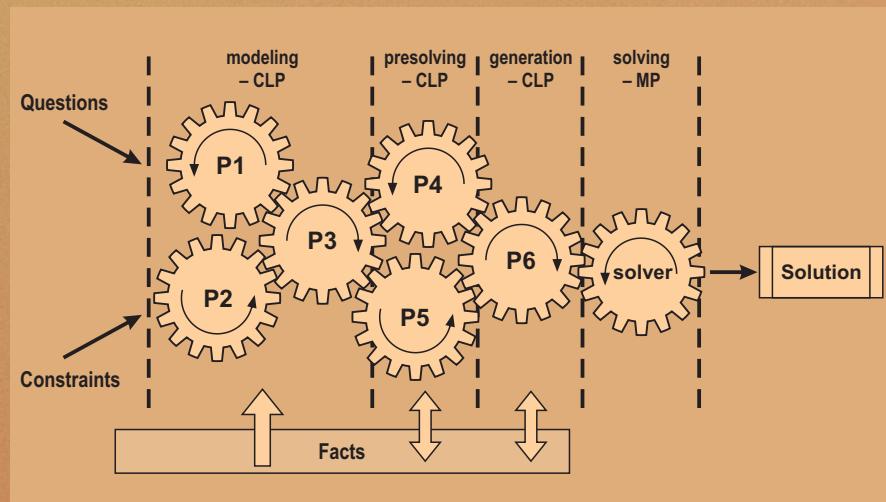


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A HYBRID APPROACH TO MODELING AND SOLVING DISTRIBUTION PROBLEMS



Politechnika Świętokrzyska

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Redaktor Naukowy serii
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PL ISSN 1897-2691
PL ISBN 978-83-65719-26-3

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- Apt, K., Wallace, M. (2006), *Constraint Logic Programming using Eclipse*, Cambridge University Press, Cambridge.
- Archetti, C., Speranza, M. (2014), *A survey on matheuristics for routing problems* [in:] EURO J Comput Optim, 2(223), doi:10.1007/s13675-014-0030-7.
- Ballou, R.H., 1989, *Heuristics: Rules of Thumb for Logistics Decision Making* [in:] Journal of Business Logistics 10(1), 122-32.
- Baptiste, P., LePape, C., Nuijten, W. (2001), *Constraint-Based Scheduling: Applying Constraint Programming to Scheduling Problems*, Kluwer Academic Publishers, Massachusetts, USA.
- Beamon, B.M. (1998), *Supply chain design and analysis: Models and methods* [in:] International Journals of Economics, 55, 281-294.
- Blum, C., Cotta, C., Fernandez, A.J., Gallardo, J.E. (2007), *A probabilistic beam search algorithm for the shortest common supersequence problem* [in:] C. Cotta, J.I. van Hemert (Eds.), Proceedings of EvoCOP 2007 – Seventh European Conference on Evolutionary Computation in Combinatorial Optimisation, Vol. 4446 of Lecture Notes in Computer Science, Springer-Verlag, Berlin, Germany, 36-47.
- Błażewicz, J., Ecker K., Pesch, E., Schmidt, G., Węglarz J. (2007), *Handbook on Scheduling From Theory to Applications*, Springer, ISBN: 978-3-540-28046-0, 2007.
- Bockmayr, A. Kasper, T. (1998), *A unifying framework for integer and finite domain constraint programming* [in:] INFORMS Journal on Computing, 10(3), 287-300, doi:<https://doi.org/10.1287/ijoc.10.3.287>.
- Borwein, J.M., Crandall, R.E. (2010), *Closed Forms: What They Are and Why We Care*. University of Newcastle, Centre for Computer Assisted Research Mathematics and its Applications (CARMA), Callaghan, NSW, Australia.
- Boschetti, M., Maniezzo, V. (2009), *Benders decomposition, Lagrangian relaxation and metaheuristic design* [in:] Journal of Heuristics 15, 283-312.
