalized as the minimization of the total cost of delivery of raw materials to the selected node from the others. Thus, the total cost of delivered products which should be minimized to find the optimal production location is

$$\min \sum_{j=1}^{N} W(j) y_j = \sum_{k=1}^{M} \sum_{i=1}^{N+1} \sum_{j=1}^{N} (p_i^k + t_{ij}) z_{ij}^k y_j. \tag{4}$$

Minimization of function (4) under constraints (1)–(3) is a mixed-integer problem with nonlinear and non-convex objective function by $z_{ij}^k$and y_j variables that leaves us a little hope for an effective accurate or approximate solution due to its NP-hardness.

The case of only one place of production is equivalent to constraint $\sum_{j}^{N} y_j = 1$. Therefore optimal $y_{j^*} = 1$ for only one j^* and $y_j = 0$ for $j \neq j^*$. In this situation, it is sufficient to solve separate N decomposed linear programs $\min W(j)$ for each j under the above-mentioned constraints (1), (2). Thus we can find the optimal node for production location as $j^* = \arg\min W(j)$. Due to the independence of these N cost minimization problems it is possible to organize parallel computations using different algorithms [5]. Let us notice that these cost minimization problems can be also decomposed into independent problems for each delivered product due to the lack of binding constraints on different products.

2. Software tool for simulation

Based on the mathematical model a software tool is implemented as a cloud service on heterogeneous computing architecture. Considering the key requirements for the software tool the IACPaaS cloud platform[1] was chosen for implementation of the visualization and control modules of the software.

The software architecture includes the simulation module and modules for control and visualization. The ontology and declarative model for information exchange between the modules are designed in JSON format. This declarative model includes the objects considered in the mathematical model which are “products”, “areas” and “communications”.

[1]*Oblachnaya platforma dlya razrabotki, upravleniya i udalennogo ispol’zovaniya intellektual’nykh oblachnykh servisov* (Intelligent Applications, Control and Platform as a Service). Available at: https://iacpaas.dvo.ru (accessed September 28, 2022).

The simulation module is implemented on a high-performance server platform. The visualization module allows us to present graphically the original and the resulting matrix data and to modify the input parameters of the model interactively. The control and visualization modules are produced within the IACPaaS cloud platform. Communication between the modules is established via asynchronous HTTP-queries.

The production location problem module which solves a set of linear programming problems is implemented using Octave open-source software[2] running on the virtual machine of “Far Eastern Computing Resource” Shared Resource Center[3]. Parallel implementation of the code use “octave-mpi” module[4] for Octave.

As an example, we take input data from the paper [6].

The nodes of potential production location are the administrative centers of 9 regions of the Far East of Russia: 1 — Primorsky Krai (Vladivostok), 2 — Khabarovsk Krai (Khabarovsk), 3 — Amur region (Blagoveshchensk), 4 — Jewish Autonomous region (Birobidzhan), 5 — the Republic of Sakha Yakutia (Yakutsk), 6 — Magadan region (Magadan), 7 — Sakhalin region (Yuzhno-Sakhalinsk), 8 — Kamchatka territory (Petropavlovsk-Kamchatsky), 9 — Chukotka Autonomous district (Anadyr). The territories which are external to the system of these regions are aggregated into region 10 labelled as “Others”. If the product flows are zero they are excluded from the figure.

The implementation of the visualization module of the cloud software solution opens a convenient opportunity to use and demonstrate the mathematical results of transportation modeling for any user over the Internet. The visualization module graphically represents matrix data about product flows in the form of a directed graph in which the arcs are product flows and the vertices represent the destination points of these flows. The visual representation of optimal transportation flows from all the nodes to the potential place for production at nodes “1” and “2” respectively for product “4” is shown in Figure 1.

