A review of the CARP and it variants using (simple) network analysis

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WARP3 - 2019 - Pizzo, Italy

https://github.com/ejwillemse/WARP3

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Faculty of Engineering, Built Environment and Information Technology
Fakulteit Ingenieurswese, Bou-omgewing en Inligtingtegnologie / Lefapha la Boetšenere, Tikologo ya Kago le Theknolotši ya Tshedimošo

1956 – 2016 60 years of Engineering Education

Outline

1. Our research focus (starting 2008)
2. General metrics of CARP publications.
3. Solution approaches and benchmark instances
4. Some ideas on future research opportunities

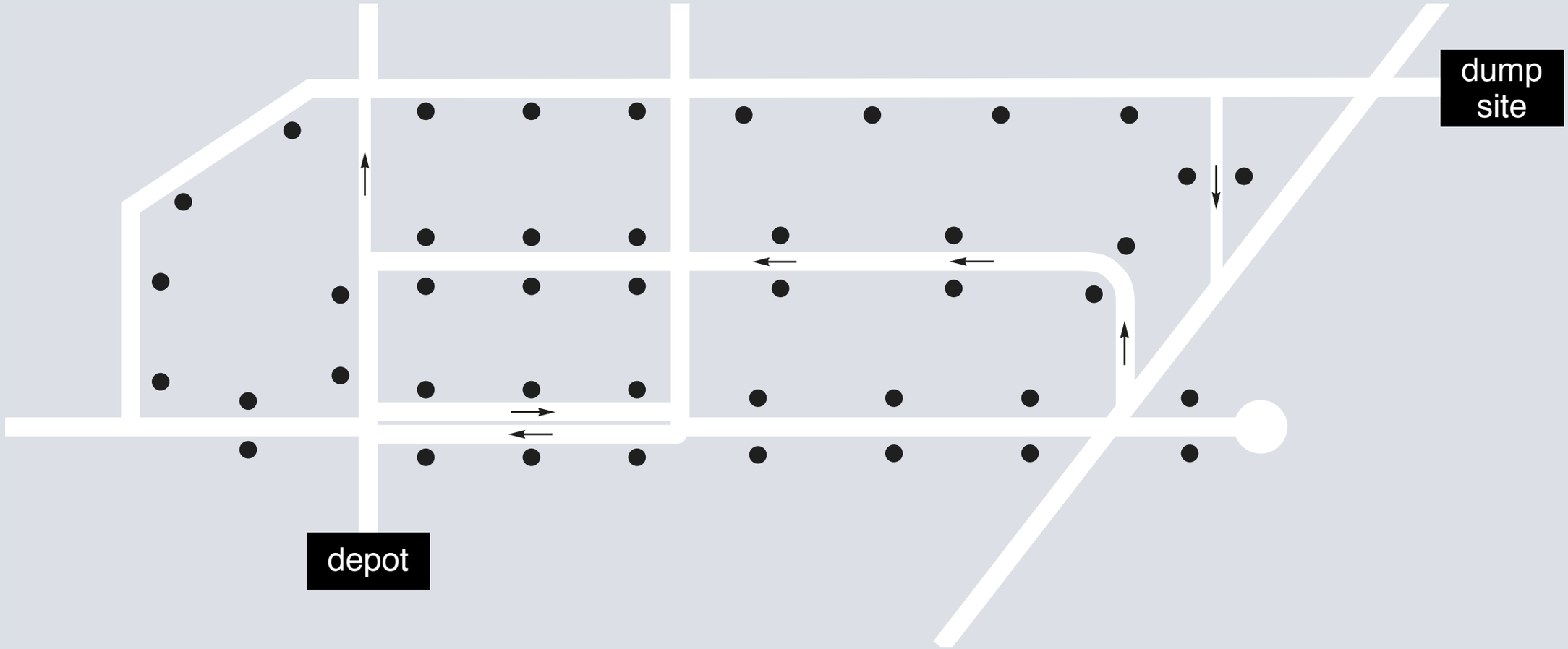

MATSim
Multi-Agent Transport Simulation
senozon

"By the end of 2003, WM had **984 fewer routes, saving $18 million**. It estimated that its savings for 2004 due to the reduction will be $44 million."

Sahoo, S., Kim, S., Kim, B. I., Kraas, B., & Popov Jr, A. (2005). **Routing optimization for waste management**. *Interfaces*, 35(1), 24-36.

6’282 required arcs and edges

Waste collection routing optimisation



Mixed Network

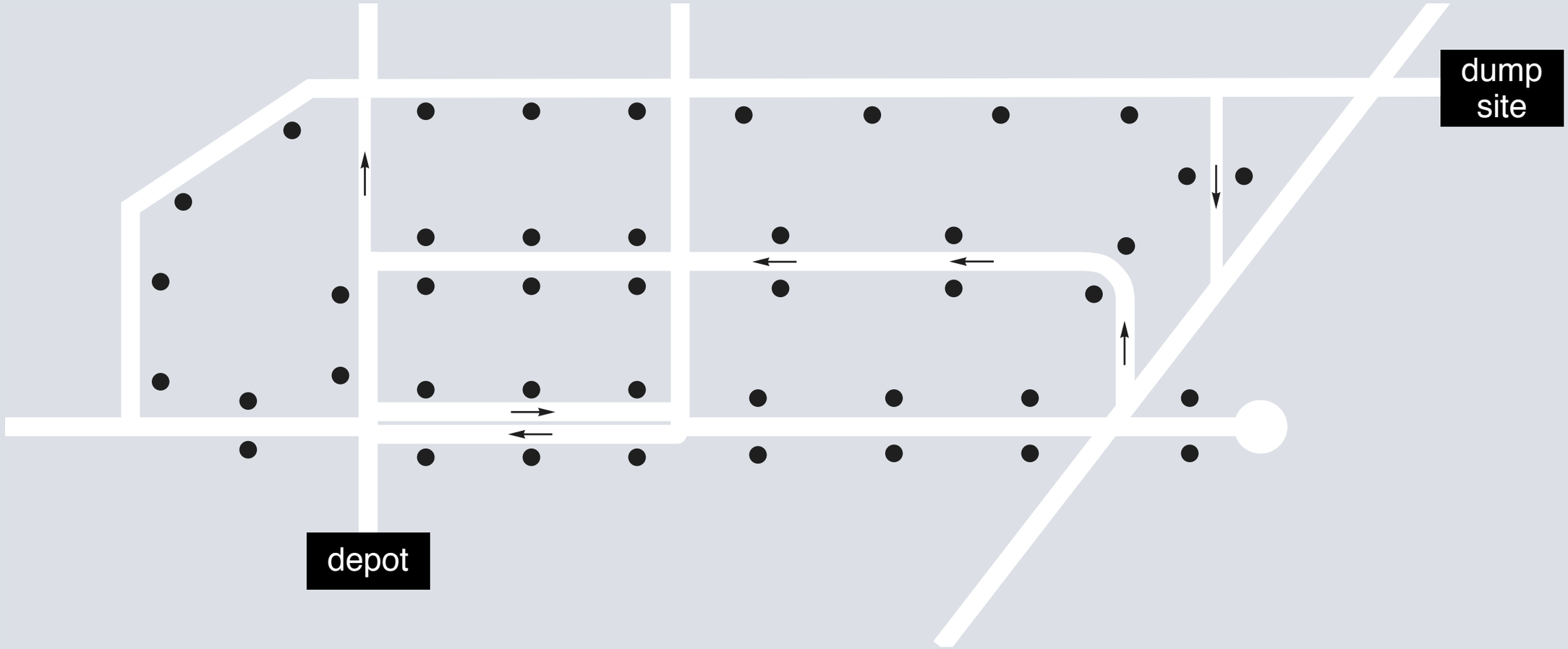
one- and two-way streets

Capacity

amount of waste a vehicle can carry in one go

Arc Routing

streets have to be serviced, instead of places



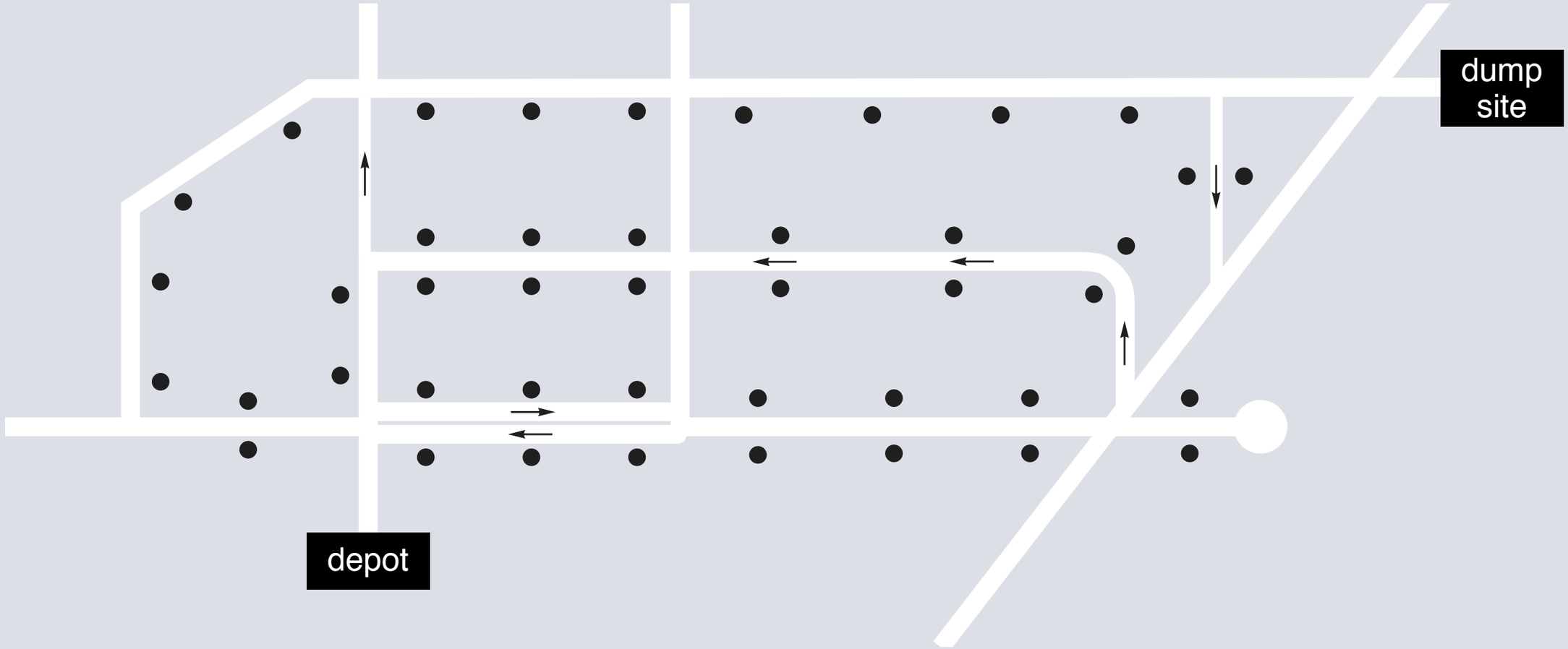
Time Restrictions

a vehicle crew works 8 hours

Intermediate Facilities

vehicle can visit a dumpsite, and offload its waste

The **M**ixed **C**apacitate **A**rc **R**outing **P**roblem under **T**ime restrictions with **I**ntermediate **F**acilities (MCARPTIF)



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Lower and upper bounds for the mixed capacitated arc routing problem

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[b]*LIMOS, Université Blaise Pascal, BP 10125, 63173 Aubière Cedex, France*
[c]*ISTIT, Université de Technologie de Troyes, BP 2060, 10010 Troyes Cedex, France*

Available online 30 March 2005

Abstract

This paper presents a linear formulation, valid inequalities, and a lower bounding procedure for the mixed capacitated arc routing problem (MCARP). Moreover, three constructive heuristics and a memetic algorithm are described. Lower and upper bounds have been compared on two sets of randomly generated instances. Computational results show that the average gaps between lower and upper bounds are 0.51% and 0.33%, respectively.

Keywords: Capacitated arc routing problem; Mixed graph; Lower bound; Cutting plane; Heuristic; Memetic algorithm; Waste collection

1. Introduction and background

The *capacitated arc routing problem* (*CARP*), introduced by Golden and Wong [1], considers an undirected network in which each edge has a traversal cost. A fleet of identical vehicles of limited capacity is based at a depot node. A subset of required edges with known demands must be serviced by a vehicle. The CARP consists of determining a set of vehicle trips of minimum total cost, such that each trip starts and ends at the depot, each required edge is serviced by one single trip and during one traversal,

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doi:10.1016/j.cor.2005.02.009

Journal of Mathematical Modelling and Algorithms **3:** 209–223, 2004.

Tabu Search Heuristics for the Arc Routing Problem with Intermediate Facilities under Capacity and Length Restrictions

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[1]*Dipartimento di Ingegneria dell'Innovazione, Università di Lecce, Strada per Arnesano, 73100 Lecce, Italy*
[2]*Dipartimento di Elettronica, Informatica e Sistemistica, Università della Calabria, 87036 Rende (CS), Italy*
[3]*Canada Research Chair in Distribution Management, HEC Montréal, 3000, Chemin de la Côte-Sainte-Catherine, Montréal, Canada H3T 2A7*

Abstract. This paper deals with the *Arc Routing Problem with Intermediate Facilities under Capacity and Length Restrictions* (CLARPIF), a variant of the classical *Capacitated Arc Routing Problem* (CARP), in which vehicles may unload or replenish at intermediate facilities and the length of any route may not exceed a specified upper bound. Three heuristics are developed for the CLARPIF: the first is a constructive procedure based on a partitioning approach while the second and the third are tailored Tabu Search procedures. Computational results on a set of benchmark instances with up to 50 vertices and 92 required edges are presented and analyzed.

Mathematics Subject Classifications (2000): 90B60, 9B10, 68T20.

Key words: capacitated arc routing problem, intermediate facilities, capacity and distance restrictions.

1. Introduction

The aim of this paper is to describe three heuristics for the *Arc Routing Problem with Intermediate Facilities under Capacity and Length Restrictions* (CLARPIF), a variant of the classical *Capacitated Arc Routing Problem* (CARP) [15]. Both these problems, in their undirected versions, are defined on a graph $G = (V, E)$ where $V = \{v_1, \ldots, v_n\}$ is a vertex set and E is a set of edges (v_i, v_j) $(i < j)$, including a subset R of *required* edges. Each edge of R must be serviced once but can be traversed several times. Let V_R be the set of vertices v_i such that an edge (v_i, v_j) exists in R. With each edge $e = (v_i, v_j)$ are associated a non-negative traversal *cost* or *length* $c_e = c_{ij}$ and a non-negative *demand* $q_e = q_{ij}$. If $e \notin R$, then $q_e = 0$. Denote by d_{ij} the length of a shortest chain between two vertices v_i and v_j. Vertex v_1 denotes a *depot* at which a fleet of identical *vehicles* is based. In our version of the problem, vehicles bear no fixed costs and their number is a decision variable.

The solution techniques

1

Constructive heuristics

Willemse, E. J., & Joubert, J. W. (2016). **Constructive heuristics for the mixed capacity arc routing problem under time restrictions with intermediate facilities.** *Computers & Operations Research*, 68, 30-62.

