Central European Journal of Operations Research (2024) 32:1–9
https://doi.org/10.1007/s10100-023-00898-6

Optimization methods and algorithms

Péter Biró[1,2] · Sándor Bozóki[2,3] · Tamás Király[4] · Alexandru Kristály[5,6]

Accepted: 7 December 2023 / Published online: 16 January 2024

Abstract
Recent results of three areas, pickup and delivery, optimal mass transportation, matching under preferences are highlighted. The topics themselves have been selected from the active research fields of Hungarian Operations Research. We also provide a short summary of selected research results from the 34th Hungarian Operations Research Conference, held in Cegléd, Hungary, August 31–September 2, 2021.

Keywords Pickup and delivery · Optimal mass transportation · Matching under preferences

✉ Sándor Bozóki
bozoki.sandor@sztaki.hun-ren.hu

Péter Biró
peter.biro@krtk.hun-ren.hu

Tamás Király
tamas.kiraly@ttk.elte.hu

Alexandru Kristály
alexandru.kristaly@ubbcluj.ro

1 Centre for Economic and Regional Studies (HUN-REN KRTK), HUN-REN Institute of Economics, Budapest, Hungary

2 Department of Operations Research and Actuarial Sciences, Institute of Operations and Decision Sciences, Corvinus University of Budapest, Budapest, Hungary

3 Laboratory on Engineering and Management Intelligence, HUN-REN Institute for Computer Science and Control (HUN-REN SZTAKI), Research Group of Operations Research and Decision Systems, Budapest, Hungary

4 Department of Operations Research, Eötvös Loránd University, Budapest, Hungary

5 Department of Economics, Babes-Bolyai University, Cluj-Napoca, Romania

6 Institute of Applied Mathematics, Óbuda University, Budapest, Hungary

1 Quickest route

The *International Conference on Automated Planning and Scheduling (ICAPS)* hosted four competitions in 2021. One of these, the *Dynamic Pickup and Delivery Problem (DPDP)* competition was organized by Huawei Noah's Ark Lab (Hao et al. 2022). This competition was based on a real-life scenario of Huawei Technologies Co. Ltd. The DPDP can be stated as follows. There is a homogeneous fleet of vehicles to serve pickup-and-delivery requests that arrive over the day. Each request has a pickup and a delivery location, a quantity and a due-date. The vehicles cannot carry more orders than their capacity, and unloading the orders has to respect the last-in-first-out rule. The locations have a limited number of docking ports for loading and unloading the vehicles, which may force the vehicles to wait. The goal is to satisfy all the requests such that a combination of tardiness penalties and traveling costs is minimized. The problem is dynamic in the sense, that the orders are not known in advance, but arrive online, and at certain time points there is an opportunity to make decisions, i.e., to re-plan routes, reflecting on the new information.

The task of the participants was to create an algorithm to assign new orders, and possibly re-assign already allocated orders to vehicles at the decision points. The organizers provided a public benchmark dataset along with a simulator for testing the algorithms. A single run simulated an entire day, i.e., the arrival of new orders, along with the movement of the vehicles and the transportation of the orders. The algorithm was called every ten minutes (in simulation time) to update the route plans of the vehicles.

152 teams joined the competition, including the team '*Quickest Route*', formed by Markó Horváth, Tamás Kis, and Péter Györgyi. The team developed a so-called *cost function approximation* method for the problem, where they perturbed the objective function in order to obtain vehicle routes that are flexible for possible future changes. Then, the problem at each decision point was solved by a local search-based procedure.

After a two months long preparation and trial submission phase, the three-week competition began, where each team could submit their algorithm for evaluation 5 times per day. The evaluation was performed by the organizers on a hidden dataset, and the teams were ranked based on their best scores. The publicly available leaderboard was updated every three hours, which made the competition very exciting. Six hours before the end of the competition, with their last attempts, the team *Quickest Route* moved from fifth place to second place. However, another team was able to improve, taking the second place at the penultimate update of the leaderboard. After that, the podium was not changed, so the team *Quickest Route* took the third place of the competition.

Since then, many articles have addressed the problem (Cai et al. 2022, 2022; Du et al. 2023; Cai et al. 2023). The team also improved their algorithm, with which they obtained significantly better results on the benchmark dataset than the former approaches. Their manuscript is currently under review.

