Models and algorithms for the cell formation problem

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Introduction

Cellular manufacturing is a manufacturing philosophy that attempts to convert a manufacturing system into a number of cells.

Cellular manufacturing offers certain advantages production lines like the reduction of setup and transfer costs, the minimization of inventory, improved quality, and significant savings in plant space.

Cell Formation Problem

Informal definition: We are given a set of machines (rows), set of parts (columns) and processing plans. The task is to group machines and parts into production cells (clusters) to optimize production process in some ways.

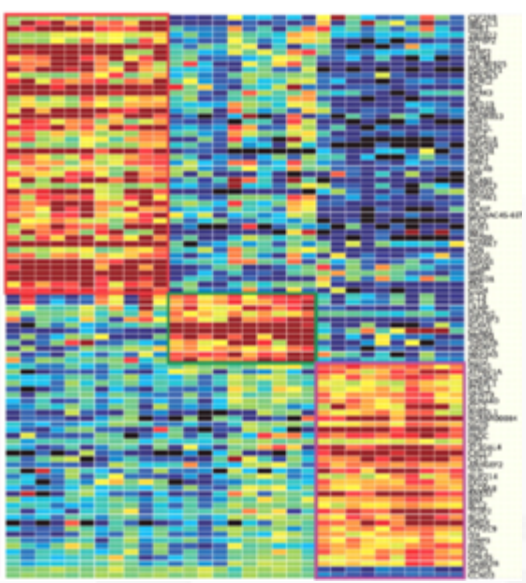
	1	2	3	4	5	6	7
1	1	0	0	0	1	1	1
2	0	1	1	1	1	0	0
3	0	0	1	1	1	1	0
4	1	1	1	1	0	0	0
5	0	1	0	1	1	1	0

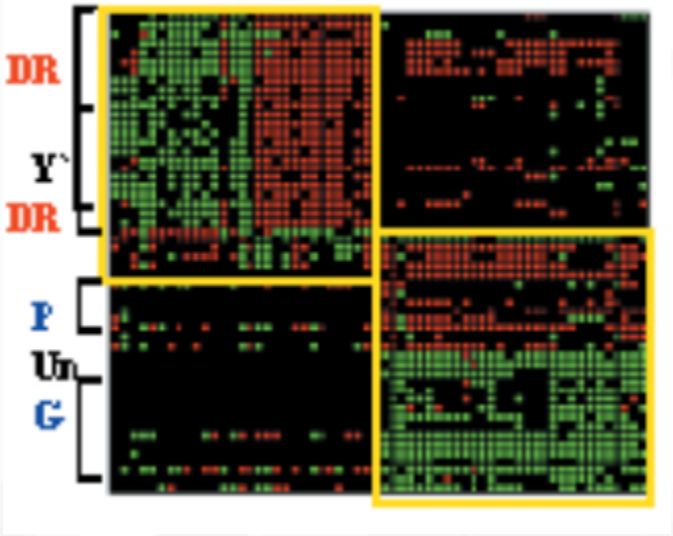
Problem instance with 5 machines and 7 parts

	5	4	2	3	1	6	7
5	1	1	1	0	0	1	0
4	0	1	1	1	1	0	0
2	1	1	1	1	0	0	0
3	1	1	0	1	0	1	0
1	1	0	0	0	1	1	1

Solution

Biclustering Problems





Li, Guojun, et al. "QUBIC: a qualitative biclustering algorithm for analyses of gene expression data." *Nucleic acids research* 37.15 (2009): e101-e101.

Cell Formation Problem

CFP Variants & Constraints

- cell size (zerotones, singletones, bounded cell size)
- number of cells (fixed or variable)
- processing sequences
- alternate process plans

Cell Formation Problem

Objective functions

- Grouping Efficiency (Chandrasekharan & Rajagopalan, 1989)

$$\eta = q\eta_1 + (1-q)\eta_2, \qquad \eta_1 = \frac{n_1^{in}}{n^{in}},\ \eta_2 = \frac{n_0^{out}}{n^{out}}$$

- Grouping Efficacy (Chandrasekharan & Rajagopalan, 1990)

$$\tau = \frac{n_1 - n_1^{out}}{n_1 + n_0^{in}} = \frac{n_1^{in}}{n_1 + n_0^{in}}.$$