2

Local Search

Willemse, E. J., & Joubert, J. W. (2019). **Efficient local search strategies for the Mixed Capacitated Arc Routing Problems under Time Restrictions with Intermediate Facilities.** *Computers & Operations Research*, 105, 203-225.

3

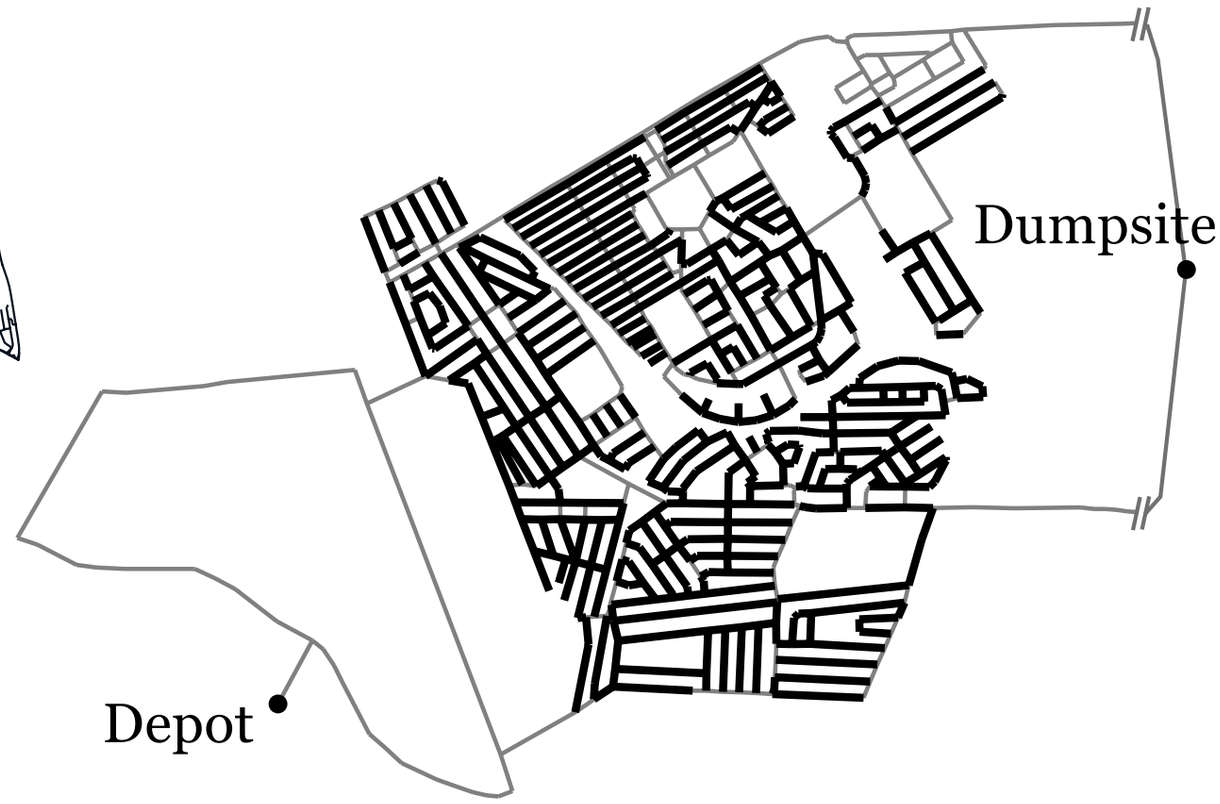
Very simple tabu-search

Willemse, E. J. (2016). **Heuristics for large-scale Capacitated Arc Routing Problems on mixed networks** (Doctoral dissertation, University of Pretoria).

New benchmark sets

Cen

Act-IF



Willemse, E. J., & Joubert, J. W. (2016). **Benchmark dataset for undirected and mixed capacitated arc routing problems under time restrictions with intermediate facilities**. *Data in brief*, *8*, 972-977.

Outline

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WEB OF SCIENCE

SEARCH: ‘**arc routing**’ | ‘**general routing problem**’ | ‘**postman problem**’ | ‘**postmen problem**’ in period 2010 - 2017

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RESULTS: **321**

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REFERENCED: **210**

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WoS INDEXED: **175**

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RESULTS: **321**

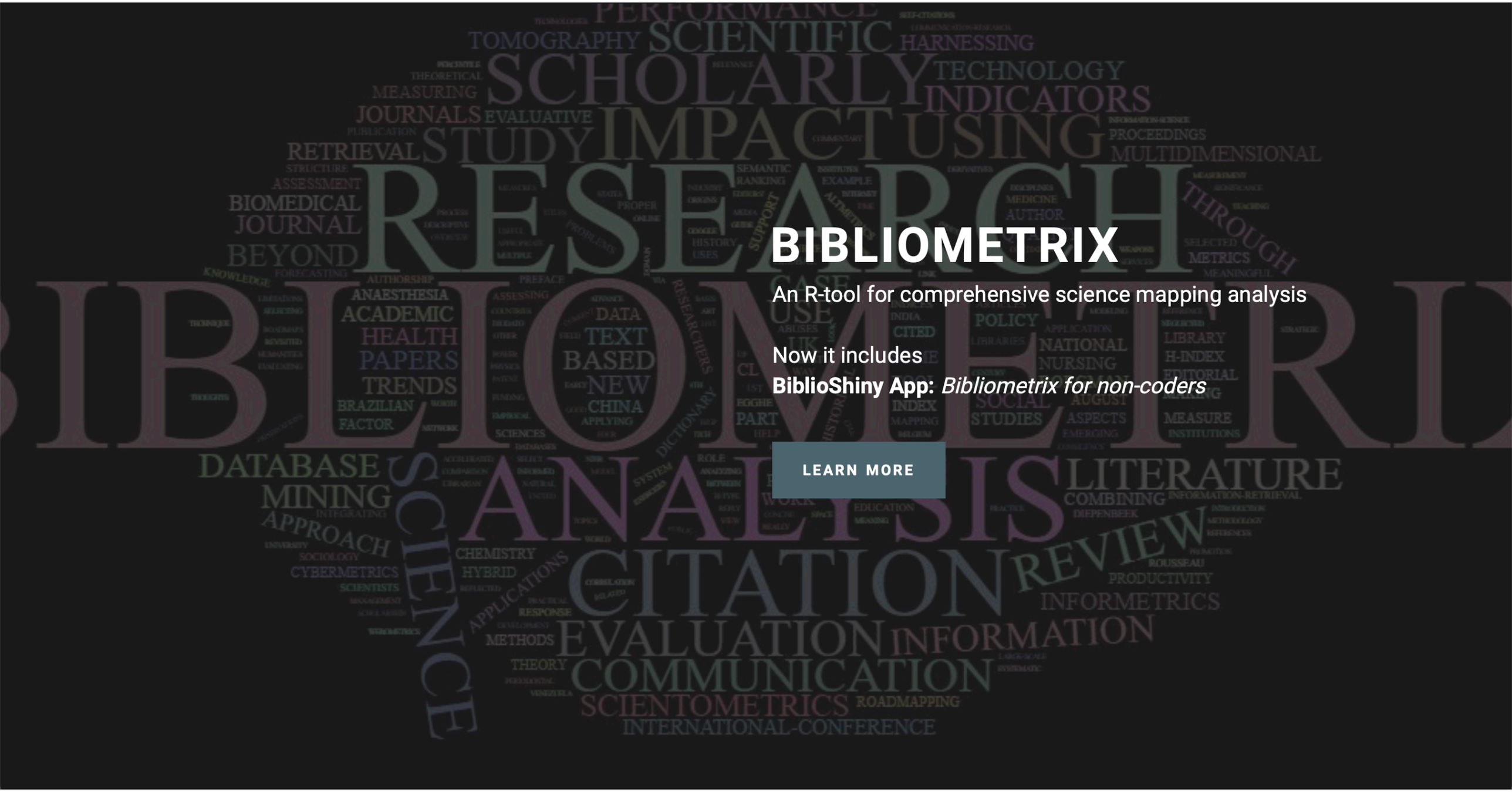
REFERENCED: **210**

WoS INDEXED: **175**

ARTICLES IN BOTH: **153**

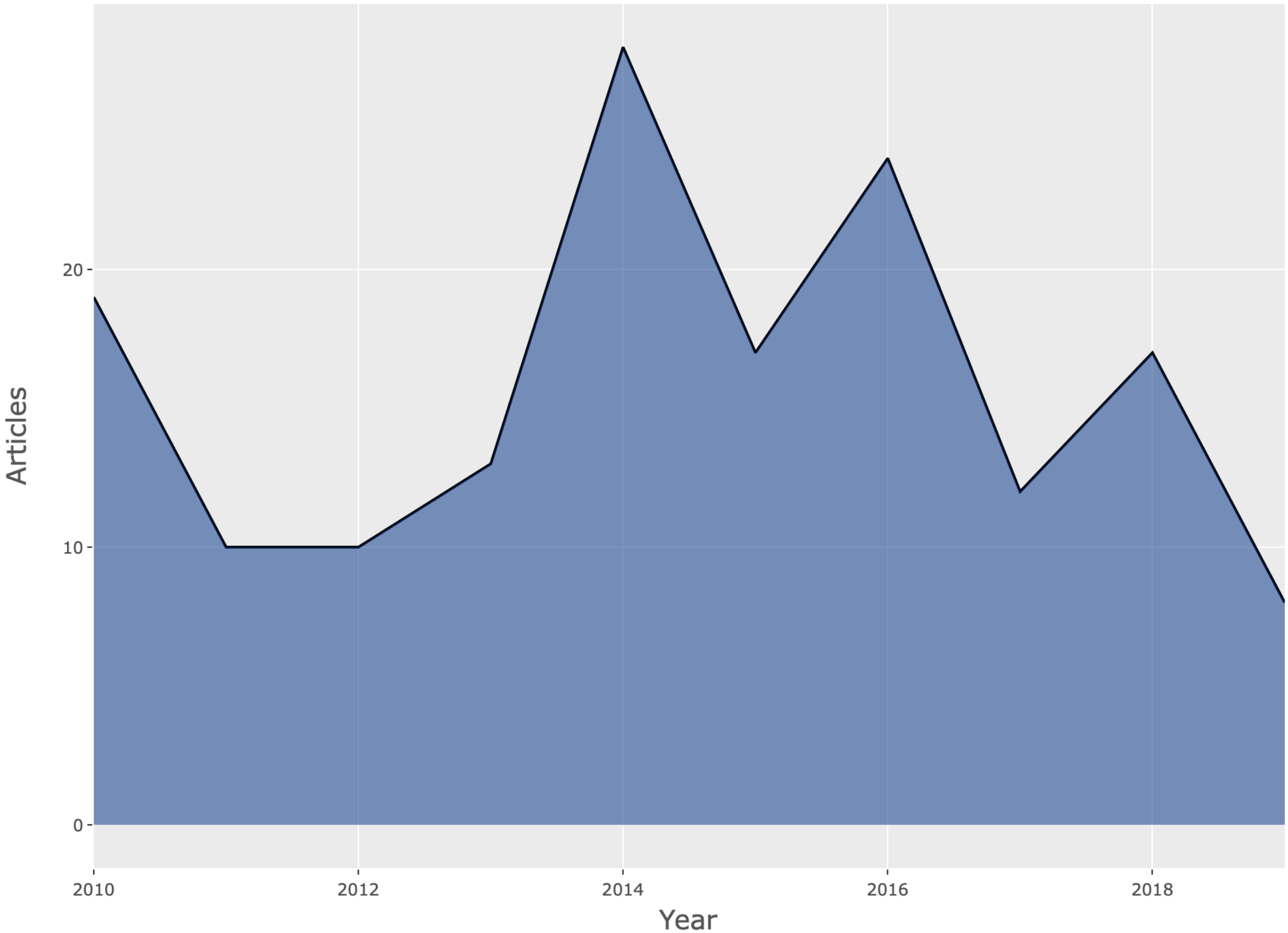
SEARCH: ‘**capacitated arc routing**’ | ‘**general routing problem**’ in period 2010 - 2019

Aria, M., & Cuccurullo, C. (2017). **bibliometrix: An R-tool for comprehensive science mapping analysis.** *Journal of Informetrics* , 11(4), 959-975