2 Optimal mass transportation

Optimal Mass Transportation (OMT), as its name suggests, provides solutions for transporting a unit measure from one source to another target measure using minimal work/energy with respect to certain cost function, associating a suitable Wasserstein metric. The problem dates back to G. Monge, and its rigorous mathematical approach was developed by L. Kantorovich, who relaxed Monge's original problem into a linear programming problem. In a breakthrough work by Y. Brenier, the author observed that under very mild assumptions, optimal transport maps between two marginal masses are realized by the gradient of a convex function. In this way, a whole machinery were applied from operation research, nonlinear and convex analysis to study various aspects of OMT. The theory of OMT is still a very active research area with various applications (in geometric optics, isoperimetric inequalities, meteorology, chemistry, etc), culminated in the works of two Fields Medalist, A. Figalli and C. Villani.

By using OMT on sub-riemannian objects, Balogh et al. (2018, 2019) provided a positive answer to the tacitly accepted view that no meaningful geometric inequalities can be proved on singular spaces as Heisenberg and Carnot groups. Their geometric inequalities imply various forms of the sub-riemannian distorted Borell–Brascamp–Lieb, Brunn–Minpkowski and Prékopa–Leindler inequalities.

Balogh and Kristály (2023), by using OMT and Brunn-Minkowski inequality, provided the sharp isoperimetric inequality on Riemannian manifolds with nonnegative Ricci curvature, where the so called asymptotic volume ratio plays a crucial role. As a consequence, one can obtain sharp Sobolev-type inequalities, characterizing also the equality cases. Equality in the geometric inequalities have been also established in Balogh and Kristály (2018), using quantitative OMT theory.

Nowadays another side of the OMT has become very active, the so-called noncommutative / quantum optimal transport theory. In this setting, the quantum analogue replaces the usual measures by quantum states (which are positive-semidefinite trace-class operators of a unit trace) acting on a separable Hilbert space. A very successful event "Workshop: Optimal Transport on Quantum Structures" was organized by T. Titkos and D. Virosztek at the Alfréd Rényi Institute of Mathematics, 26–30 September 2022, attracting leading experts in OMT.

Gehér et al. (2023a) considered two quadratic quantum cost operators on a qubit state space (i.e., on a two-dimensional Hilbert space) by classifying the corresponding isometries.

A series of papers has been published by see e.g. Gehér et al. (2023b), Gehér et al. (2022), Gehér et al. (2019), where aspects of the isometry group of Wasserstein spaces have been investigated in various aspects (Hilbert case, metric case, discrete case, etc).

3 Matching under preferences

In this section we will present the most important recent research results by the Hungarian OR community on the topic of matching under preferences. We will cover papers on classical two-sided matching markets (such as the college admission problem), allocation problems (e.g., vaccine allocation), pairing at tournaments, exchange problems (with application of kidney exchanges), assignment games and auctions for power and gas markets, and stable flow and network problems.

The seminal paper of Gale and Shapley (1962) on college admission problem initiated the scientific research on the interdisciplinary field of matching under preferences. They provided a model and efficient algorithm for solving the college admission problem, where both the students and the colleges have preferences and the matching is computed by a centralised algorithm. Hungarian college admissions has four special features, ties, lower quotas, common quotas and paired applications, and each of the last three features makes the problem NP-hard to solve. The Hungarian application uses a Gale-Shapley type heuristic algorithm, however, Ágoston et al. (2016) showed that lower quotas can be solved for optimality by IP-techniques, and in a recent paper Ágoston et al. (2022) covered also the cases of common quotas and ties. The CEMS Business project allocation is a task every year at Corvinus University of Budapest, that has been solved also at partner universities in Germany and Poland by also IP-techniques for this special setting of matching under distributional constraints by Ágoston et al. (2018). General cutoff-score based solutions have been studied by Aziz et al. (2022) also with IP-technique. A recent survey on the combinatorics of two-sided stable matching problems has been written by Fleiner (2023).

In object allocation problems only one side has preferences. A new solution concept of constrained efficient allocations was proposed by Biró and Gudmundsson (2021) motivated by school choice and refugee allocation applications. The general problem is NP-hard, but IP-techniques were used for conducting simulations on an Estonian kindergarten allocation problem. Vaccine allocation was an interesting application for preference based allocation problem during the COVID-pandemic, especially in Hungary where besides the EU-approved vaccines Russian and Chinese vaccines were also available in large quantities. The vaccine acceptance choices made by the Hungarian population were studied in Kutasi et al. (2022). Computer simulations for vaccine allocation were conducted by Reguly et al. (2022) and Angelov et al. (2023). Another application developed during the pandemic was for allocating voluntary mentors to students in Hungary by using optimisation techniques by Biró and Gyetvai (2023).