- E + V (exceptional elements + voids)

Cell Formation Problem

	1	2	3	4	5
1	1	0	0	1	0
2	0	1	1	1	0
3	0	0	1	0	0
4	0	0	0	1	1
5	0	1	0	1	1

Grouping Efficiency = 88.88%
Grouping Efficacy = 63.63%
E + V = 4

With grouping efficiency even a bad solution having large number of exceptional elements may have efficiency value from 75% to 100%

Grouping efficacy measure addresses the best the block-diagonal structure

Sarker B.R., Khan M.(2001). A comparison of existing grouping efficiency measures and a new weighted grouping efficiency measure. IIE Transactions, 33,11-27.

Straightforward formulation

Decision variables:

$$x_{ik} = \begin{cases} 1, & \text{if machine } i \text{ belongs to cell } k, \\ 0, & \text{otherwise} \end{cases}$$

$$y_{jk} = \begin{cases} 1, & \text{if part } j \text{ belongs to cell } k, \\ 0, & \text{otherwise} \end{cases}$$

$$max \quad \frac{\sum_{i=1}^{m}\sum_{j=1}^{p}\sum_{k=1}^{c} a_{ij}x_{ik}y_{jk}}{\sum_{i=1}^{m}\sum_{j=1}^{p} a_{ij} + \sum_{i=1}^{m}\sum_{j=1}^{p}\sum_{k=1}^{c}(1-a_{ij})x_{ik}y_{jk}} \qquad (1)$$

$$\sum_{k=1}^{c} x_{ik} = 1 \quad i = 1, \ldots, m \qquad (2)$$

$$\sum_{k=1}^{c} y_{jk} = 1 \quad j = 1, \ldots, p \qquad (3)$$

$$\sum_{i=1}^{m} x_{ik} \le m \cdot \sum_{j=1}^{p} y_{jk} \quad k = 1, \ldots, c \qquad (4)$$

$$\sum_{j=1}^{p} y_{jk} \le p \cdot \sum_{i=1}^{m} x_{ik} \quad k = 1, \ldots, c \qquad (5)$$

Cell Formation Problem

Approaches:

- clustering methods (rank-order clustering, single-linkage clustering , direct clustering algorithm)

- metaheuristics (genetic algorithms, tabu search, particle-swarm optimization, simulated annealing)

- graph partitioning approaches

- mathematical programming

Only a few authors have aimed to develop exact methods and most of these methods have some major restrictions such as a fixed number of production cells.

Exact Approaches

MILP model by **Elbenani and Ferland(2012)**

Suggested a linear integer programming model and used Dinkelbach algorithm for grouping efficacy linearization.

Problem is solved for fixed number of production cells, so the solutions cannot be considered as global optimal solutions.

Generally this model is quite fast, but in some cases algorithm has been stopped due to cpu time/memory limitations.

Elbenani, Bouazza, and Jacques A. Ferland. *Cell formation problem solved exactly with the Dinkelbach algorithm*. Vol. 7. CIRRELT, 2012.

Exact Approaches

2 exact approaches from **Brusco (2015)**

MILP model

Model based on two-mode clustering with some special assumptions (same number of clusters for rows and columns). Also used fixed number of production cells, but several numbers are considered in some cases. The model runs too long even on medium-sized problem instances.

Branch-and-Bound

Using its own ILS heuristic for initial solution generation. Works quite fast on the problem instances with grouping efficacy value from 0.65 to 0.7. Several possible numbers of production cells are considered for small-sized problem instances.

Brusco, Michael J. "An exact algorithm for maximizing grouping efficacy in part–machine clustering." *IIE Transactions* 47.6 (2015): 653-671.

Exact Approaches

MILP model by **Bychkov et al. (2014)**

The optimal number of production cells are determined automatically.

Works fast on the small-sized instances, but number of variables and constraints grows as $O(m^2 * p)$. This doesn't allow to solve even medium-sized problem instances.

Bychkov, I.S., Batsyn, M.V., Pardalos P.M.(2014). Exact model for the cell formation problem. Optimization Letters, 8(8), 2203-2210.