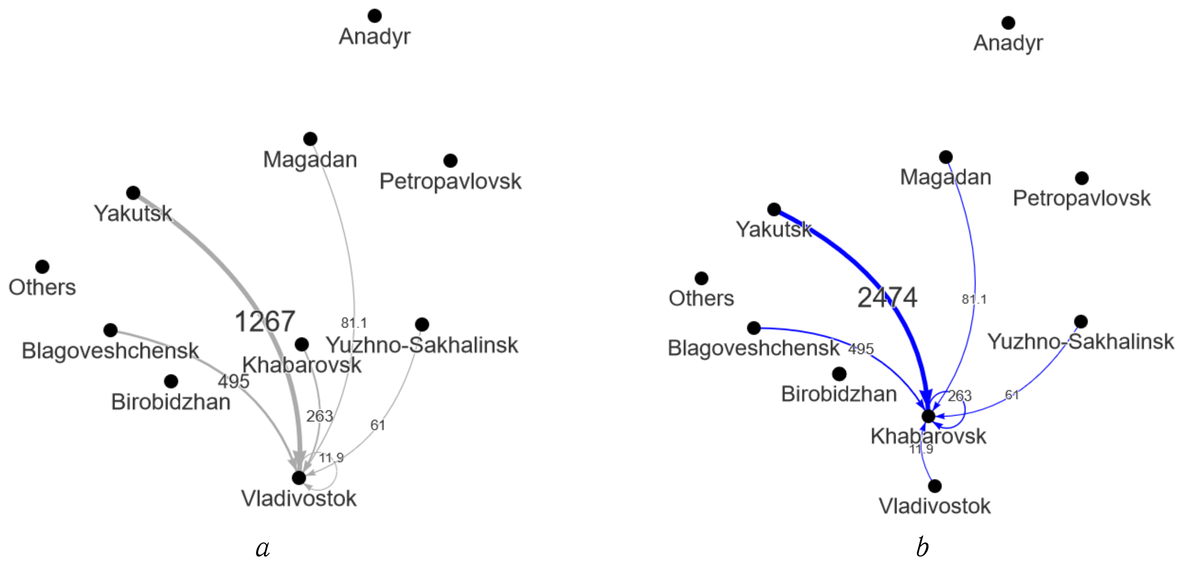

Fig. 1. Visualization of production location at Vladivostok region (*a*) and Khabarovsk region (*b*) for product “4”

[2] *GNU Octave: High-level language for numerical computations*. Available at: https://www.gnu.org/software/octave/ (accessed September 28, 2022).

[3] *Shared Resource Center “Far Eastern Computing Resource”*. Available at: https://www.cc.dvo.ru (accessed September 28, 2022).

[4] *Octave-mpi module*. Available at: https://github.com/carlodefalco/octave-mpi (accessed September 28, 2022).

The visualization module of the software tool could also visualize aggregate information for any subgroup of products and regions. This could be used as a tool for the assessment of the self-sufficiency of regions by products as it is shown in Figure 2. The presented example allows us to find out the nature of the interrelations of economies of regions of the Far East of Russia in the conditions of the existing spatial structure of the location of demand and supply.