Pairing teams or individuals in the rounds of a competition is also a matching problem. Various tournament designs were compared by simulations by Sziklai et al. (2022), where the Swiss tournament was found to be the best in approximating the real power rankings. The Swiss systems are also the most popular design in chess tournaments, these were analysed by Führlich et al. (2022). A fair scheduling problem for The International Young Physicists' Tournament was solved with optimisation techniques by Cechlárová et al. (2023).

Paired kidney exchanges match incompatible donor-recipient pairs together in order for swapping their donors, so that everyone can receive immunologically compatible pairs. Larger cycles are also possible, but due to the simultaneity of the transplants, only 3-way exchanges are allowed in most applications. In Europe there are at least ten large countries operating national or international kidney exchange programs with various optimisation criteria, surveyed by Biró et al. (2021). The ENCKEP COST Action during 2016–2021 provided a network for studying and coordinating these applications. As part of that project the ENCKEP-simulator was also developed that can be used to evaluate the performance national and international kidney exchange policies. This simulator was extended by Matyasi and Biró (2023) for analysing failure-aware polices. Individual fairness of the solution can be potentially improved if the goal of the kidney exchange program is not simply maximising the number of transplants, but rather finding stable/core solutions. This approach was studied with IP-techniques by Klimentova et al. (2023), and also by Biró et al. (2023), where the latter paper also showed that core solutions provide good incentives to the recipients to bring better or more donors to the pool. More general circulation problems were studied by Andersson et al. (2021) and Biró et al. (2022), motivated by time banks and portfolio compression, here agents are exchanging their time or liabilities with each other.

Surprisingly, the problem of balancing the benefits of international kidney exchange programmes by compensation schemes, see e.g., Benedek et al. (2021), is closely related to partitioned assignment games. A comprehensive survey on generalised assignment games was written by Benedek et al. (2023). The classical assignment game of Shapley and Shubik (1971) was studied by Solymosi (2023) with respect of the sensitivity of the solution by the preferences and also for changing market participation by Solymosi (2023). The problem setting with the presence of middlemen in assignment games was studied by Atay et al. (2023). Another, related TU-game, the liability games were studied by Csóka et al. (2022).

The matching with payment model is also the base of auctions. Auctions in power markets have been studied by Csercsik (2023) in a complex setting with coordinated balancing capacity procurement, and by Csercsik (2021) for minimum income conditions. Predicting electricity consumption by AI-techniques can help reaching desirable solutions in power markets, as shown in Čegovnik et al. (2023). Auctions have been also used in European gas markets for pipe network capacities, analysed by Csercsik (2022). Game theory models were used to predict the effect of gas network changes in Europe in Sziklai et al. (2020). Finally, a combinatorial auction model was proposed for efficient and fair channel assignments by Csercsik and Jorswieck (2023).

Stability in network was studied by Fleiner et al. (2019), where they proved the existence of a so-called trail-stable solution in a very general environment with choice functions over possible contracts. The computational complexity of computing stable solutions was studied by Fleiner et al. (2023). Stable flows were also studied by using the stable fractional solutions by the Scarf-algorithm by Csáji (2022). Finally, Cseh et al. (2022) analysed the special case of three dimensional stable matchings with cyclic preferences using constraints programming.

4 The 34th Hungarian Operations Research Conference

The 34th Hungarian Operations Research Conference, organized by the Hungarian Society for Economic Modelling, co-organized by the János Bolyai Mathematical Society and by the Hungarian Operations Research Society was held in Cegléd, August 31-September 2, 2021.

Ágoston and E-Nagy (2024) apply mixed integer linear programming for the minimum sum-of-squares clustering problem in order to find global optimum, instead of a local one, usually found by the KMEANS algorithm. The MILP formulations are flexible: additional constraints, regarding e.g. balanced cluster sizes, can also be included.

Bánhidi and Dobos (2024) investigate the sensitivity of the ranking calculated by TOPSIS, a multi-criteria decision model (see, e.g. in Dzemydienė et al. (2022)). Data of Digital Economy and Social Index (DESI) with respect to five criteria (connectivity, human capital, use of internet, integration of digital technology, digital public services) are used.