Exact Approaches

Exact algorithm by **Pinheiro et al. (2016)**

Used bicluster graph editing problem to solve manufacturing cell formation.

Have 2 cases considered – with no restrictions on cell's sizes and with minimum size 2x2

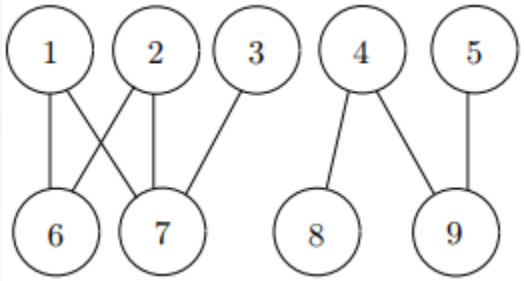
Runs very fast, proved optimality for many problem instances.

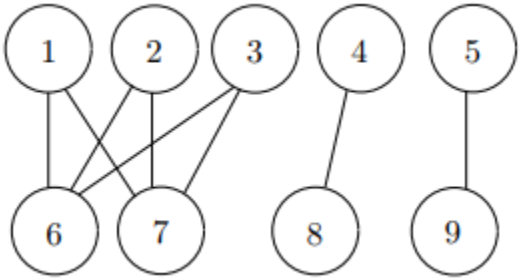
Pinheiro, R. G. S.; Martins, I. C.; Protti, F.; Ochi, L. S.; Simonetti, L. & Subramanian, A. (2016), On Solving Manufacturing Cell Formation via Bicluster Editing, European Journal of Operational Research, 254, 3, 769-779

Exact Approaches

Exact algorithm by **Pinheiro et al. (2016)**

Used **Bicluster Graph Editing Problem** to solve manufacturing cell formation.





	6	7	8	9
1	1	1	0	0
2	1	1	0	0
3	0	1	0	0
4	0	0	1	1
5	0	0	0	1

(c) MCFP instance.

	6	7	8	9
1	1	1	0	0
2	1	1	0	0
3	0	1	0	0
4	0	0	1	1
5	0	0	0	1

(d) MCFP solution.

Three-Index Model

Proposition 1 *Let τ be the grouping efficacy value for some feasible CFP solution. Then n_0^{in} in the optimal solution is not greater than $\left\lfloor \frac{1-\tau}{\tau} n_1 \right\rfloor$.*

Proof Since τ is the value of the objective function of a feasible CFP solution, then it is not greater than the optimal value τ^*

$$\tau \leq \tau^* = \frac{n_1^{in}}{n_1 + n_0^{in}}$$

Therefore,

$$n_0^{in} \leq \frac{n_1^{in} - \tau n_1}{\tau}$$

Since $n_1^{in} \leq n_1$ and n_0^{in} is integer, we have the required upper bound

$$n_0^{in} \leq \left\lfloor \frac{1-\tau}{\tau} n_1 \right\rfloor$$

Note that when the considered feasible solution is optimal ($\tau = \tau^*$) and it contains all the ones inside the cells ($n_1^{in} = n_1$) then n_0^{in} is exactly equal to this upper bound. □

Three-Index Model

$$max \sum_{i=1}^{m}\sum_{j=1}^{p}\sum_{k=1}^{c} a_{ij} z_{ijk} \quad (1)$$

$$z_{ijk} \le x_{ik} \quad \forall i = 1, \ldots, m, \ \forall j = 1, \ldots, p, \ \forall k = 1, \ldots, c \quad (2)$$

$$z_{ijk} \le y_{jk} \quad \forall i = 1, \ldots, m, \ \forall j = 1, \ldots, p, \ \forall k = 1, \ldots, c \quad (3)$$

$$z_{ijk} \ge x_{ik} + y_{jk} - 1 \quad \forall i = 1, \ldots, m, \ \forall j = 1, \ldots, p, \ \forall k = 1, \ldots, c \quad (4)$$

$$\sum_{k=1}^{c} x_{ik} = 1 \quad \forall i = 1, \ldots, m \quad (5)$$

$$\sum_{k=1}^{c} y_{jk} = 1 \quad \forall j = 1, \ldots, p \quad (6)$$

$$\sum_{i=1}^{m}\sum_{j=1}^{p} z_{ijk} \ge \sum_{i=1}^{m} x_{ik} \quad \forall k = 1, \ldots, c \quad (7)$$