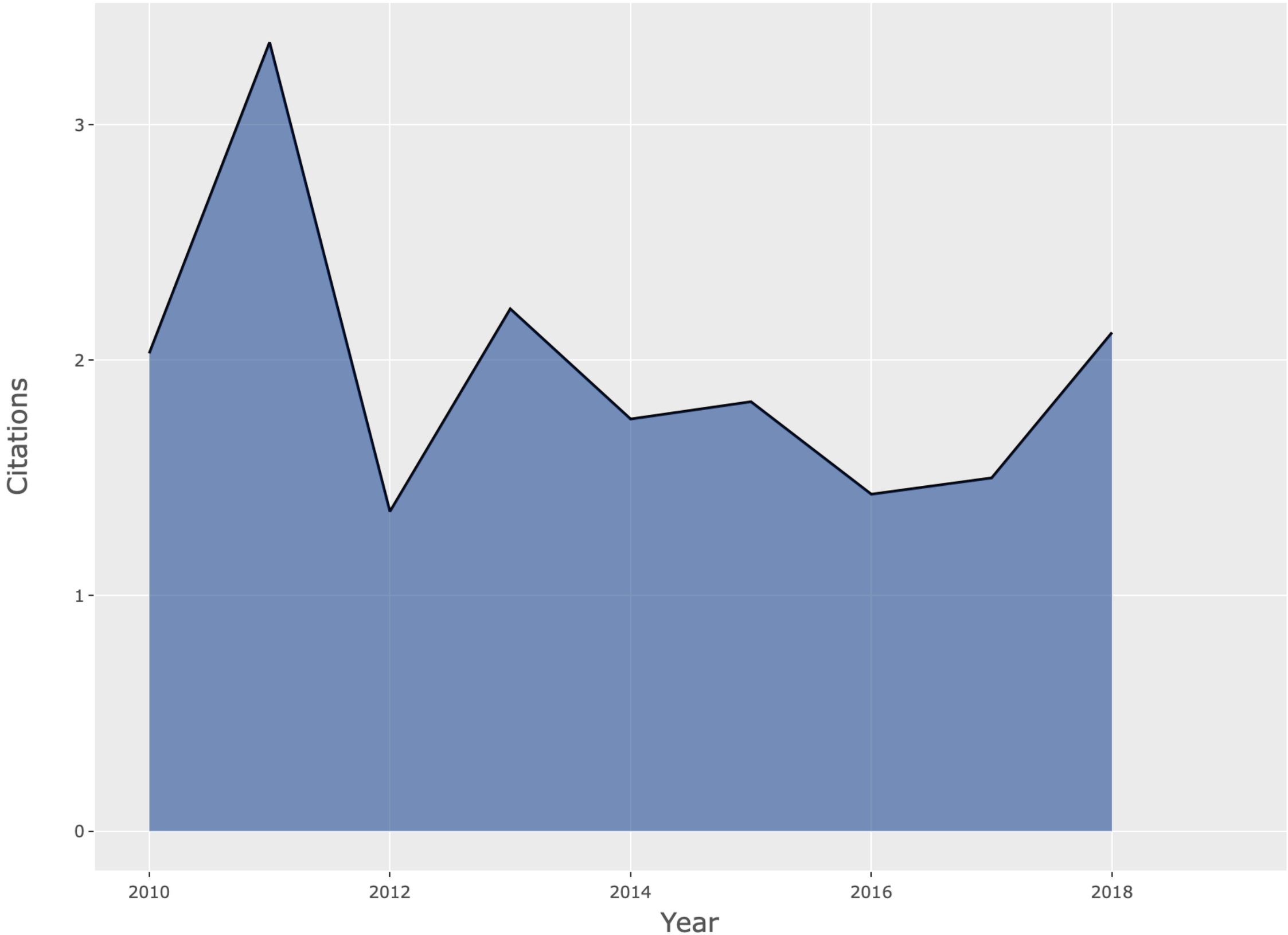


http://www.bibliometrix.org

Annual Scientific Production

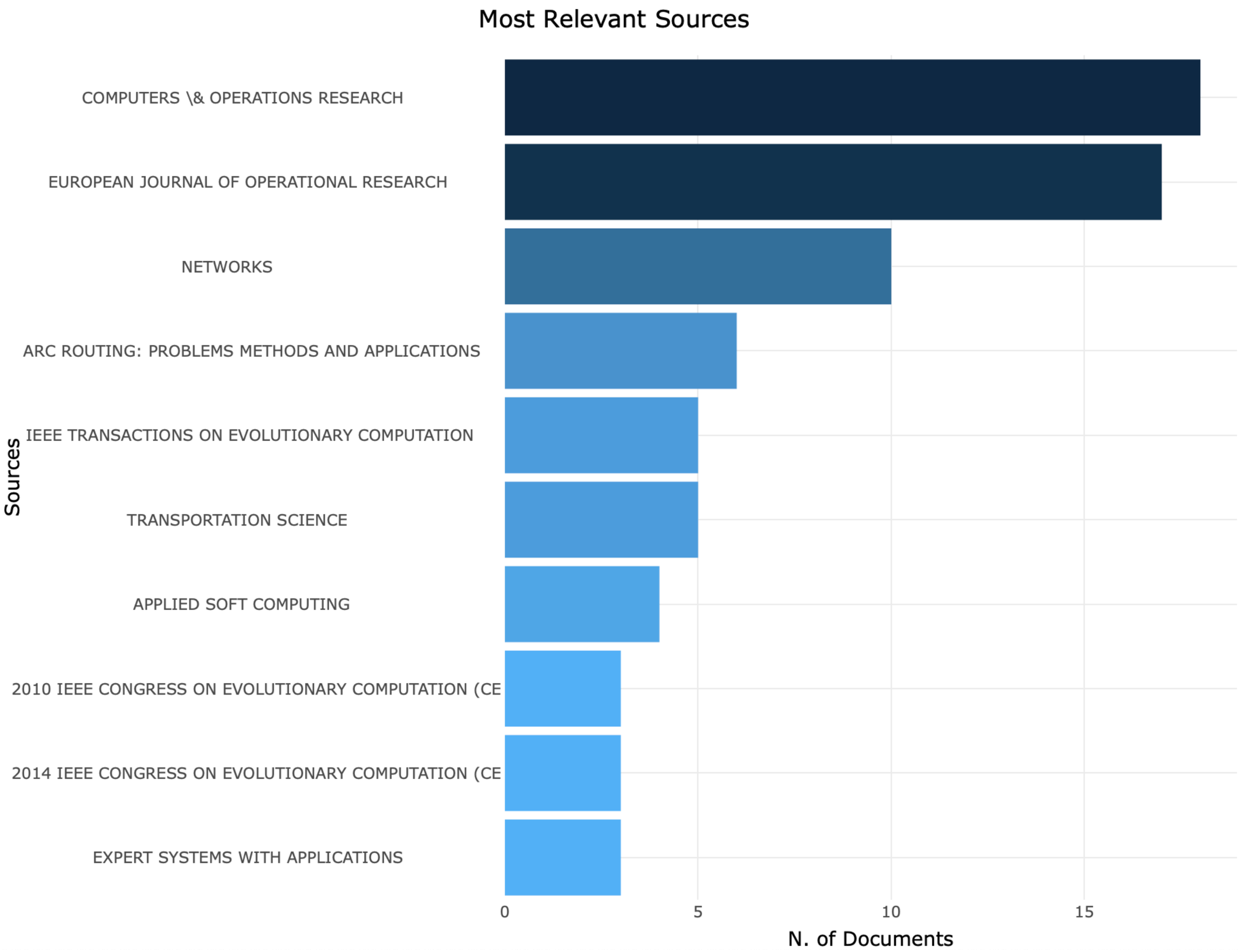


Average Article Citations per Year



Most Relevant Sources

Which Journal has the most CARP publications?


Most Relevant Sources
COMPUTERS \& OPERATIONS RESEARCH
EUROPEAN JOURNAL OF OPERATIONAL RESEARCH
NETWORKS
ARC ROUTING: PROBLEMS METHODS AND APPLICATIONS
IEEE TRANSACTIONS ON EVOLUTIONARY COMPUTATION
TRANSPORTATION SCIENCE
APPLIED SOFT COMPUTING
2010 IEEE CONGRESS ON EVOLUTIONARY COMPUTATION (CE
2014 IEEE CONGRESS ON EVOLUTIONARY COMPUTATION (CE
EXPERT SYSTEMS WITH APPLICATIONS
Sources
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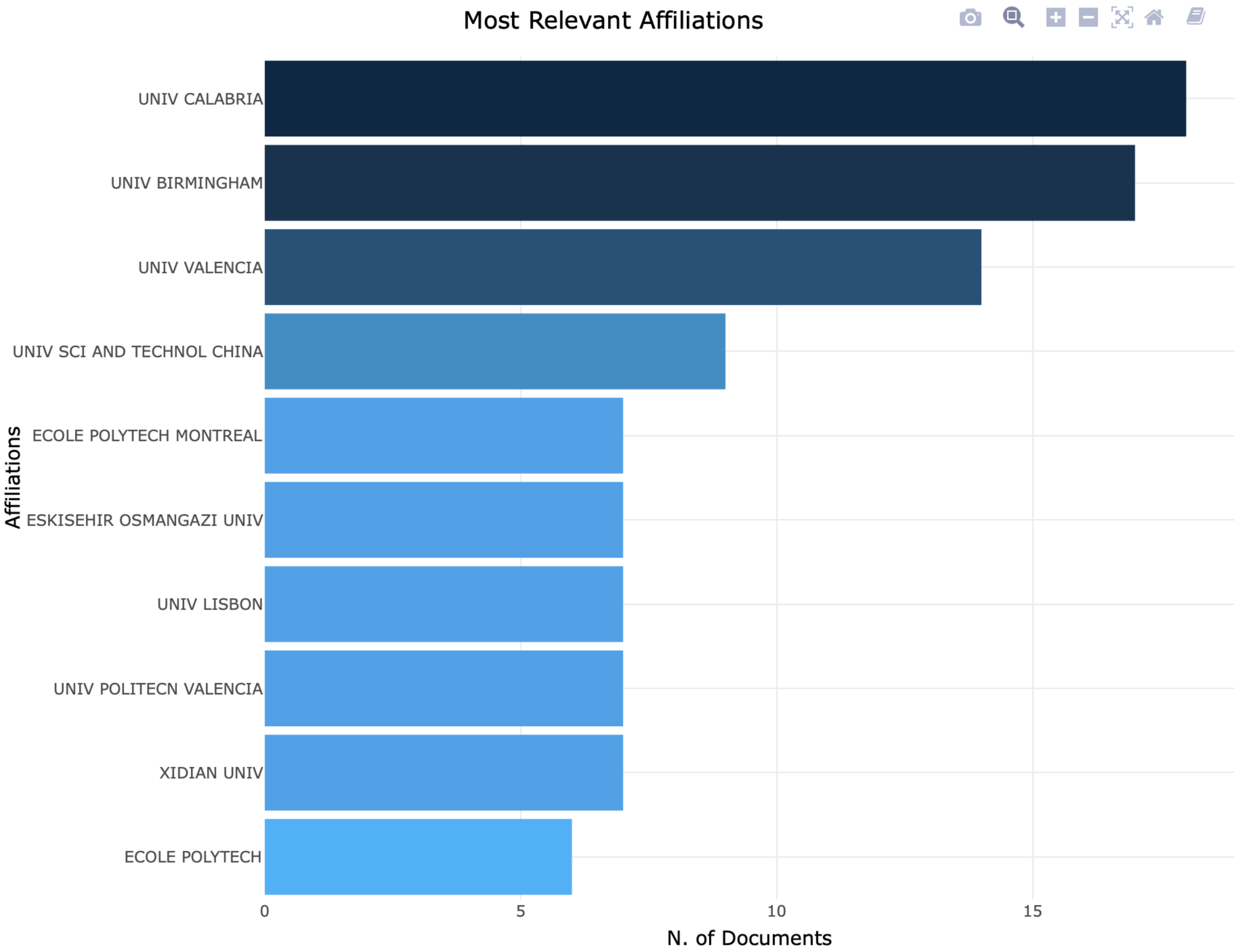
5
10
15
N. of Documents

Most Relevant Affiliations

Which University has the most CARP publications?


Most Relevant Affiliations
UNIV CALABRIA
UNIV BIRMINGHAM
UNIV VALENCIA
UNIV SCI AND TECHNOL CHINA
ECOLE POLYTECH MONTREAL
ESKISEHIR OSMANGAZI UNIV
UNIV LISBON
UNIV POLITECN VALENCIA
XIDIAN UNIV
ECOLE POLYTECH
Affiliations
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5
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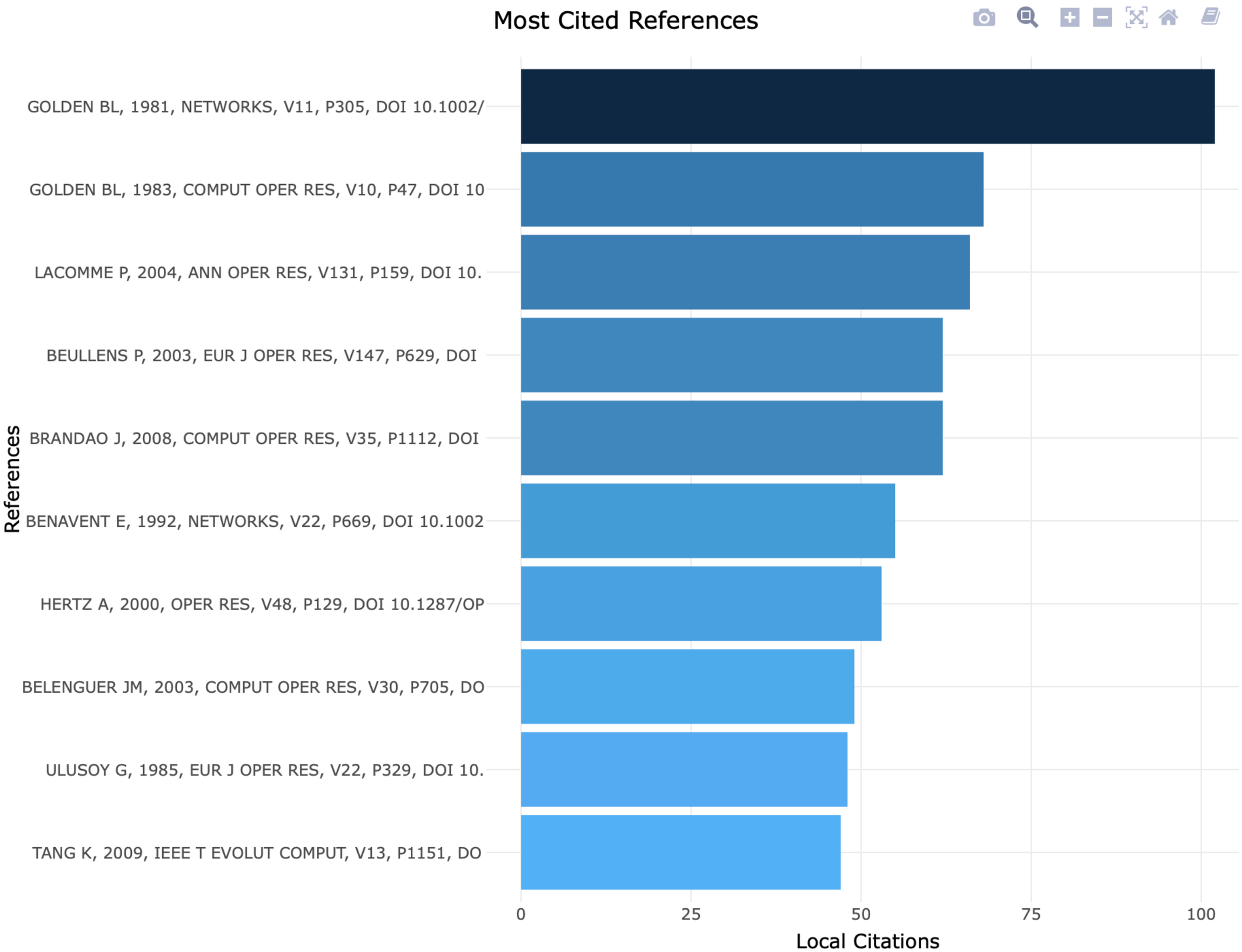
15
N. of Documents

Most cited CARP publications (pre 2019)?