- Brailsford, S., Hubbard, P., Smith, B., Williams, H. (1996), *Organizing a social event - A difficult problem of combinatorial optimization* [in:] Computers and Operations Research, 23(9), 845-856, doi: [https://doi.org/10.1016/0305-0548\(96\)00001-9](https://doi.org/10.1016/0305-0548(96)00001-9).
- Brooke, A., Kendrick, D., Meeraus, A., Raman. R. (1997), GAMS Language Guide. Release 2.25. GAMS Development Corporation, Washington, DC.
- Burke, E.K., Kendall, G., Newall, J., Hart, E., Ross, P., Schulenburg, S. (2003), *Hyperheuristics: an emerging direction in modern search technology* [in:] Handbook of Metaheuristics, 57 of International Series in Operations Research and Management Science, Kluwer Academic Publishers, 457-474.
- Chandru, V., Rao, M. (1996), *Combinatorial optimization: an integer programming perspective* [in:] ACM Computing Surveys (CSUR), 28(1), 55-58, doi: <http://dx.doi.org/10.1145/234313.234341>.
- Christofides, N., Elion, S. (1996), *An algorithm for the vehicle dispatching problem* [in:] Operational Research Quarterly, 20(3), 309-318, doi: <https://doi.org/10.1057/jors.1969.75>.

- Christou, I. (2012), *Quantitative Methods in Supply Chain Management-models and algorithms* [in:] Springer-Verlag, London, doi: <https://doi.org/10.1007/978-0-85729-766-2>.
- Codd, E. (1970), *A relational model of data for large shared data banks*, Communications of the ACM, 13(6), 377-387, 1970, doi: <http://dx.doi.org/10.1145/362384.362685>.
- De Jaegere, N., Defraeye, M., Van Nieuwenhuyse, I. (2014), *The vehicle routing problem: state of the art classification and review*, FEB Research Report KBI_1415, FEB Research Report KBI_1415, <https://doi.org/10.1016/j.cie.2015.12.007>.
- ECLiPSe (2016), *Home*, <http://eclipseclp.org/>, Accessed April 20 2016.
- Fourer, R., Gay, D., Kernighan, B. (2002), *AMPL: A Modeling Language for Mathematical Programming*, Duxbury Press, Brooks/Cole Publishing, Pacific Grove, CA.
- Glover, F., Kochenberger, G.A. (2003), *Handbook of Metaheuristics*. Boston: Kluwer Academic Publishers, xi–xii.
- Griffis, S.E., Bell, J.E., Closs, D.J. (2012), *Metaheuristics in Logistics and Supply Chain Management* [in:] Journal of Business Logistics, 33: 90-106, doi:10.1111/j.0000-0000.2012.01042.x.
- Gueret, C., Prins, C., Sevaux, M., Heipcke, S. (2002), *Applications of optimization with XPRESS-MP*, Dash Optimization Ltd, Blisworth House Blisworth.
- Harjunkoski, I., Grossmann, I. (2002), *Decomposition techniques for multistage scheduling problems using mixed-integer and constraint programming methods* [in:] Computers & Chemical Engineering, 26(11), 1533-1552, doi: [https://doi.org/10.1016/S0098-1354\(02\)00100-X](https://doi.org/10.1016/S0098-1354(02)00100-X).
- Harjunkoski, I., Jain, V., Grossmann, I. (2000), *Hybrid mixedinteger/constraint logic programming strategies for solving scheduling and combinatorial optimization problems* [in:] Computers & Chemical Engineering, 24(2-7): 337-343, doi: [https://doi.org/10.1016/S0098-1354\(00\)00470-1](https://doi.org/10.1016/S0098-1354(00)00470-1).
- Hooker, J. (2002), *Logic, optimization and constraint programming* [in:] INFORMS Journal on Computing, 14(4), 295-321, doi: 10.1287/ijoc.14.4.295.2828.