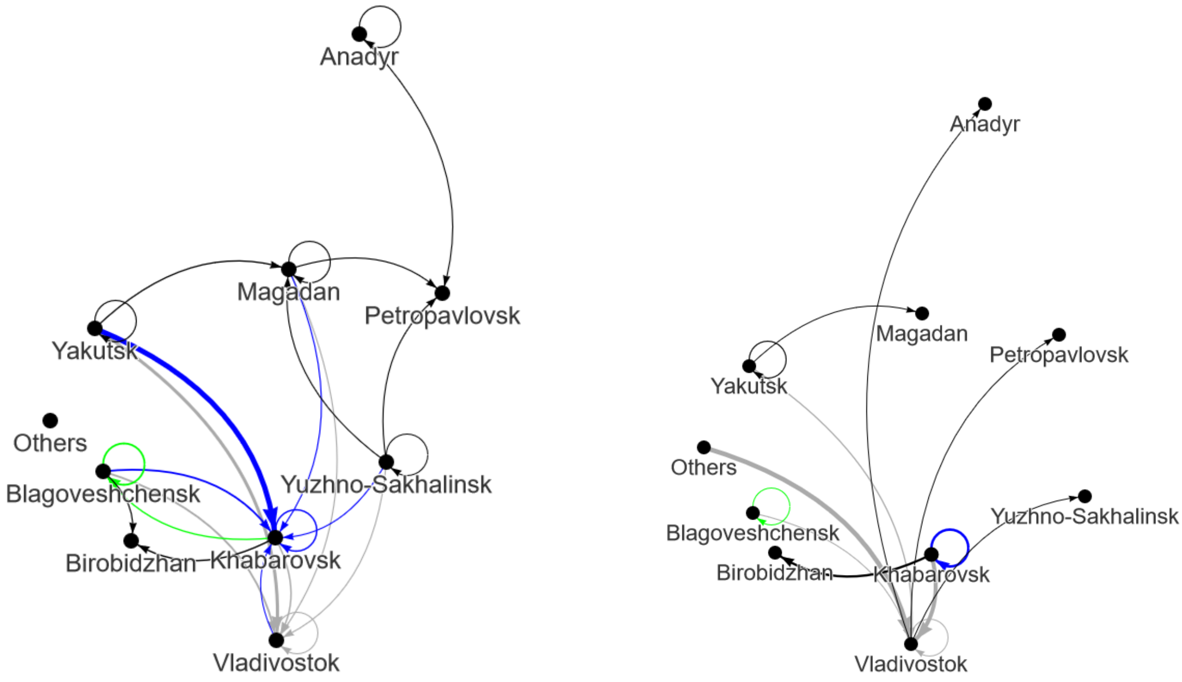

Fig. 2. Visualization of “self-sufficiency” of regions for product “4” (*a*) and product “5” (*b*)

Conclusion

The paper describes the cloud software solution that is intended for interactive simulation of production location. The simulation service is cloud-based and consists of three main modules: the production location module, the control module, and the visualization module.

The module of simulation of production locations is based on the mathematical model of input product cost minimization. The simulation module is implemented on a high-performance computing architecture, and the control and visualization modules are implemented on the IACPaaS cloud platform using a multi-agent approach. Interaction between the computing cluster and the IACPaaS platform is carried out via the HTTP protocol based on dynamic asynchronous requests.

The software tool is intended for businesses that intend to simulate the possible production location. Also, it could be used by specialists of various ministries and departments dealing with the problem of production location planning and can be used for simulation for other regions of Russia.

References

1. Rahul M., Shukla R., Singh S., Yadav V., Mishra A. A survey on state-of-the-art of cloud computing: Its challenges and solutions. In: *Recent Trends in Communication and Electronics. Proceedings of the International Conference on Recent Trends in Communication and Electronics (ICCE-2020), Ghaziabad, India, 28–29 November, 2020*. London, Imprint CRC Press, 2021. 6 p. https://doi.org/10.1201/9781003193838

2. Henzel R., Herzwurm G. Cloud Manufacturing: A state-of-the-art survey of current issues. *Procedia CIRP*, 2018, vol. 72, pp. 947–952. https://doi.org/10.1016/j.procir.2018.03.055
3. Gribova V. V., Velichko A. S., Kolmogorov A. V. The concept of a digital platform for industrial activities. *Information Technologies*, 2019, vol. 25, iss. 8, pp. 502–511 (in Russian). https://doi.org/10.17587/it.25.502-511, EDN: EIWHZK
4. Velichko A. S. Interactive simulation software for multi-regional model of freight transportation. *CEUR Workshop Proceedings*, 2018, vol. 2098, pp. 419–430.
5. Velichko A. S. Parallel algorithms with feasible set partitioning for large-scale optimization problems. *Upravlenie bol'shimi sistemami* [Large Systems Management], 2016, vol. 62, pp. 60–74 (in Russian). EDN: WKHFKP
6. Velichko A. S., Gribova V. V., Fedorishchev L. A. Cloud service for interactive simulation of interregional trade flows. *Automatic Control and Computer Sciences*, 2019, vol. 53, iss. 7, pp. 811–820. https://doi.org/10.3103/S0146411619070289

Поступила в редакцию / Received 22.11.2022
Принята к публикации / Accepted 25.12.2022
Опубликована / Published 31.08.2023