Most Cited References
GOLDEN BL, 1981, NETWORKS, V11, P305, DOI 10.1002/
GOLDEN BL, 1983, COMPUT OPER RES, V10, P47, DOI 10
LACOMME P, 2004, ANN OPER RES, V131, P159, DOI 10.
BEULLENS P, 2003, EUR J OPER RES, V147, P629, DOI
BRANDAO J, 2008, COMPUT OPER RES, V35, P1112, DOI
BENAVENT E, 1992, NETWORKS, V22, P669, DOI 10.1002
HERTZ A, 2000, OPER RES, V48, P129, DOI 10.1287/OP
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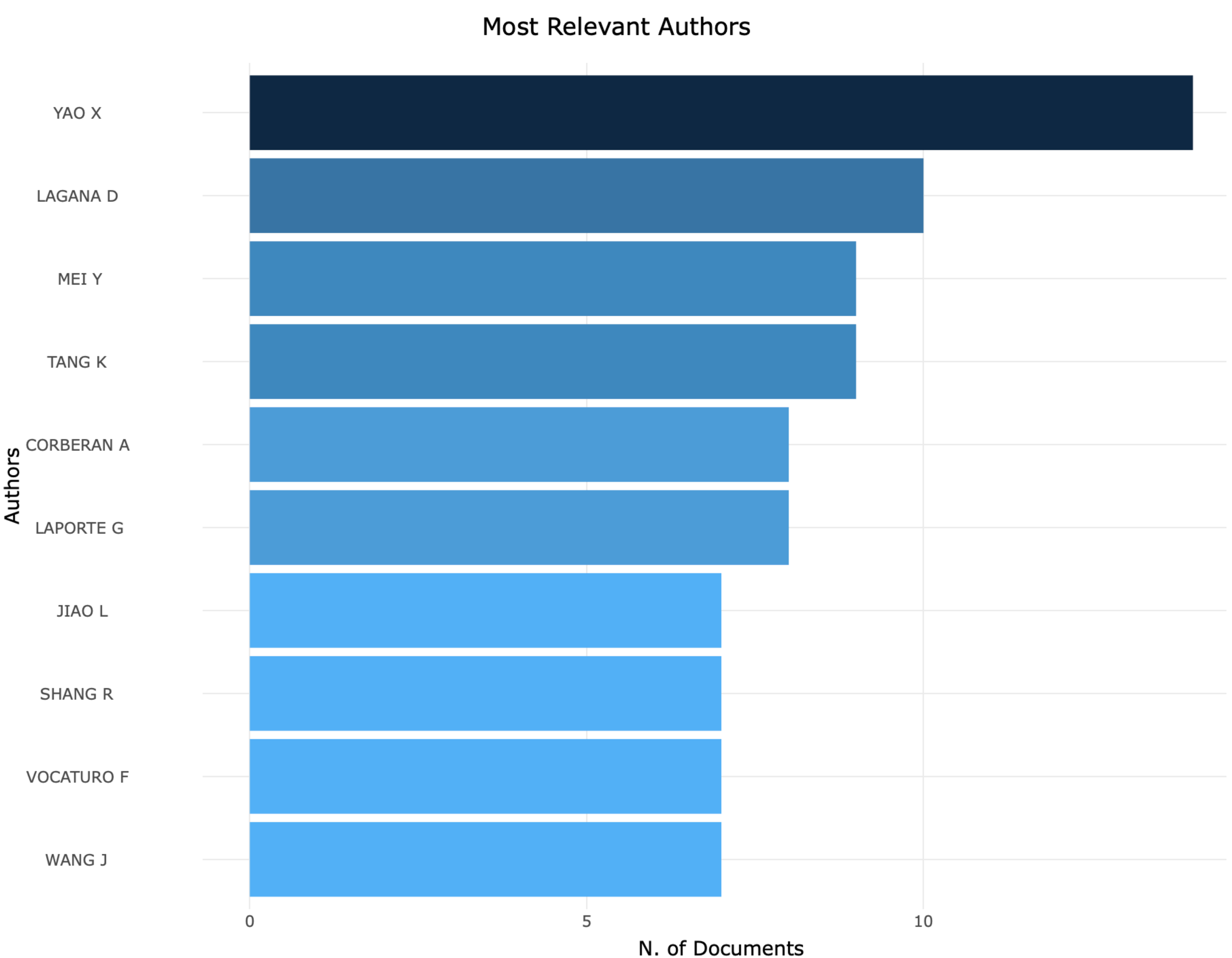
ULUSOY G, 1985, EUR J OPER RES, V22, P329, DOI 10.
TANG K, 2009, IEEE T EVOLUT COMPUT, V13, P1151, DO
References
0
25
50
75
100
Local Citations

Most Relevant Authors

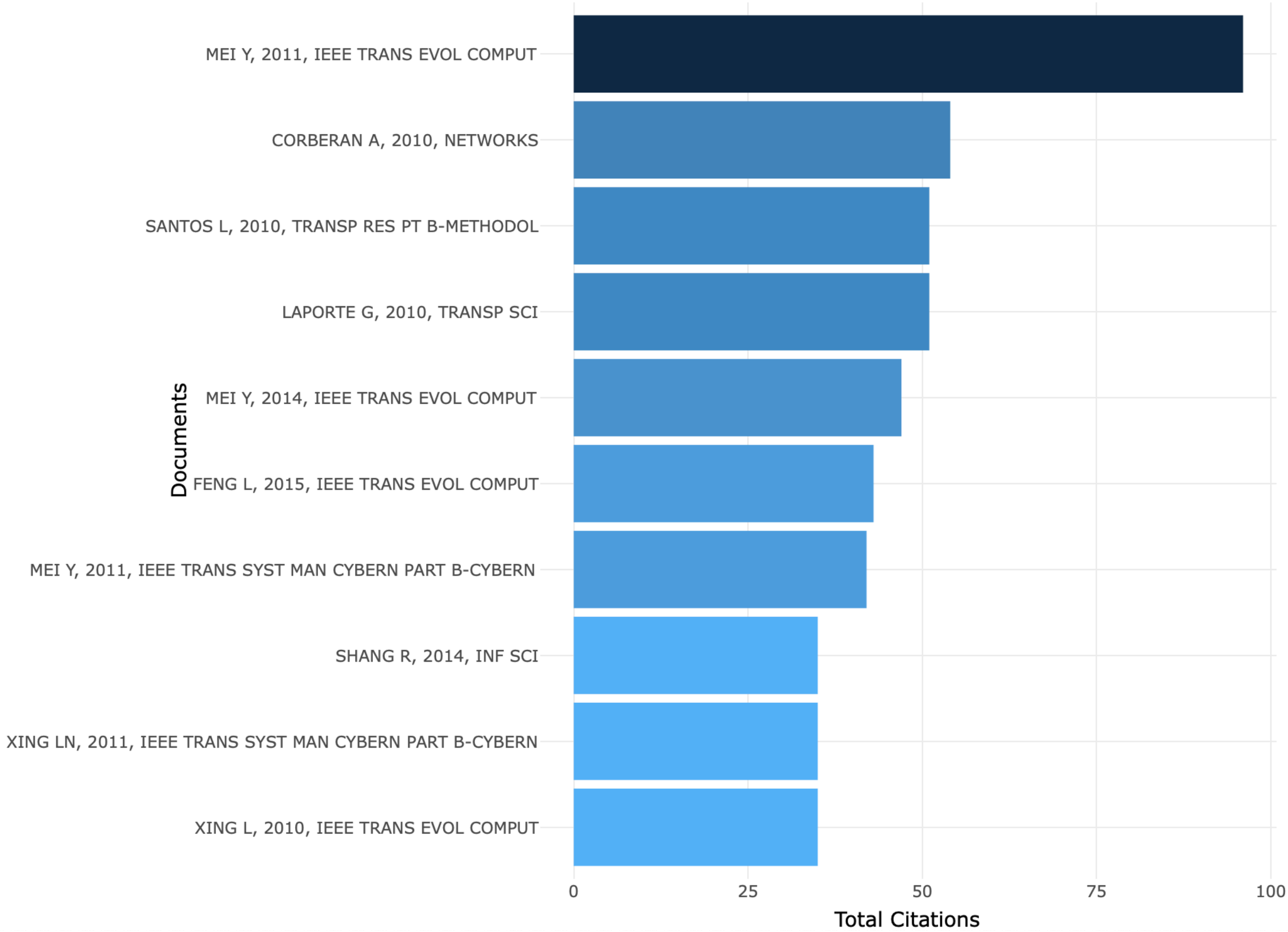
Most productive CARP authors (2010-2019)?


Most Relevant Authors
YAO X
LAGANA D
MEI Y
TANG K
CORBERAN A
LAPORTE G
JIAO L
SHANG R
VOCATURO F
WANG J
Authors
0
5
10
N. of Documents

Most Cited Documents

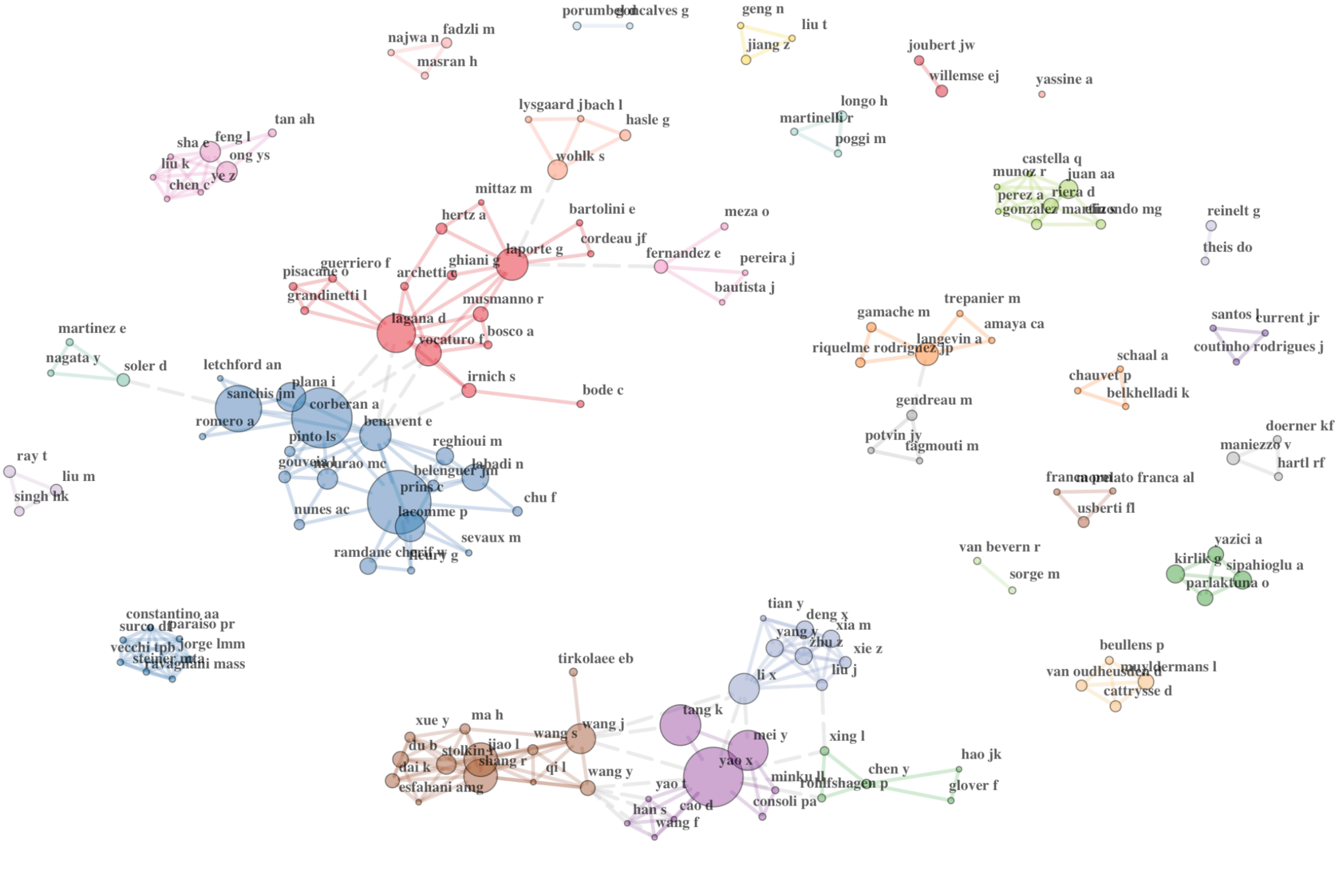
Most cited CARP document (2010-2019)?