$$\sum_{i=1}^{m}\sum_{j=1}^{p} z_{ijk} \ge \sum_{j=1}^{p} y_{jk} \quad \forall k = 1, \ldots, c \quad (8)$$

$$\sum_{i=1}^{m}\sum_{j=1}^{p}\sum_{k=1}^{c} (1 - a_{ij}) z_{ijk} = n_0^{in} \quad (9)$$

$$x_{ik}, y_{jk}, z_{ijk} \in \{0, 1\} \quad \forall i = 1, \ldots, m, \ \forall j = 1, \ldots, p, \ \forall k = 1, \ldots, c \quad (10)$$

Three-Index Model

#	Test Instance	Size	Efficacy	Time	Zeroes in
1	King and Nakornchai	5×7	82.35	0.63	3
2	Waghodekar and Sahu	5×7	69.57	2.29	3
3	Seifoddini	5×18	79.59	5.69	3
4	Kusiak	6×8	76.92	1.86	4
5	Kusiak and Chow	7×11	60.87	9.14	0
6	Boctor	7×11	70.83	5.15	3
7	Seifoddini and Wolfe	8×12	69.44	13.37	1
8	Chandrasekharan and Rajagopalan	8×20	85.25	18.33	0
9	Chandrasekharan and Rajagopalan	8×20	58.72	208.36	18
10	Mosier and Taube	10×10	75.00	6.25	4
11	Chan and Milner	10×15	92.00	2.93	4
12	Askin and Subramanian	14×23	72.06	259.19	10
13	Stanfel	14×24	71.83	179.21	10
14	McCormick et al.	16×24	51.61a	20,829.38a	8
15	Srinivasan et al.	16×30	69.00a	13,719.99a	13
16	King	16×43	57.53a	24,930.93a	20
17	Carrie	18×24	57.73a	13,250.01a	8
18	Mosier and Taube	20×20	38.71a	43,531.77a	44

#	Test Instance	Size	Efficacy	Time	Zeroes in
19	Kumar et al.	20×23	46.72a	33,020.13a	9
20	Carrie	20×35	77.85a	11,626.98a	22
21	Boe and Cheng	20×35	46.75a	33,322.08a	1
22	Chandrasekharan and Rajagopalan	24×40	100.00	1.64	0
23	Chandrasekharan and Rajagopalan	24×40	85.11a	6,916.24a	11
24	Chandrasekharan and Rajagopalan	24×40	56.49a	14,408.88a	0
25	Chandrasekharan and Rajagopalan	24×40	46.56a	34,524.47a	0
26	Chandrasekharan and Rajagopalan	24×40	43.51a	41,140.94a	0
27	Chandrasekharan and Rajagopalan	24×40	41.22a	44,126.76a	0
28	McCormick et al.	27×27	54.02a	22,627.28a	31
29	Carrie	28×46	24.65a	71,671.08a	4
30	Kumar and Vannelli	30×41	48.44a	22,594.20a	0
31	Stanfel	30×50	50.65a	31,080.82a	0
32	Stanfel	30×50	38.32a	48,977.01a	0
33	King and Nakornchai	30×90	39.41a	99,435.64a	29
34	McCormick et al.	37×53	59.60a	47,744.04a	17
35	Chandrasekharan and Rajagopalan	40×100	84.03a	24,167.76a	37

Objective Linearization

If we consider a fractional programming model with the following objective function:

$$Q(x) = \frac{P(x)}{D(x)}, \tag{6}$$

then Dinkelbach procedure is the following:

- **Step 1** take some feasible solution x^0, compute $\lambda_1 = \frac{P(x^0)}{D(x^0)}$ and let $k = 1$
- **Step 2** solve the original problem with objective function $Q(x)$ replaced with $F(\lambda_k) = P(x) - \lambda_k D(x) \rightarrow max$ and let x^k be the optimal solution
- **Step 3** If $F(\lambda_k) = 0$ (or less then some predefined tolerance) then stop the procedure and return x^k as the optimal solution.
  Else $k = k + 1, \lambda_k = \frac{P(x^k)}{D(x^k)}$ and goto step 2.