Borgulya (2024) develops a hybrid estimation of distribution algorithm for the offline two-dimensional variable-sized bin packing problem, where the goal is to pack the rectangles into the bins without overlap, parallel to the sides, so that the total area of the used bins (or total cost) is minimized. The proposed algorithm uses a probabilistic model or selection and mutation operators to generate descendants. Local search procedures improve the quality of the solutions.

Dobos and Vörösmarty (2024) focus on data transformation in several models of Data Envelopment Analysis (DEA, (see, e.g. in Hosseinzadeh et al. (2023); Wu et al. (2023); Zýková (2022))) and draw the attention to the possibility of biases. Supplier selection is used as an illustrative example.

Domokos and Regős (2024) examine geological crack patterns and develop a planar, discrete time evolution model. They define two local, random evolutionary events, corresponding to secondary fracture and rearrangement of cracks. The existence of limit points is proved for several types of trajectories.

Hajba, Horváth, Heitz and Psenák (2024) study the replenishment problem of a European petrol company. Station replenishment problem is a special vehicle routing problem, where different types of fuels are transported from the depots to the customers. A mixed integer linear programming model is developed. Customers are clustered in order to reduce the size of the problem.

Orbán-Mihálykó, Mihálykó and Gyarmati (2024) apply paired comparison methods to aggregate rankings of different groups. Results are applied to the data from the European Handball Federation Women's Champions League (2020/2021, two groups).

Varga (2024) provides a guide to determine optimised child and spousal support payment. The aim is to minimize the risk of poverty after divorce for the child and the custodial parent. A dynamic, globally applicable model is proposed based on simulations based on German child support data.

Vörös (2024) proves that the maximal loss on a loan portfolio is located at the frontier of the given Mahalanobis distance, furthermore explicit formulas are given. In case of two macro state variables, efficient initial solutions are generated.

Acknowledgements The contribution of Tamás Kis, Péter Györgyi and Markó Horváth to Sect. 1 is highly appreciated.

Funding Open access funding provided by Corvinus University of Budapest.

Declarations

Conflict of interest The authors have no conflict of interest to declare.

References

Ágoston KC, E-Nagy M (2024) Mixed integer linear programming formulation for K-means clustering problem. Central Eur J Oper Res. https://doi.org/10.1007/s10100-023-00881-1

Ágoston KC, Biró P, McBride I (2016) Integer programming methods for special college admissions problems. J Comb Optim 32:1371–1399

Ágoston KC, Biró P, Szántó R (2018) Stable project allocation under distributional constraints. Oper Res Perspect 5:59–68

Ágoston KC, Biró P, Kováts E, Jankó Z (2022) College admissions with ties and common quotas: integer programming approach. Eur J Oper Res 299(2):722–734

Andersson T, Cseh Á, Ehlers L, Erlanson A (2021) Organizing time exchanges: lessons from matching markets. Am Econ J Microecon 13(1):338–373

Angelov G, Kovacevic R, Stilianakis NI, Veliov VM (2023) Optimal vaccination strategies using a distributed model applied to Covid-19. CEJOR 31(2):499–521

Atay A, Bahel E, Solymosi T (2023) Matching markets with middlemen under transferable utility. Ann Oper Res 322(2):539–563

Aziz H, Baychkov A, Biró P (2022) Cutoff stability under distributional constraints with an application to summer internship matching. Math Programm 1–23

Balogh Z, Kristály A (2018) Equality in Borell-Brascamp-Lieb inequalities on curved spaces. Adv Math 339:453–494. https://doi.org/10.1007/s00208-022-02380-1

Balogh Z, Kristály A (2023) Sharp isoperimetric and Sobolev inequalities in spaces with nonnegative Ricci curvature. Math Ann 385(3–4):1747–1773. https://doi.org/10.1007/s00208-022-02380-1

Balogh Z, Kristály A, Sipos K (2018) Geometric inequalities on Heisenberg groups. Calc Var Partial Differ Equ 57(2):61. https://doi.org/10.1007/s00526-018-1320-3

Balogh Z, Kristály A, Sipos K (2019) Geometric inequalities on Heisenberg groups. J Funct Anal 277(12):108293. https://doi.org/10.1016/j.jfa.2019.108293

Bánhidi Z, Dobos I (2024) Sensitivity of TOPSIS ranks to data normalization and objective weights on the example of digital development. Central Eur J Oper Res. https://doi.org/10.1007/s10100-023-00876-y

Benedek M, Biró P, Johnson M, Paulusma D, Ye X (2023) The complexity of matching games: a survey. J Artif Intell Res 77:459–485