Most Cited Documents

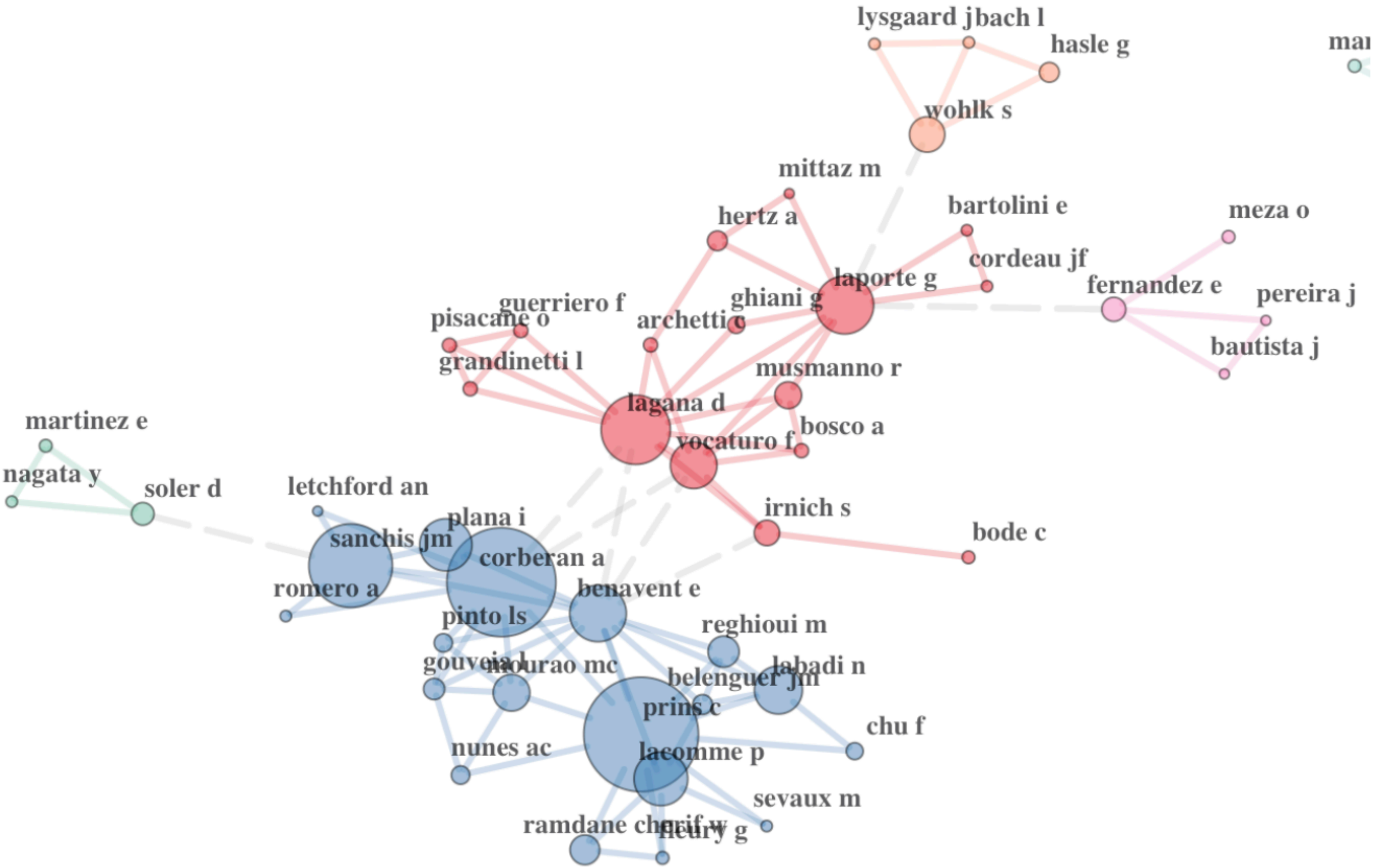


Co-author network

Co-author network



Co-author network



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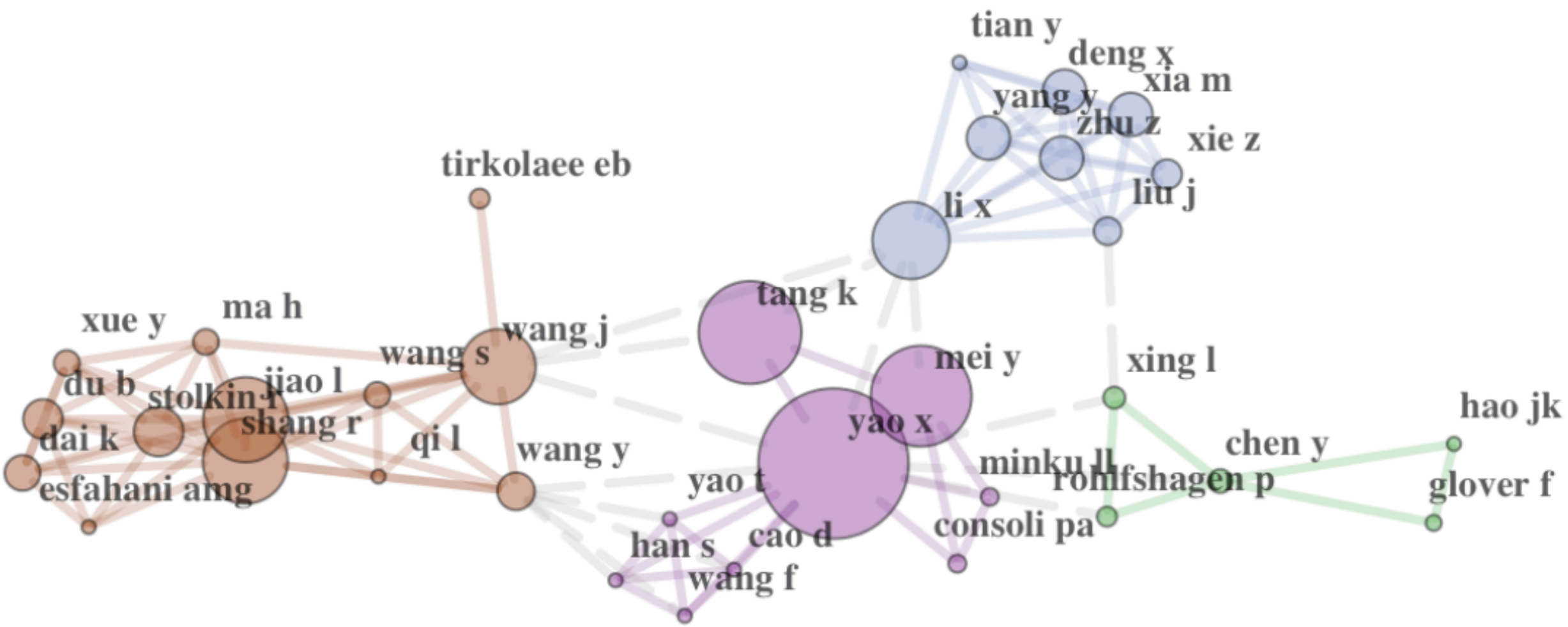


Authors

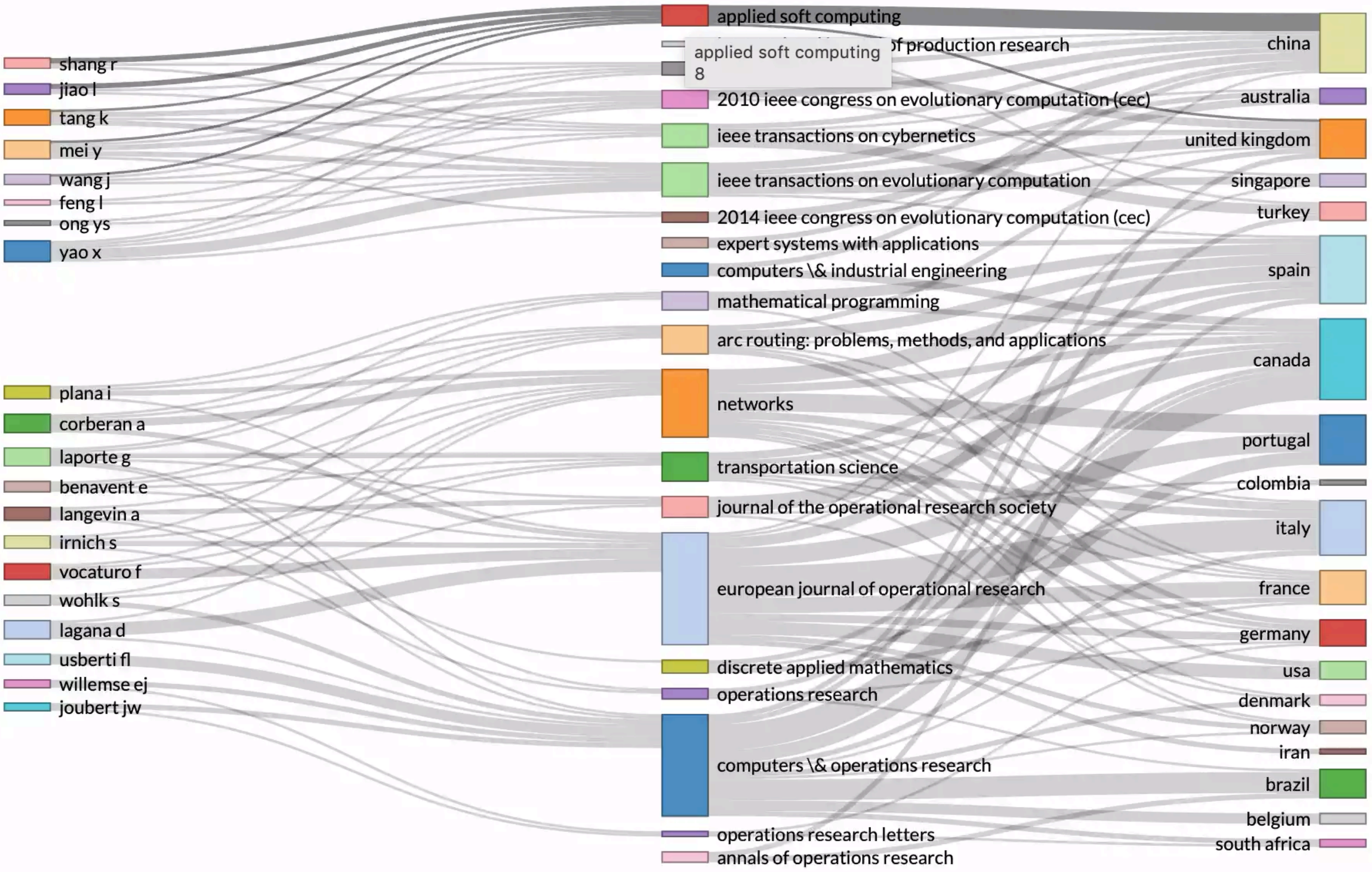
Journals

Countries

Authors

Journals

Countries



General research focus

General research focus

1

New-variants

Exact solution methods
Adaption of heuristic methods
Modification of existing benchmarks

General research focus

1	New-variants	Exact solution methods Adaption of heuristic methods Modification of existing benchmarks
2	Technique improvements	Exact solution methods for existing variants Heuristics (mostly MAs) methods for existing variants.

General research focus

1	New-variants	Exact solution methods Adaption of heuristic methods Modification of existing benchmarks
2	Technique improvements	Exact solution methods for existing variants Heuristics (mostly MAs) methods for existing variants.
3	Practical improvements	New variants and benchmarks from real or near-real problem settings. Adaption and improvements of heuristics.

Outline

1 Our research focus (starting 2008)

2 General metrics of CARP publications.

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4 Some ideas on future research opportunities

Second round of analysis

1

Scanned 158 papers and noted their solution technique, benchmark instances used, and origins of instances.

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Techniques crudely grouped into exact methods, Evolutionary Algorithms, and other heuristics.

Second round of analysis

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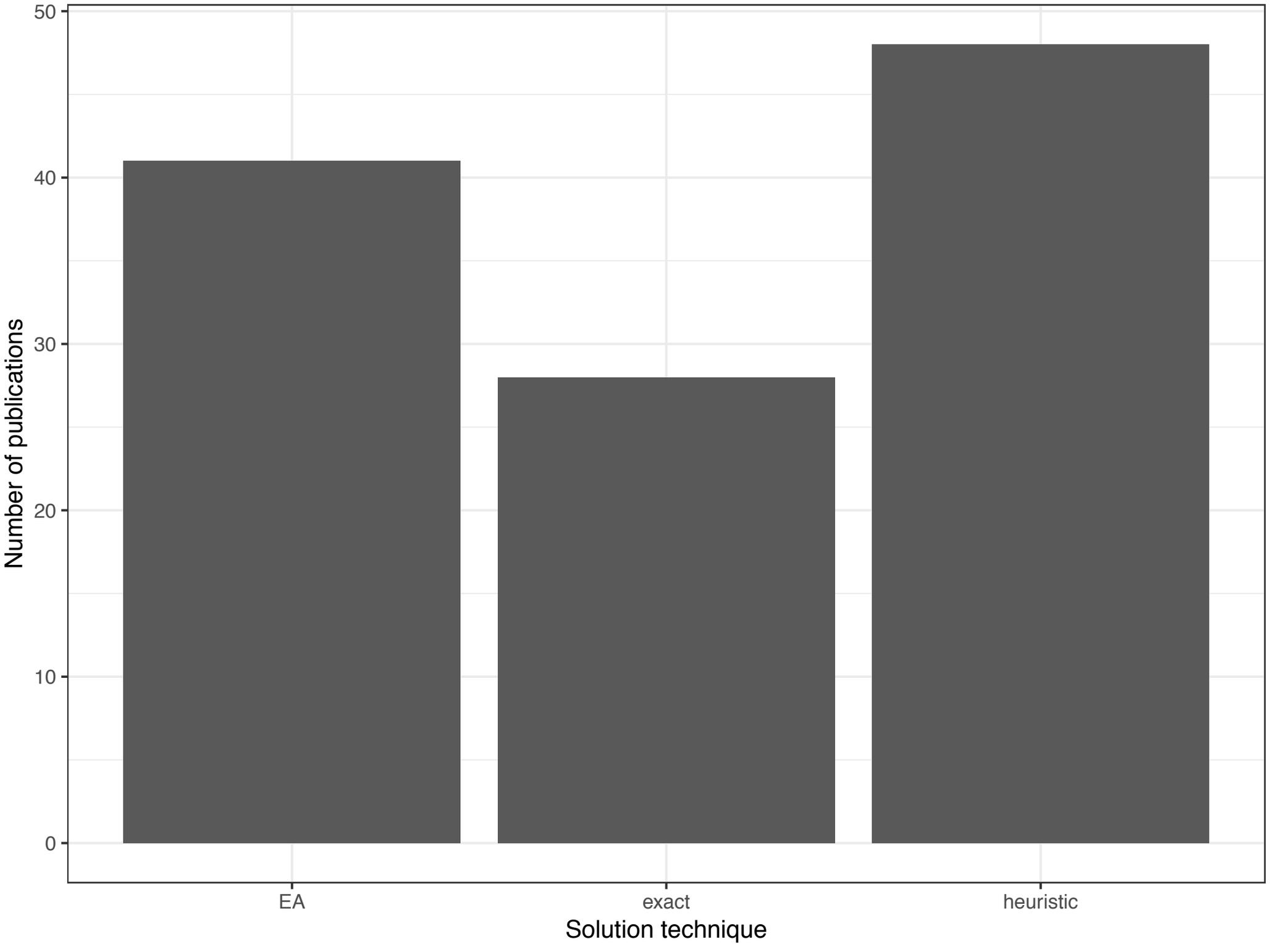
2

Techniques crudely grouped into exact, methods, Evolutionary Algorithms, and other heuristics.

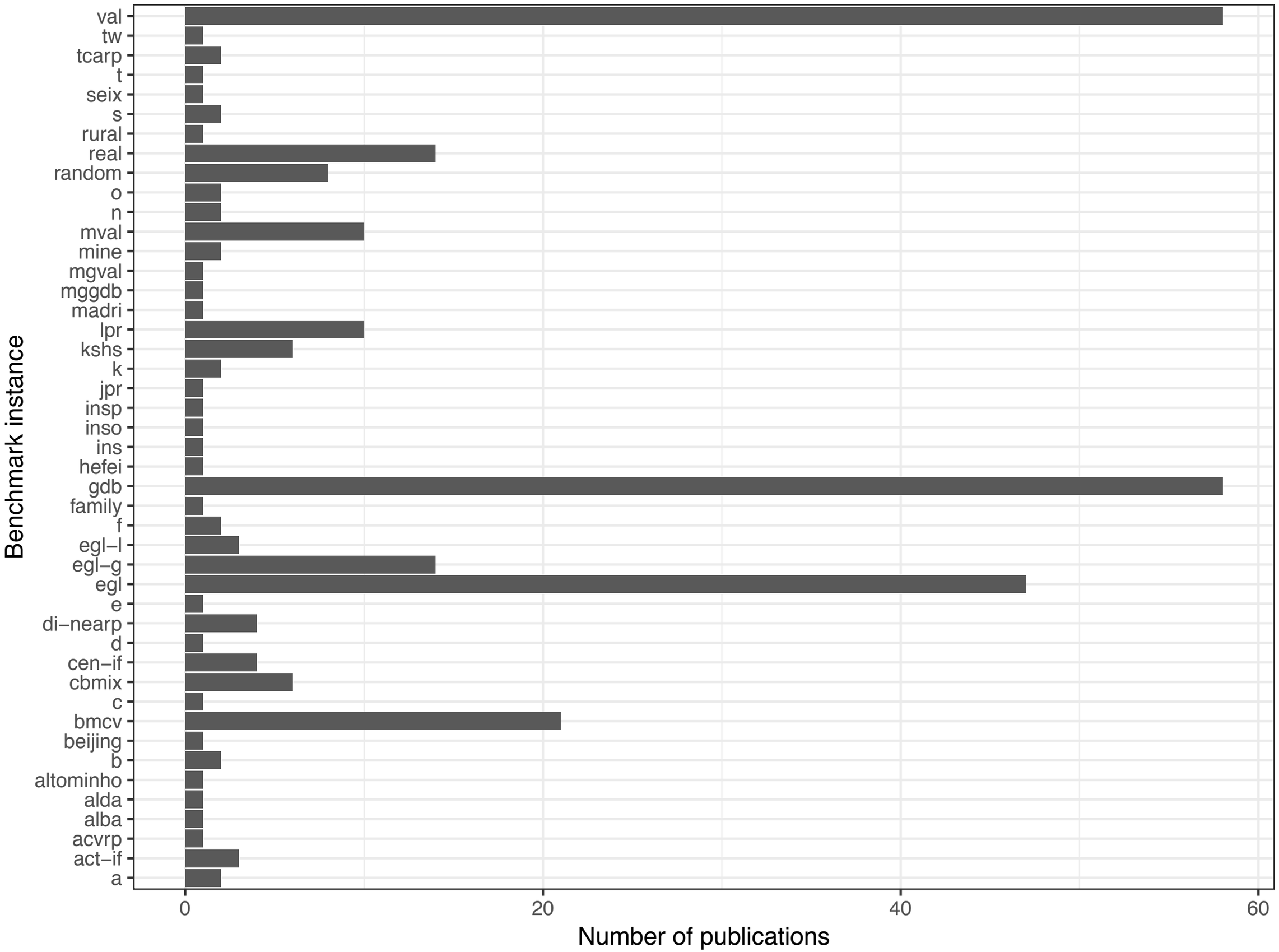
3

Analysed which benchmark instances, traced back to their origins, occured in which technique grouping.