- Hooker, J., Osorio, M. (1999), *Mixed logical linear programming* [in:] Discrete Applied Mathematics, 96-97(1-3), 395-442, doi: [https://doi.org/10.1016/S0166-218X\(99\)00100-6](https://doi.org/10.1016/S0166-218X(99)00100-6).
- Hooker, J., Ottosson, G., Thorsteinsson, E. (2000), *A scheme for unifying optimization and constraint satisfaction methods* [in:] Knowledge Engineering Review, 15(1), 11-30, doi: <https://doi.org/10.1017/S0269888900001077>.
- Hoos, H., Stutzle, T. (2005), *Stochastic Local Search – Foundations and Applications*, Morgan Kaufmann Publishers.
- Huang, G., Lau, J., Mak, K. (2003), *The impacts of sharing production information on supply chain dynamics: a review of the literature* [in:] International Journal of Production Research, 41(7), 1483-1517, doi: <http://dx.doi.org/10.1080/0020754031000069625>.
- IBM ILOG CPLEX (2016), <https://www.ibm.com/us-en/marketplace/ibm-ilog-cplex>, Accessed April 20 2016.
- Jain, V., Grossmann, I. (1999), *Algorithms for hybrid MILP/CLP models for a class of optimization problems* [in:] Technical report, Carnegie Mellon University, Department of Chemical Engineering, Pittsburg, PA, USA, doi: <https://doi.org/10.1287/ijoc.13.4.258.9733>.

- Jairo, R., Montoya, T., Francob, J.L, Isazac, S.N., Jiménezd, H.F., Herazo-Padillae, N. (2015), *A literature review on the vehicle routing problem with multiple depots* [in:] Computers & Industrial Engineering, 79, January 2015, 115-129.
- Jung, H., Jeong, B., Lee, C. (2008), *An order quantity negotiation model for distributor-driven supply chains* [in:] International Journal of Production Economics 111(1), 147-158, doi: <https://doi.org/10.1016/j.ijpe.2006.12.054>.
- Kanyalkar, A., Adil, G. (2005), *An integrated aggregate and detailed planning in a multi-site production environment using linear programming* [in:] International Journal of Production Research, 43(20), 4431–4454, doi: <http://dx.doi.org10.1080/00207540500142332>.
- Kiziltan, Z., Lodi, A., Milano, M., Parisini, F. (2007), *CP-based local branching* [in:] C. Bessiere (Ed.), Principles and Practice of Constraint Programming – CP 2007, 4741 of Lecture Notes in Computer Science, Springer-Verlag, Berlin Heidelberg, Germany, 847-855.
- Kumar, S.N., Panneerselvam, R. (2012), *A Survey on the Vehicle Routing Problem and Its Variants* [in:] Intelligent Information Management, 4, 66-74, doi: 10.4236/iim.2012.43010.
- Lindo (2016), <http://www.lindo.com/>, Accessed April 20 2016.
- Lozano, M., Garcia-Martinez, C. (2010), *Hybrid metaheuristics with evolutionary algorithms specializing in intensification and diversification: overview and progress report* [in:] Computers and Operations Research 37(3), 481-497.
- Mahajan, A. (2011), *Presolving Mixed–Integer Linear Programs*. Wiley Encyclopedia of Operations Research and Management Science, doi: 10.1002/9780470400531.eorms0437.
- Maximal Software – Optimization Modeling (2016), <http://www.maximalsoftware.com/>, Accessed April 20 2016.
- Min, H., Zhou, G. (2002), *Supply chain modeling: past, present and future* [in:] Computers and Industrial Engineering, 43(1-2), 231-249, doi: [https://doi.org/10.1016/S0360-8352\(02\)00066-9](https://doi.org/10.1016/S0360-8352(02)00066-9).
- Mula J., Peidro D., Diaz-Madronero M., Vicens E. (2010), *Mathematical programming models for supply chain production and transport planning* [in:] European Journal of Operational Research, 204(3), 377-390, doi: <https://doi.org/10.1016/j.ejor.2009.09.008>.