Benedek M, Biró P, Kern W, Paulusma D (2021) Computing balanced solutions for large international kidney exchange schemes. arXiv preprint arXiv:2109.06788

Biró P, Gudmundsson J (2021) Complexity of finding Pareto-efficient allocations of highest welfare. Eur J Oper Res 291(2):614–628

Biró P, Gyetvai M (2023) Online voluntary mentoring: optimising the assignment of students and mentors. Eur J Oper Res 307(1):392–405

Biró P, van de Klundert J, Manlove D, Pettersson W, Andersson T, Burnapp L, Chromy P, Delgado P, Dworczak P, Haase B et al (2021) Modelling and optimisation in European kidney exchange programmes. Eur J Oper Res 291(2):447–456

Biró P, Klijn F, Pápai S (2022) Serial rules in a multi-unit Shapley-Scarf market. Games Econ Behav 136:428–453
Biró P, Klijn F, Klimentova X, Viana A (2023) Shapley–Scarf housing markets: respecting improvement, integer programming, and kidney exchange. Math Oper Res
Borgulya I (2024) A hybrid estimation of distribution algorithm for the offline 2D variable-sized bin packing problem. Central Eur J Oper Res. https://doi.org/10.1007/s10100-023-00858-0
Cai J, Zhu Q, Lin Q (2022) Variable neighborhood search for a new practical dynamic pickup and delivery problem. Swarm Evol Comput 75:101182
Cai J, Zhu Q, Lin Q, Li J, Chen J, Ming Z (2022) An efficient multi-objective evolutionary algorithm for a practical dynamic pickup and delivery problem. In: International conference on intelligent computing, pp 27–40. Springer
Cai J, Zhu Q, Lin Q, Ma L, Li J, Ming Z (2023) A survey of dynamic pickup and delivery problems. Neurocomputing, 126631
Cechlárová K, Cseh Á, Jankó Z, Kireš M, Miňo L (2023) A quest for a fair schedule: the international young physicists' tournament. J Sched 26(1):3–18
Čegovnik T, Dobrovoljc A, Povh J, Rogar M, Tomšič P (2023) Electricity consumption prediction using artificial intelligence. Central Eur J Oper Res 1–19
Csáji G (2022) On the complexity of stable hypergraph matching, stable multicommodity flow and related problems. Theoret Comput Sci 931:1–16
Cseh Á, Escamocher G, Genç B, Quesada L (2022) A collection of constraint programming models for the three-dimensional stable matching problem with cyclic preferences. Constraints 27(3):249–283
Csercsik D (2021) Strategic bidding via the interplay of minimum income condition orders in day-ahead power exchanges. Energy Econ 95:105126
Csercsik D (2022) Convex combinatorial auction of pipeline network capacities. Energy Econ 111:106084
Csercsik D (2023) Simulation-based estimation of the economic benefits implied by coordinated balancing capacity procurement and deployment in a day-ahead market model. Energy Strat Rev 50:101248
Csercsik D, Jorswieck E (2023) Preallocation-based combinatorial auction for efficient fair channel assignments in multi-connectivity networks. IEEE Trans Wirel Commun 22(11):8407–8422
Csóka P, Illés F, Solymosi T (2022) On the Shapley value of liability games. Eur J Oper Res 300(1):378–386
Dobos I, Vörösmarty Gy (2024) Input and output reconsidered in supplier selection DEA model. Central Eur J Oper Res. https://doi.org/10.1007/s10100-023-00845-5
Domokos G, Regős K (2024) A discrete time evolution model for fracture networks. Central Eur J Oper Res. https://doi.org/10.1007/s10100-022-00838-w
Du J, Zhang Z, Wang X, Lau HC (2023) A hierarchical optimization approach for dynamic pickup and delivery problem with LIFO constraints. Transp Res Part E Logist Transp Rev 175:103131
Dzemydienė D, Dzemydaitė G, Gopisetti D (2022) Application of multicriteria decision aid for evaluation of ICT usage in business. CEJOR 30(1):323–343. https://doi.org/10.1007/s10100-020-00691-9
Fleiner T (2023) Combinatorics of stable matchings. Online Matching-Based Market Design 264
Fleiner T, Jagadeesan R, Jankó Z, Teytelboym A (2019) Trading networks with frictions. Econometrica 87(5):1633–1661
Fleiner T, Jankó Z, Schlotter I, Teytelboym A (2023) Complexity of stability in trading networks. Int J Game Theor 1–20
Führlich P, Cseh Á, Lenzner P (2022) Improving ranking quality and fairness in swiss-system chess tournaments. In: Proceedings of the 23rd ACM conference on economics and computation, pp 1101–1102
Gale D, Shapley LS (1962) College admissions and the stability of marriage. Am Math Mon 69(1):9–15
Gehér Gy P, Titkos T, Virosztek D (2019) On isometric embeddings of Wasserstein spaces-the discrete case. J Math Anal Appl 480(2):123435. https://doi.org/10.1016/j.jmaa.2019.123435
Gehér Gy P, Titkos T, Virosztek D (2022) The isometry group of Wasserstein spaces: the Hilbertian case. J Lond Math Soc 106(4):3865–3894. https://doi.org/10.1112/jlms.12676
Gehér Gy P, Pitrik J, Titkos T, Virosztek D (2023) Quantum Wasserstein isometries on the qubit state space. J Math Anal Appl 522(2):126955. https://doi.org/10.1016/j.jmaa.2022.126955
Gehér Gy P, Titkos T, Virosztek D (2023) Isometric rigidity of Wasserstein tori and spheres. Mathematika 69(1):20–32. https://doi.org/10.1112/mtk.12174