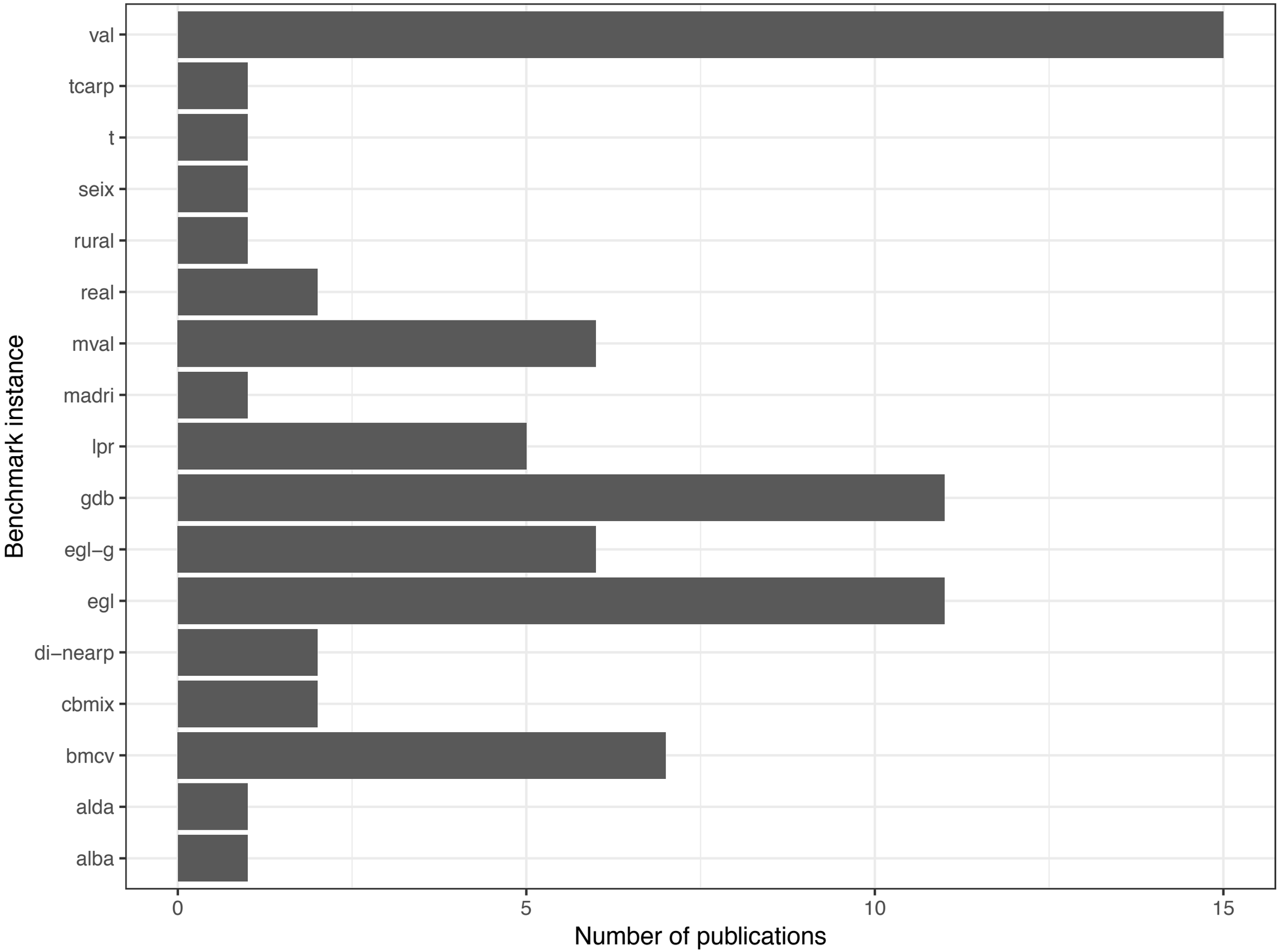
Technique analysis



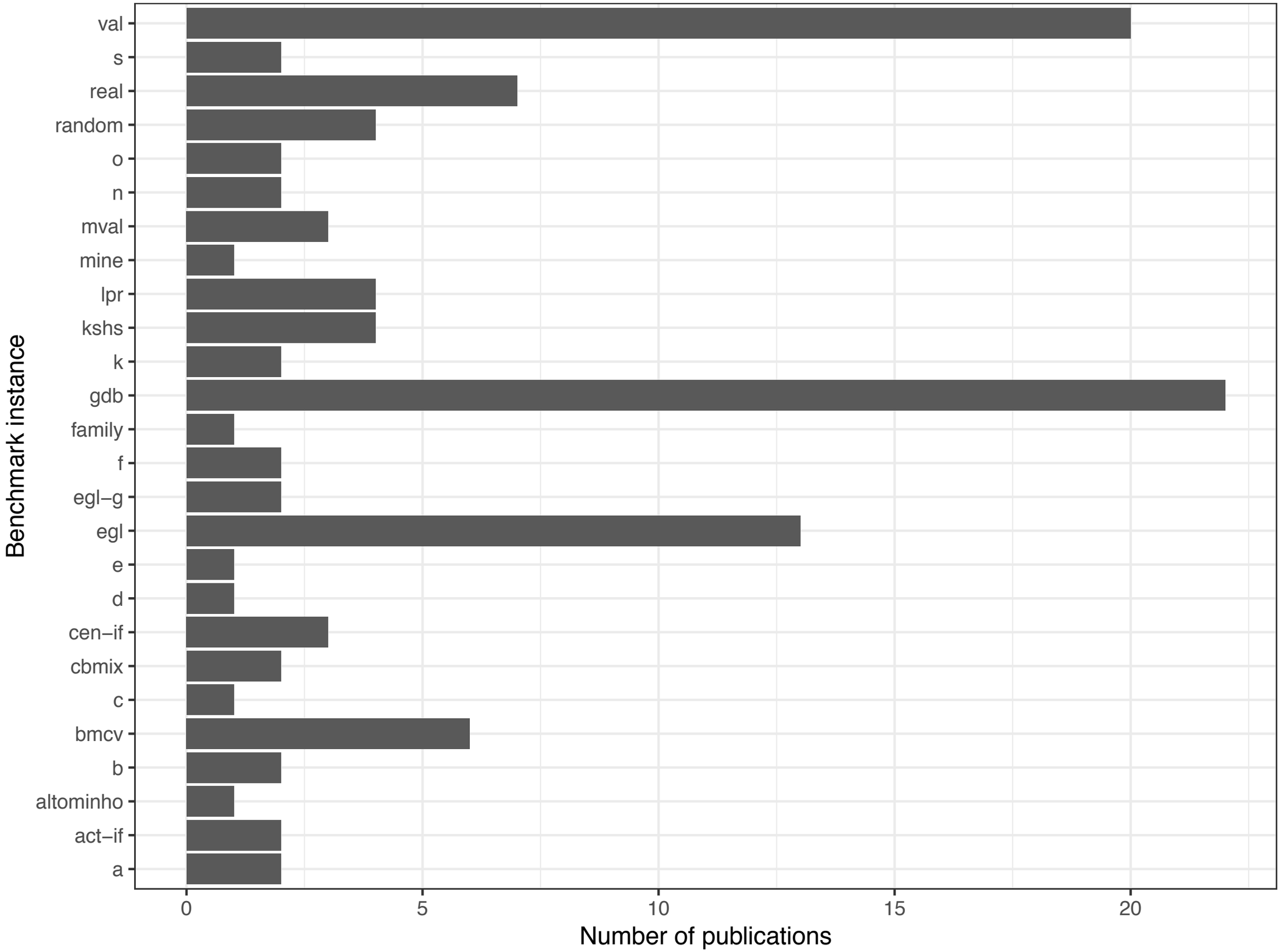
Benchmarks analysis



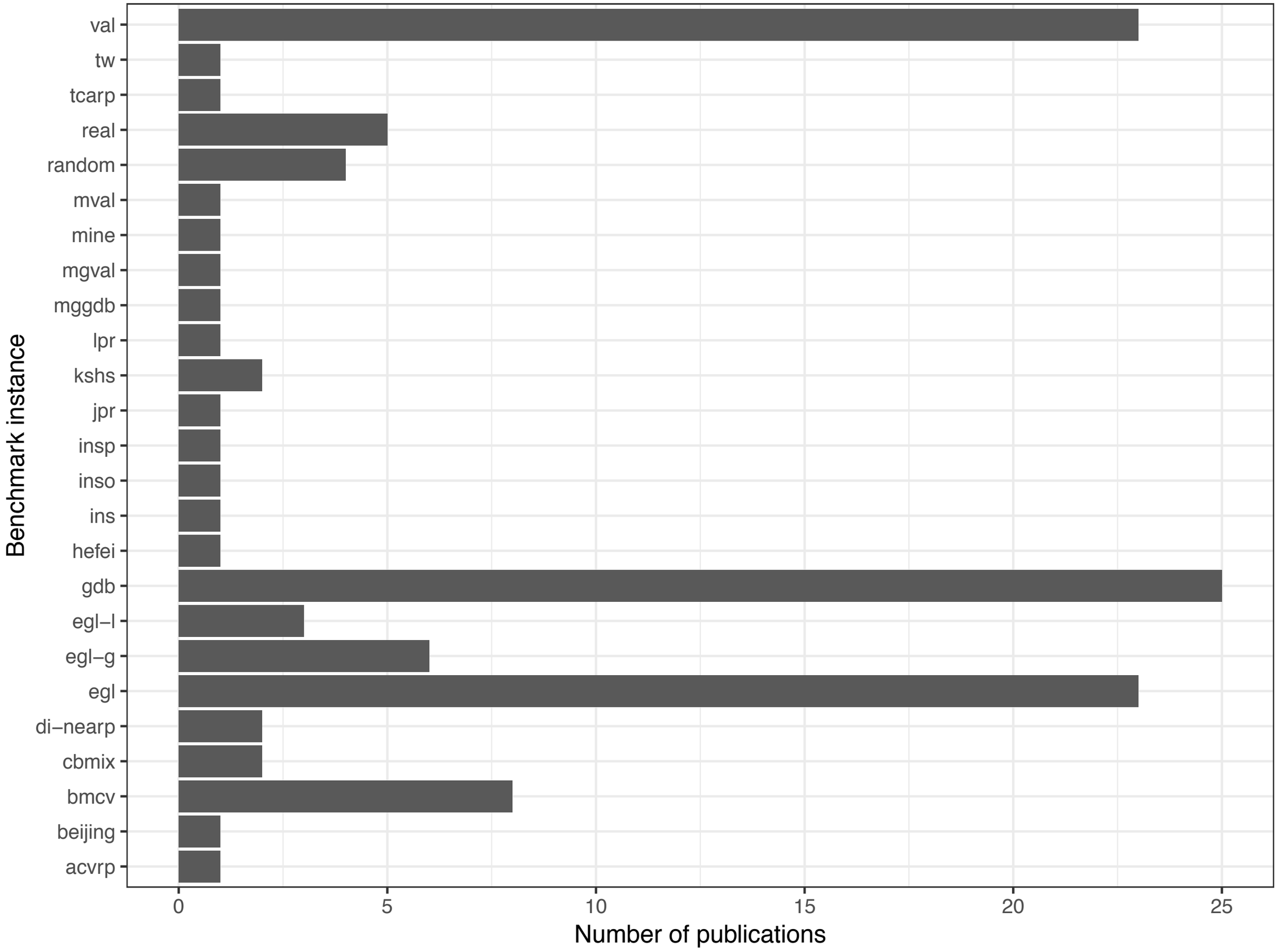
Exact (19 used)



Heuristics (26)



EAs (25 used)


val
tw
tcarp
real
random
mval
mine
mgval
mggdb
lpr
kshs
jpr
insp
inso
ins
hefei
gdb
egl–l
egl–g
egl
di–nearp
cbmix
bmcv
beijing
acvrp
Benchmark instance
0
5
10
15
20
25
Number of publications

Benchmarks analysis

Benchmark sets and instances	$\lvert A' \cup E' \rvert$	$\lvert A_r \cup E_r \rvert$	trips	
			min #	#Arcs/ trip
Waste collection problem instances				
Case study	540	679	5	136
Case study	223	153	3	51
Act-IF-a	259	401	2	76
Act-IF-b	509	151	6	67
Act-IF-c	410	250	4	63
Cen-IF-a	441	1012	17	60
Cen-IF-c	486	2519	37	68
Cen-IF-b	360	2755	39	71
Cen-IF-full	1282	6289	92	68
Lpr-IF-a-05	250	806	18	45
Lpr-IF-b-05	75	801	18	45
Lpr-IF-c-05	38	803	23	35

Benchmarks analysis

Benchmark sets and instances	$\lvert A' \cup E' \rvert$	$\lvert A_r \cup E_r \rvert$	trips	
			min #	#Arcs/ trip
Mean values over randomly generated benchmark sets				
Lpr	71	352	7	28
mval	0	88	5	21
gdb	0	29	6	5
gdb	0	29	6	5
bccm	0	63	5	15
bccm	0	63	5	15
Mean values over realistic snow-removal benchmark sets				
bmcv	22	66	6	12
eglese	34	110	15	7
egl-large	14	361	31	12

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Open-research questions

?

What effect does the reuse of classical benchmark problems have on the development/ tuning/choice of heuristics and metaheuristics?

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How does instance characteristics influence heuristic performance?