Two-Index Model

Two-index model:

$$x_{ik} = \begin{cases} 1, & \text{if machines } i \text{ and } k \text{ are in the same cell,} \\ 0, & \text{otherwise} \end{cases}$$

$$y_{ij} = \begin{cases} 1, & \text{if machine } i \text{ and part } j \text{ are in the same cell,} \\ 0, & \text{otherwise} \end{cases}$$

$$max \quad \sum_{i=1}^{m}\sum_{j=1}^{p} a_{ij}y_{ij} - \lambda \cdot \left(\sum_{i=1}^{m}\sum_{j=1}^{p}(1-a_{ij})y_{ij} + \sum_{i=1}^{m}\sum_{j=1}^{p} a_{ij}\right) \quad (7)$$

Subject to:

$$2x_{ik} - y_{ij} - y_{kj} \geq -1 \quad i,k = 1,\ldots,m \quad j = 1,\ldots,p \quad (8)$$

$$y_{ij} - y_{kj} - x_{ik} \geq -1 \quad i,k = 1,\ldots,m \quad j = 1,\ldots,p \quad (9)$$

$$y_{kj} - y_{ij} - x_{ij} \geq -1 \quad i,k = 1,\ldots,m \quad j = 1,\ldots,p \quad (10)$$

$$\sum_{j=1}^{p} y_{ij} \geq 1 \quad i = 1,...,m \quad (11)$$

$$\sum_{i=1}^{m} y_{ij} \geq 1 \quad j = 1,...,p \quad (12)$$

We start with setting λ equal to the best known efficacy value for the considered cell formation problem instance.

Datasets

Table 3: Testset A - Instances

ID	Source	m	p
A1	King and Nakornchai (1982) - Figure 1a	5	7
A2	Waghodekar and Sahu (1984) - Problem 2	5	7
A3	Seifoddini (1989b)	5	18
A4	Kusiak and Cho (1992)	6	8
A5	Kusiak and Chow (1987)	7	11
A6	Boctor (1991) - Example 1	7	11
A7	Seifoddini and Wolfe (1986)	8	12
A8	Chandrasekaran and Rajagopalan (1986a)	8	20
A9	Chandrasekaran and Rajagopalan (1986b)	8	20
A10	Mosier and Taube (1985a)	10	10
A11	Chan and Milner (1982)	15	10
A12	Askin and Subramanian (1987)	14	24
A13	Stanfel (1985)	14	24
A14	McCormick et al. (1972)	16	24
A15	Srinivasan et al. (1990)	16	30
A16	King (1980)	16	43
A17	Carrie (1973)	18	24
A18	Mosier and Taube (1985b)	20	20
A19	Kumar et al. (1986)	23	20
A20	Carrie (1973)	20	35
A21	Boe and Cheng (1991)	20	35
A22	Chandrasekharan and Rajagopalan (1989) - Dataset 1	24	40
A23	Chandrasekharan and Rajagopalan (1989) - Dataset 2	24	40
A24	Chandrasekharan and Rajagopalan (1989) - Dataset 3	24	40
A25	Chandrasekharan and Rajagopalan (1989) - Dataset 5	24	40
A26	Chandrasekharan and Rajagopalan (1989) - Dataset 6	24	40
A27	Chandrasekharan and Rajagopalan (1989) - Dataset 7	24	40
A28	McCormick et al. (1972)	27	27
A29	Carrie (1973)	28	46
A30	Kumar and Vannelli (1987)	30	41
A31	Stanfel (1985) - Figure 5	30	50
A32	Stanfel (1985) - Figure 6	30	50
A33	King and Nakornchai (1982)	30	90
A34	McCormick et al. (1972)	37	53
A35	Chandrasekharan and Rajagopalan (1987)	40	100