- ORO Group Web-page (2016), <http://www.orgroup.polito.it/>, Accessed April 20 2016.
- Ottosson, G., Thorsteinsson, E., Hooker, J. (2002), *Mixed global constraints and inference in hybrid CLP–IP solvers* [in:] Annals of Mathematics and Artificial Intelligence, 34(4), 271–290, doi: <https://doi.org/10.1023/A:1014440424150>.
- Panos, M., Pardalos, D., Graham, R. (2013), *Handbook of Combinatorial Optimization*, Springer-Verlag, New York, ISBN: 978-1-4419-7996-4.
- Park, Y. (2005), *An integrated approach for production and distribution planning in supply chain management* [in:] International Journal of Production Research, 43(6), 1205-1224, doi: <http://dx.doi.org/10.1080/00207540412331327718>.
- Perboli, G., Tadei, R., Vigo, D. (2012), *The Two-Echelon Capacitated Vehicle Routing Problem: Models and Math-Based Heuristics* [in:] Transportation Science, 45(3), 364-380, doi: <https://doi.org/10.1287/trsc.1110.0368>.

- Perea-Lopez, E., Ydstie, B.E., Grossmann, I.E. (2003), *A model predictive control strategy for supply chain optimization* [in:] Computers and Chemical Engineering, 27(8-9), 1201-1218, doi: [https://doi.org/10.1016/S0098-1354\(03\)00047-4](https://doi.org/10.1016/S0098-1354(03)00047-4).
- Rizk, N., Martel, A., D'amours, S. (2006), *Multi-item dynamic production-distribution planning in process industries with divergent finishing stages* [in:] Computers and Operations Research, 33(12), 3600-3623, doi: <https://doi.org/10.1016/j.cor.2005.02.047>.
- Rodosek, R., Wallace, M., Hajian, M. (1999), *A new approach to integrating mixed integer programming and constraint logic programming* [in:] Annals of Operations Research, 86(0), 63-87, doi: <https://doi.org/10.1023/A:1018904229454>.
- Rossi, F., Van Beek, P., Walsh, T. (2006), *Handbook of Constraint Programming (Foundations of Artificial Intelligence)* [in:] Elsevier Science Inc., New York.
- Salhi, S., Wassan, N., Hajarat, M. (2013), *The Fleet Size and Mix Vehicle Routing Problem with Backhauls: Formulation and Set Partitioning-based Heuristics* [in:] Transportation Research Part E: Logistics and Transportation Review, 56, 22-35, doi: <https://doi.org/10.1016/j.tre.2013.05.005>.
- Schrijver, A. (1998), *Theory of Linear and Integer Programming*, John Wiley & Sons, New York.
- SCIP (2016), <http://scip.zib.de/>, Accessed April 20 2016.
- Shapiro, J.F. (2001), *Modeling the Supply Chain*. Pacific Grove, CA: Thomson Learning Inc.
- Shaw, P. (1998), *Using constraint programming and local search methods to solve vehicle routing problems* [in:] M. Maher, J.-F. Puget (Eds.), Principle and Practice of Constraint Programming – CP98, 1520 of Lecture Notes in Computer Science, Springer-Verlag, Berlin, Germany, 417-431.
- Sitek P. (2015), *A Concept of Decision Support in Supply Chain Management – A Hybrid Approach* [in:] Architectures and Structures. BDAS 2015, Communications in Computer and Information Science, Springer, Cham, 521, 565-574, doi: https://doi.org/10.1007/978-3-319-18422-7_50.
- Sitek, P., Wikarek, J. (2015A), *A hybrid approach to the optimization of multiechelon systems* [in:] Mathematical Problems in Engineering volume 2015, Article ID 925675, 12 pages, doi: <http://dx.doi.org/10.1155/2014/925675>.
- Sitek, P., Wikarek, J. (2015B), *A hybrid framework for the modelling and optimisation of decision problems in sustainable supply chain management* [in:] International Journal of Production Research, 53(21) 6611-6628, doi: <http://dx.doi.org/10.1080/00207543.2015.1005762>.