Open-research questions

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The solution techniques

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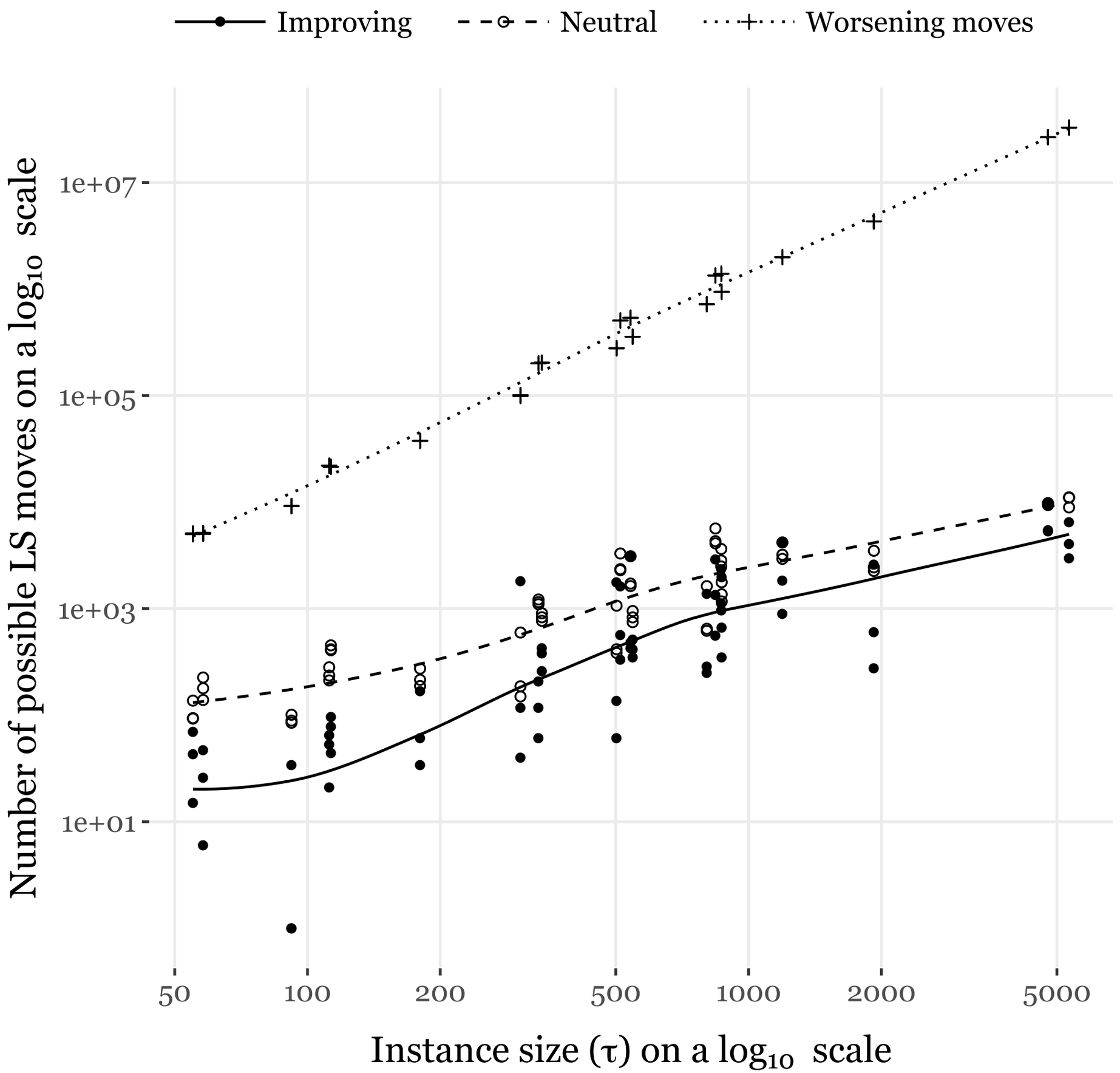
3

Very simple tabu-search

Willemse, E. J. (2016). **Heuristics for large-scale Capacitated Arc Routing Problems on mixed networks** (Doctoral dissertation, University of Pretoria).

Local Search Operators

1. Remove-insert
2. Exchange
3. Cross (swop between end segments of routes)


Improving
Neutral
Worsening moves
Number of possible LS moves on a log10 scale
1e+07
1e+05
1e+03
1e+01
50
100
200
500
1000
2000
5000
Instance size (τ) on a log10 scale

The solution techniques

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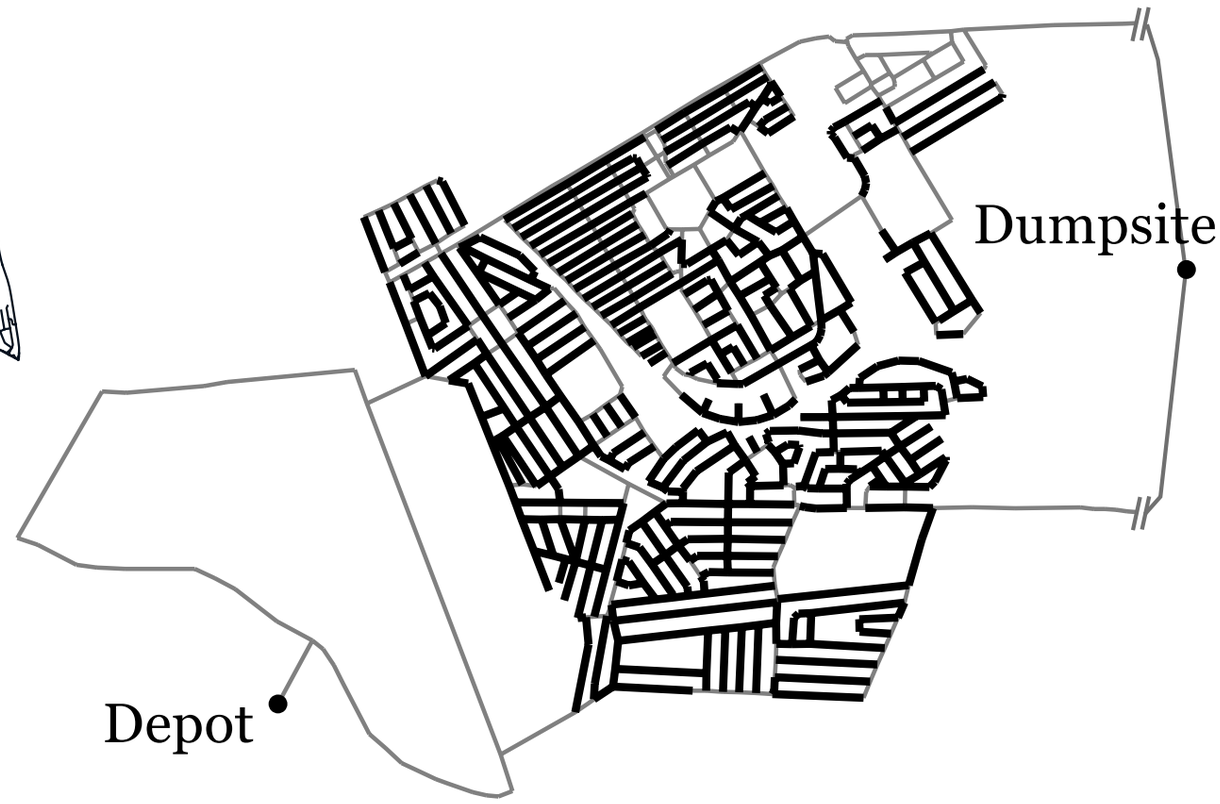
New benchmark sets

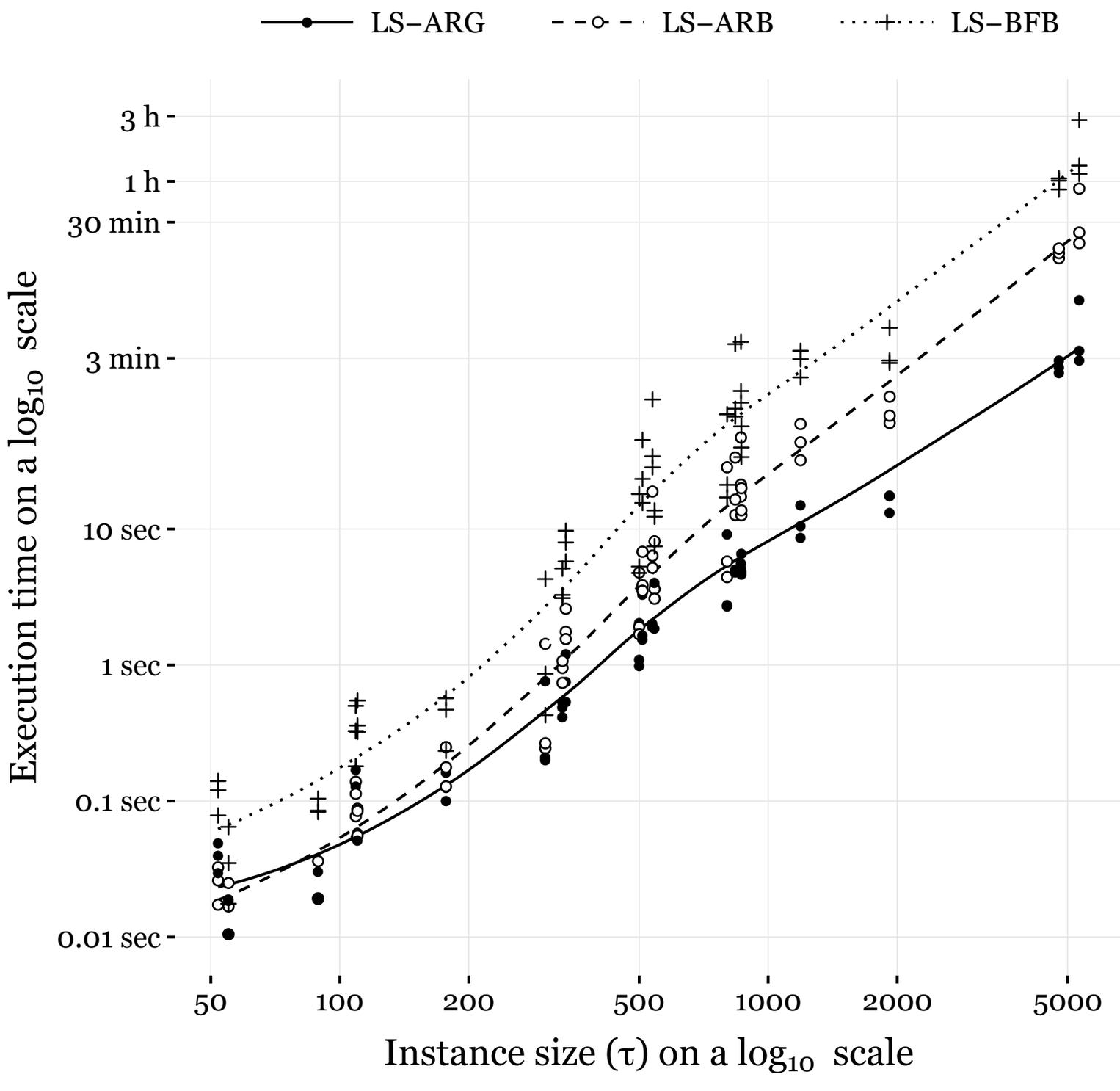
Cen

Act-IF

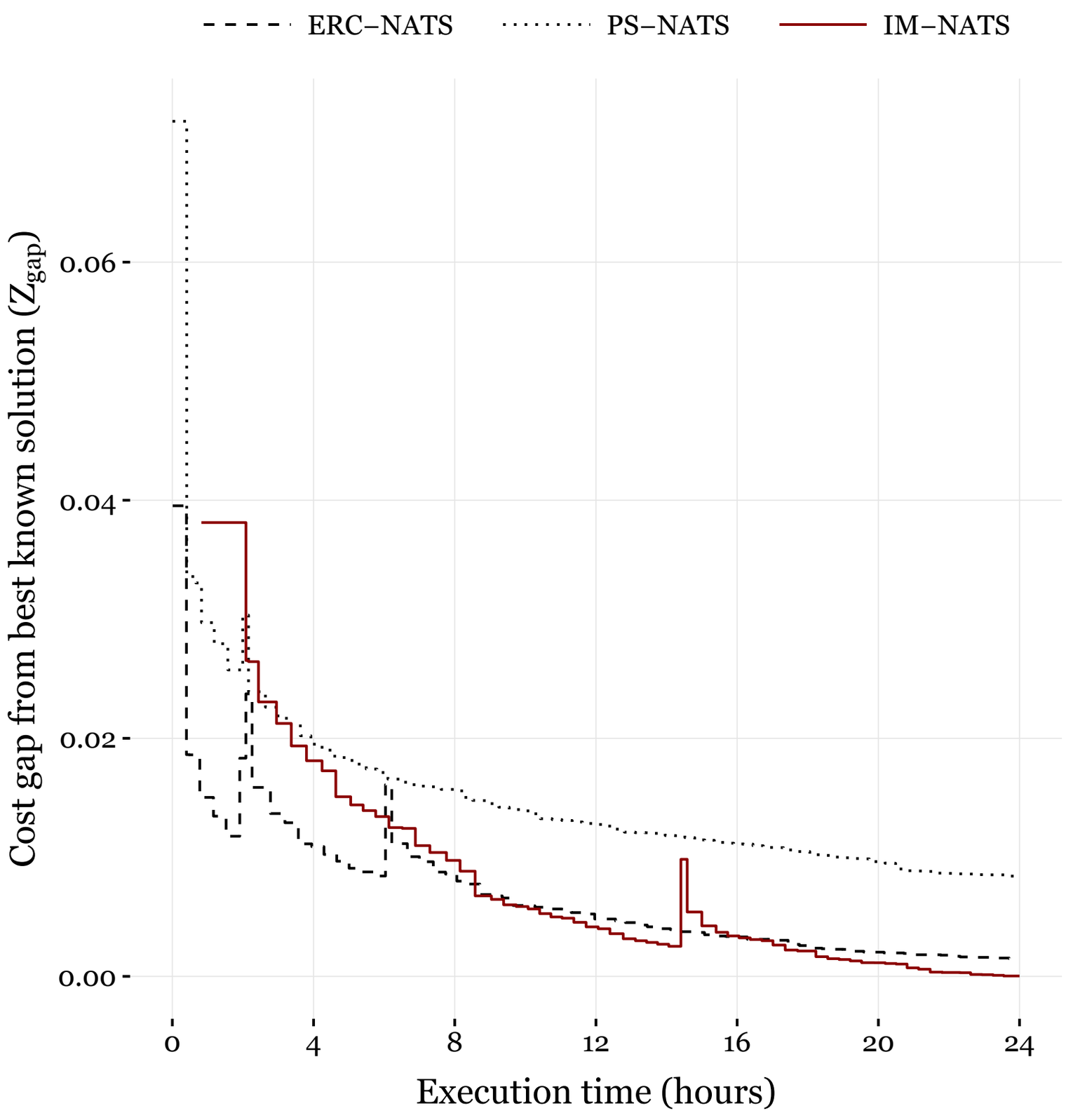


Willemse, E. J., & Joubert, J. W. (2016). **Benchmark dataset for undirected and mixed capacitated arc routing problems under time restrictions with intermediate facilities**. *Data in brief*, *8*, 972-977.