Table 5: Testset B - Instances

ID	Source	m	p
B1	Adil (1996)	6	6
B2	Pa Rkin and Li (1997)	6	7
B3	Brown and Sumichrast (2001)	6	11
B4	Chan and Milner (1982)	7	5
B5	Kusiak and Chow (1987)	7	8
B6	Zolfaghari and Liang (2002)	7	8
B7	Won and Kim (1997)	7	10
B8	Sarker and Khan (2001)	8	8
B9	Nair (1999)	8	10
B10	Islam and Sarker (2000)	8	10
B11	Kumar et al. (1986)	9	15
B12	Ham et al. (1985)	10	8
B13	Viswanathan (1996)	10	12
B14	Shargal et al. (1995)	10	38
B15	Won and Kim (1997)	11	10
B16	Seifoddini (1988)	11	22
B17	Moon and Chi (1992)	12	19
B18	Li (2003)	14	14
B19	Chan and Milner (1982) - Fig.3a	15	10
B20	Yang and Yang (2008) - Fig.6b	15	15
B21	Yang and Yang (2008) - Fig.6c	15	15
B22	Yang and Yang (2008) - Fig.6d	15	15
B23	Harhalakis et al. (1994)	17	20
B24	Seifoddini and Djassemi (1991)	18	24
B25	Sandbothe (1998)	20	10
B26	Nagi et al. (1990)	20	51
B27	Won and Kim (1997)	26	28
B28	Yang and Yang (2008) - Fig.7	28	35
B29	Seifoddini and Djassemi (1996)	35	15
B30	Seifoddini and Djassemi (1996)	41	50
B31	Yang and Yang (2008) - Fig.12	46	105
B32	Zolfaghari and Liang (1997)	50	150

Computational experiments

#	Time, sec			Efficacy		
	Elbenani & Ferland (2012)	Bychkov et al. (2014)	two-index model	Elbenani & Ferland (2012) (cells)	Bychkov et al. (2014)	two-index model
A1	2.3	0.63	0.00	0.8235(2)	0.8235	0.8235
A2	1.6	2.29	0.00	0.6957(2)	0.6957	0.6957
A3	3.1	5.69	0.00	0.7959(2)	0.7959	0.7959
A4	2.0	1.86	0.09	0.7692(2)	0.7692	0.7692
A5	30.6	9.14	0.17	0.6087(5)	0.6087	0.6087
A6	4.3	5.15	0.01	0.7083(4)	0.7083	0.7083
A7	9.6	13.37	0.02	0.6944(4)	0.6944	0.6944
A8	3.1	18.33	0.01	0.8525(3)	0.8525	0.8525
A9	3.5	208.36	0.45	0.5872(2)	0.5872	0.5872
A10	1.1	6.25	0.00	0.7500(5)	0.7500	0.7500
A11	1.6	2.93	0.02	0.9200(3)	0.9200	0.9200
A12	2188.7	259.19	0.19	0.7206(7)	0.7206	0.7206
A13	593.2	179.21	0.23	0.7183(7)	0.7183	0.7183
A14	15130.5	*	4.24	0.5326(8)	*	**0.5326**
A15	252.5	*	0.25	0.6953(6)^{E}	*	**0.6899**
A16	183232.5	*	4.80	0.5753(8)	*	**0.5753**
A17	2345.6	*	3.82	0.5773(9)	*	**0.5773**
A18	*	*	32243.10	*	*	**0.4345**
A19	131357.5	*	245.59	0.5081(7)	*	**0.5081**
A20	31.1	*	0.22	0.7791(5)	*	**0.7791**
A21	14583.6	*	24.34	0.5798(5)	*	**0.5798**
A22	11.3	1.64	0.14	1.0000(7)	1.0000	1.0000
A23	230.7	*	0.12	0.8511(7)	*	**0.8511**
A24	1101.1	*	0.16	0.7351(7)	*	**0.7351**
A25	*	*	1026.96	*	*	**0.5329**
A26	*	*	178182.24	*	*	**0.4895**
A27	*	*	*	*	*	*
A28	958714.1	*	1964.00	0.5482(5)	*	**0.5482**
A29	*	*	*	*	*	*
A30	378300.0	*	8.72	0.6331(14)	*	**0.6331**
A31	*	*	136.00	0.6012(13)^{E}	*	**0.5977**
A32	*	*	*	*	*	*
A33	*	*	*	*	*	0.4800
A34	268007.6	*	16323.71	0.6064(3)	*	**0.6064**
A35	7365.3	*	1.34	0.8403(10)	*	**0.8403**