- Sitek, P., Bzdyra K., Wikarek, J. (2016), *A Hybrid Method for Modeling and Solving Supply Chain Optimization Problems with Soft and Logical Constraints* [in:] Mathematical Problems in Engineering, volume 2016, Article ID 1532420, 16 pages, doi: <http://dx.doi.org/10.1155/2016/1532420>.
- Sitek, P., Wikarek, J. (2016A), *A Hybrid Programming Framework for Modeling and Solving Constraint Satisfaction and Optimization Problems* [in:] Scientific Programming, volume 2016(2016), Article ID 5102616, 13 pages, doi: <http://dx.doi.org/10.1155/2016/5102616>.

- Sitek, P., Wikarek, J. (2016B), *A Constraint-Based Approach to Modeling and Solving Resource-Constrained Scheduling Problems* [in:] Conference: 8th International Conference on Computational Collective Intelligence (ICCCI), Book Series: Lecture Notes in Artificial Intelligence, Volume: 9875, Pages: 423-433.
- Sniedovich, M., Vos, S. (2006), *The corridor method: a dynamic programming inspired metaheuristic* [in:] Control and Cybernetics 35(3), 551-578.
- Smith, B. (1995), *A tutorial on constraint programming*, Technical Report 95.14, University of Leeds, Division of Artificial Intelligence, Leeds, UK. School of Computer Studies, Research Report Series.
- Solnon, C. (2010), *Ant Colony Optimization and Constraint Programming*, Wiley-ISTE.
- Stutzle, T. (2006), *Iterated local search for the quadratic assignment problem* [in:] European Journal of Operational Research 174(3), 1519-1539.
- Thorsteinsson, E. (2001), *Hybrid Approaches to Combinatorial Optimisation*, PhD thesis, Carnegie Mellon University, Graduate School of Industrial Administration, Pittsburgh, Pennsylvania, USA.
- Timpe, C., Kallrath, J. (2000), *Optimal planning in large multi-site production networks* [in:] European Journal of Operational Research, 126(2), 422-435, doi: [https://doi.org/10.1016/S0377-2217\(99\)00301-X](https://doi.org/10.1016/S0377-2217(99)00301-X).
- Wallace, M., Novello, S., Schimpf, J. (1997), *ECLiPSe: A platform for constraint logic programming*, Technical report, IC-Parc, Imperial College, London, UK.
- Walukiewicz, S. (1991), *Integer Programming* [in:] Mathematics and its Applications, 46, Springer Netherlands, doi:10.1007/978-94-015-7945-2.
- Wanga, Y., Wallaceb, S.W., Shen, B., Choid, T. (2015), *Service supply chain management: A review of operational models* [in:] European Journal of Operational Research, 247, 685-698.
- Wassan, N., Wassan, N., Nagy, G., Salhi, S. (2016), *The Multiple Trip Vehicle Routing Problem with Backhauls: Formulation and a Two-Level Variable Neighbourhood Search* [in:] Computers & Operations Research, 78, 454-467, doi: <https://doi.org/10.1016/j.cor.2015.12.017>.
- Wilbaut, C., Hanafi, S. (2009), *New convergent heuristics for 0-1 mixed integer programming* [in:] European Journal of Operational Research 195(1), 62-74.
- Williams, H., Wilson, J. (1998), *Connections between integer linear programming and constraint logic programming – an overview and introduction to the cluster of articles* [in:] INFORMS Journal on Computing, 10(3), 261-264, doi: <https://doi.org/10.1287/ijoc.10.3.261>.
- Wolsey, L. (1998), *Integer Programming*, John Wiley & Sons, Inc., New York, USA.
- Yeun, L., Wan, R., Khairuddin, O., Mourad, Z. (2008), *Vehicle Routing Problem: Models And Solutions* [in:] Journal Of Quality Measurement And Analysis, 4(1), 205-218.