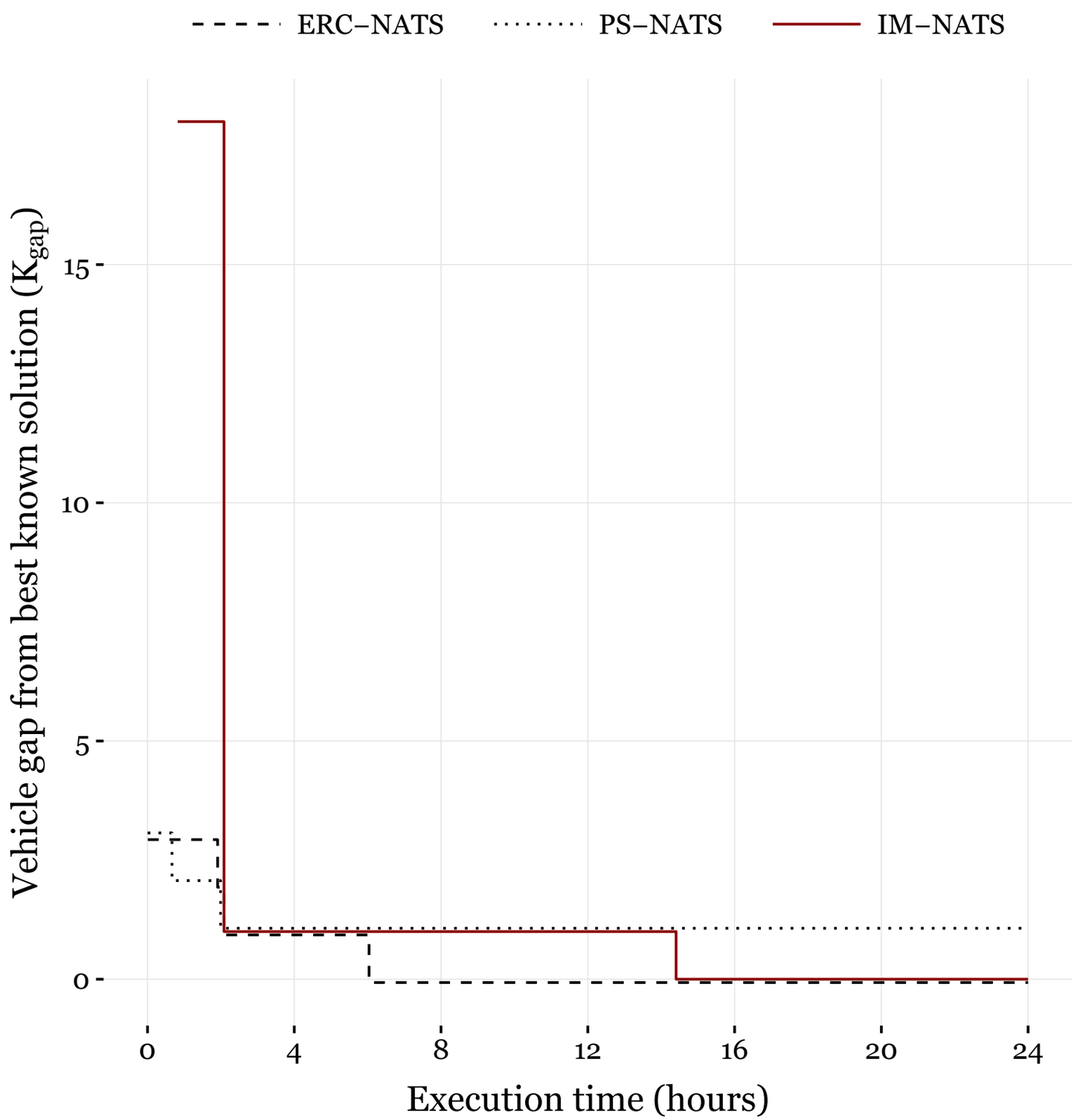
Compound Moves



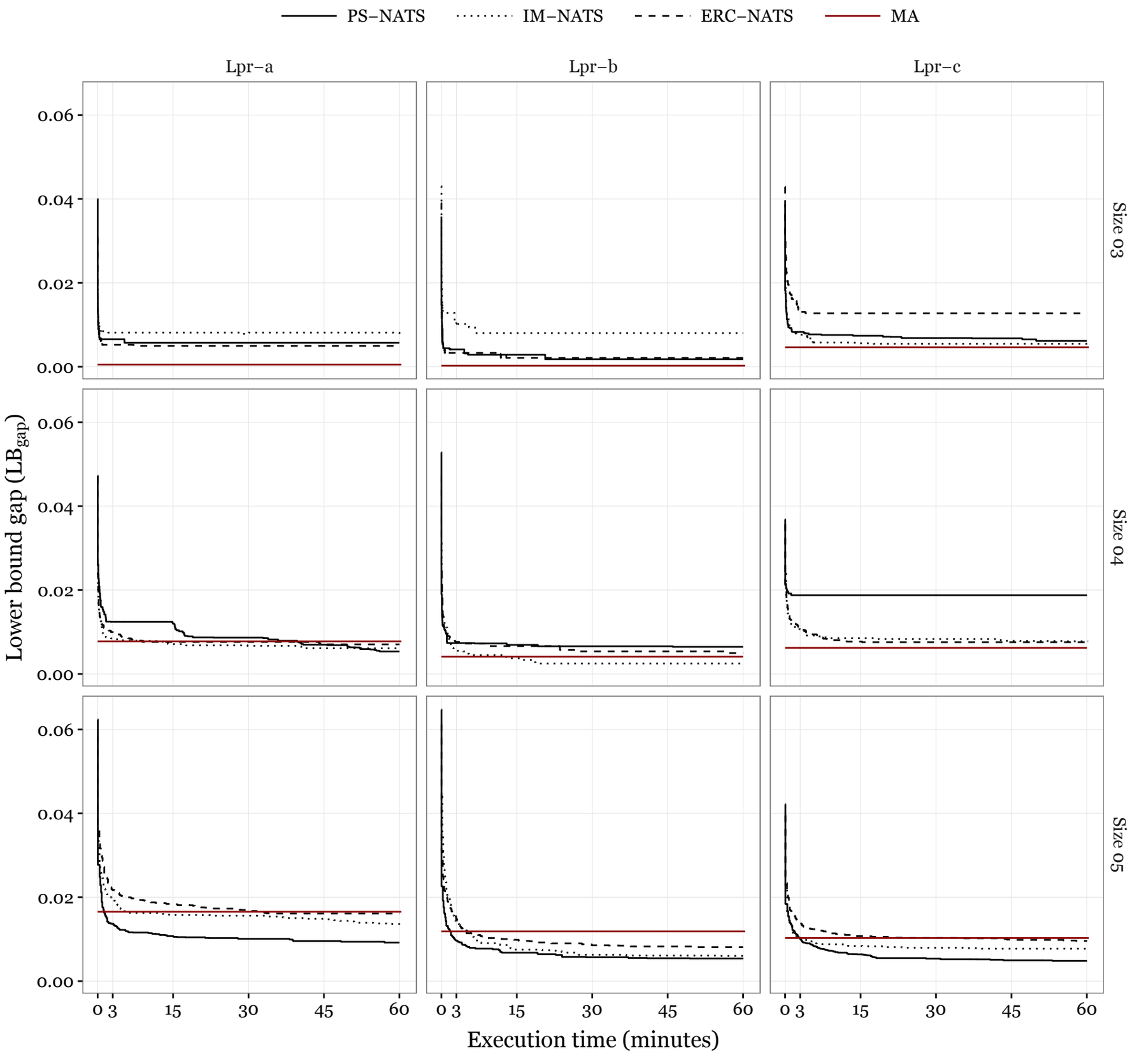
6’282 arc MCARPTIF instance



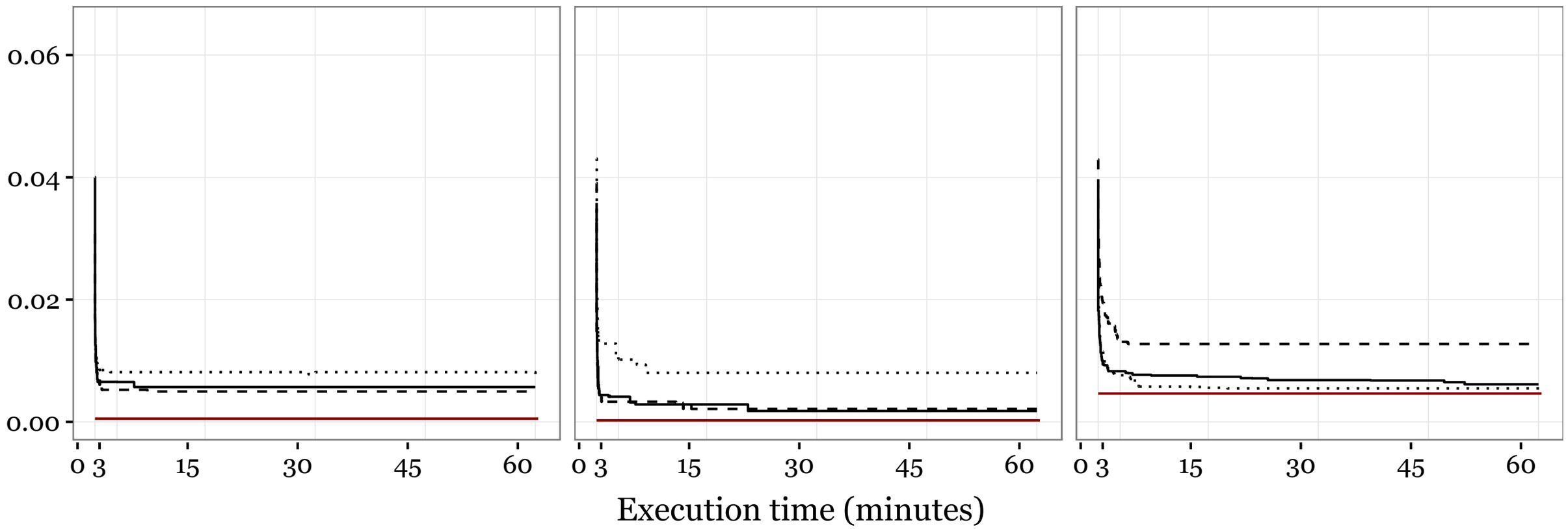
6’282 arc MCARPTIF instance



Lpr MCARP instances

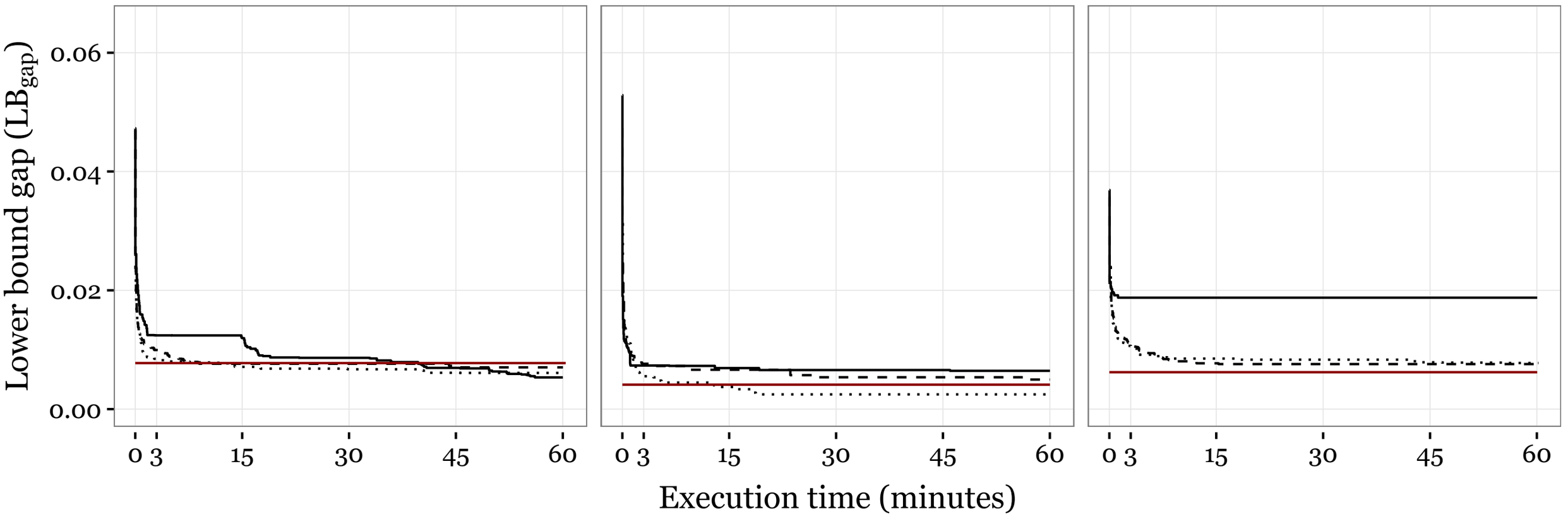


Solving the MCARP



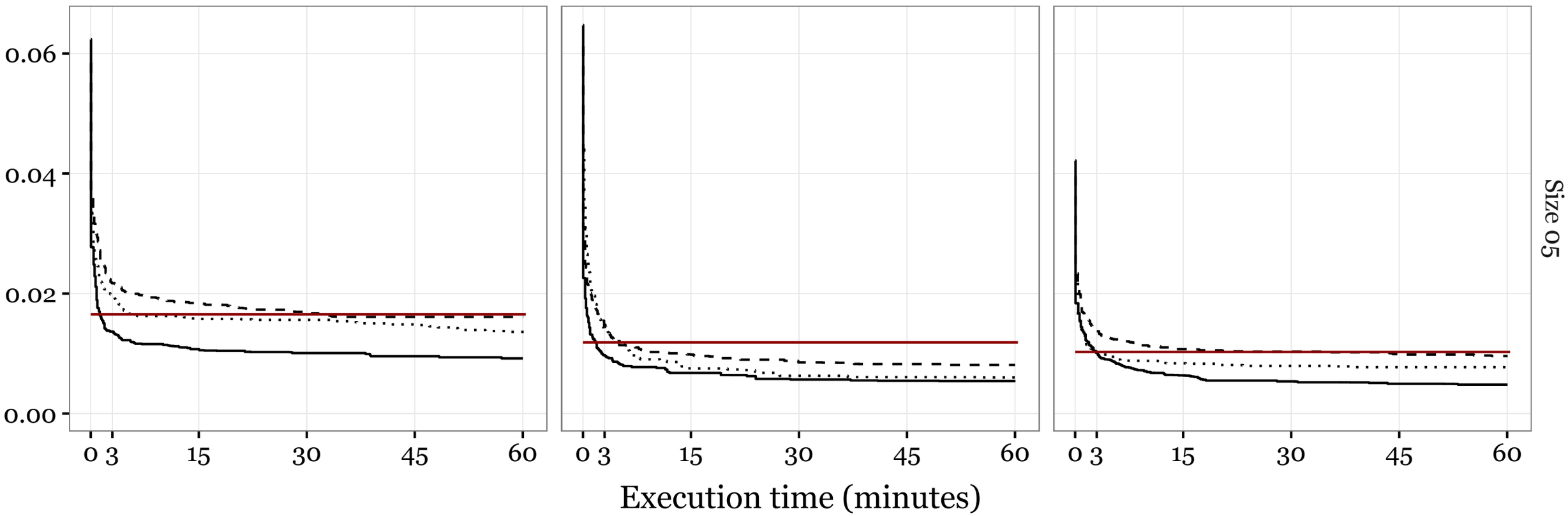
~100 arc instance

Lpr MCARP instances



~250 arc instance

Lpr MCARP instances



~806 arc instance

Next steps

1

Compare our approach against MCGRP

Vidal, T. (2017). **Node, edge, arc routing and turn penalties: Multiple problems—one neighborhood extension.** *Operations Research*, *65*(4), 992-1010.

2

Make the our implementations available on *github*.

3

Convert new benchmark instances to better evaluate performance of heuristics.

Kiilerich, L., & Wøhlk, S. (2018). **New large-scale data instances for CARP and new variations of CARP**. *INFOR: Information Systems and Operational Research*, *56*(1), 1-32.

THANK YOU!

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WARP3 - 2019 - Pizzo, Italy

https://github.com/ejwillemse/WARP3

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