Hajba T, Horváth Z, Heitz D, Psenák B (2024) A MILP approach combined with clustering to solve a special petrol station replenishment problem. Central Eur J Oper Res. https://doi.org/10.1007/s10100-023-00849-1
Hao J, Lu J, Li X, Tong X, Xiang X, Yuan M, Zhuo HH (2022) Introduction to the dynamic pickup and delivery problem benchmark – ICAPS 2021 competition
Hosseinzadeh MM, Ortobelli Lozza S, Hosseinzadeh Lotfi F, Moriggia V (2023) Portfolio optimization with asset preselection using data envelopment analysis. CEJOR 31(1):287–310. https://doi.org/10.1007/s10100-022-00808-2
Klimentova X, Biró P, Viana A, Costa V, Pedroso JP (2023) Novel integer programming models for the stable kidney exchange problem. Eur J Oper Res 307(3):1391–1407
Kutasi K, Koltai J, Szabó-Morvai Á, Röst G, Karsai M, Biró P, Lengyel B (2022) Understanding hesitancy with revealed preferences across Covid-19 vaccine types. Sci Rep 12(1):13293
Matyasi L, Biró P (2023) Testing re-optimisation strategies in international kidney exchange programmes by the enckep simulator. Central Eur J Oper Res 1–23
Orbán-Mihálykó E, Cs Mihálykó, Gyarmati L (2024) Evaluating the capacity of paired comparison methods to aggregate rankings of separate groups. Central Eur J Oper Res. https://doi.org/10.1007/s10100-023-00839-3
Reguly IZ, Csercsik D, Juhász J, Tornai K, Bujtár Z, Horváth G, Keömley-Horváth B, Kós T, Cserey G, Iván K et al (2022) Microsimulation based quantitative analysis of Covid-19 management strategies. PLoS Comput Biol 18(1):1009693
Shapley LS, Shubik M (1971) The assignment game I: the core. Internat J Game Theory 1:111–130
Solymosi T (2023) Assignment games with population monotonic allocation schemes. Soc Choice Welf 1–22
Solymosi T (2023) Sensitivity of fair prices in assignment markets. Math Soc Sci 126:1–12
Sziklai BR, Kóczy LÁ, Csercsik D (2020) The impact of nord stream 2 on the European gas market bargaining positions. Energy Policy 144:111692
Sziklai BR, Biró P, Csató L (2022) The efficacy of tournament designs. Comput Oper Res 144:105821
Varga ET (2024) What is the economically and socially optimised child support? Central Eur J Oper Res. https://doi.org/10.1007/s10100-023-00865-1
Vörös J (2024) Some properties of the maximum loss on loan portfolios. Central Eur J Oper Res. https://doi.org/10.1007/s10100-022-00837-x
Wu H, Yang J, Wu W, Chen Y (2023) Interest rate liberalization and bank efficiency: a DEA analysis of Chinese commercial banks. CEJOR 31(2):467–498. https://doi.org/10.1007/s10100-022-00817-1
Zýková P (2022) The overall efficiency of the dynamic DEA models. CEJOR 30(2):495–506. https://doi.org/10.1007/s10100-021-00777-y