Computational experiments

#	Time, sec				Efficacy		
	Brusco (2015)	Pinheiro et al. (2016) IM	Pinheiro et al. (2016) ILP	two-index	Brusco (2015) (cells)	Pinheiro et al. (2016)	two-index
A1	0.01	0.16	0.01	0.01	0.8235(2,3,4)	0.7500^{E}	0.8235
A2	0.01	0.07	0.01	0.01	0.6957(2,3,4)	0.6956	0.6957
A3	0.02	0.09	0.03	0.01	0.8085(2,3,4)	0.8085	0.8085
A4	0.01	0.02	0.01	0.01	0.7916(2,3,4)	0.7917	0.7917
A5	0.6	0,29	0.06	0.17	0.6087(2,3,4,5,6)	0.6087	0.6087
A6	0.04	0.14	0.01	0.01	0.7083(2,3,4,5)	0.7083	0.7083
A7	0.08	0.18	0.03	0.01	0.6944(2,3,4,5)	0.6944^{E}	0.6944
A8	0.01	2.06	0.04	0.01	0.8525(2,3,4)	0.8525	0.8525
A9	35.86	81.46	4.94	0.45	0.5872(2,3,4)	0.5872	0.5872
A10	0.06	0.03	0.01	0.01	0.7500(2,3,4,5,6)	0.7500	0.7500
A11	0.01	0.01	0.02	0.02	0.9200(2,3,4)	0.9200	0.9200
A12	633.91	0.49	0.09	0.03	0.7424(6,7,8)	0.7424	0.7424
A13	2631.76	0.49	0.11	0.03	0.7285(6,7,8)	0.7286	0.7286
A14	24716.34	600.98	144.91	4.88	0.5385(8)	0.5333^{E}	0.5385
A15	1279.93	7.24	0.54	0.16	0.6992(5,6,7)	0.6992^{E}	0.6992
A16	-	1156.23	125.62	4.24	-	0.5804	0.5804
A17	20840.55	87.13	42.32	3.84	0.5773(9)	0.5773^{E}	0.5773
A18	-	*	*	52810.10	-	*	**0.4397**
A19	1375608.66	23928.70	1771.99	249.52	0.5081(7)	0.5081	0.5081
A20	4830.00	1.78	14.55	0.09	0.7888(5,6,7)	0.7938^{E}	0.7888
A21	-	2145.24	305.48	22.60	-	0.5879^{E}	0.5860
A22	0.01	0.02	0.15	0.14	1.0000(7)	1.0000	1.0000
A23	42.29	10.08	0.44	0.14	0.8511(7)	0.8511	0.8511
A24	208158.02	17.46	0.78	0.20	0.7351(7)	0.7351	0.7351
A25	-	371233.00	48743.90	759.70	-	0.5329^{E}	0.5329
A26	-	*	*	134418.65	-	*	**0.4895**
A27	-	*	*	*	-	*	*
A28	-	*	*	46361.97	-	*	**0.5482**
A29	-	*	*	*	-	*	*
A30	-	183.71	41.53	8.00	-	0.6304^{E}	0.6331
A31	-	13807.50	2622.06	64.82	-	0.5977	0.5977
A32	-	*	*	234055.90	-	*	**0.5084**
A33	-	*	*	*	-	*	0.4829
A34	-	*	*	14212.57	-	*	**0.6131**
A35	-	325.53	18.22	1.61	-	0.8403	0.8403

Computational experiments

Table 9: Testset B - Computational results

#	Time		Efficacy		
	two-index (no residual cells)	two-index (allow residual cells)	Heuristic bound	two-index (no residual cells)	two-index (allow residual cells)
B1	0.01	0.01	0.8095	0.8095	0.8095
B2	0.01	0.01	0.7222	0.7222	0.7222
B3	0.25	0.03	0.6071	0.6071	0.6071
B4	0.01	0.01	0.8889	0.8889	0.8889
B5	0.01	0.01	0.7500	0.7500	0.7500
B6	0.01	0.01	0.7391	0.7391	0.7391
B7	0.01	0.01	0.8148	0.8148	0.8148
B8	0.01	0.01	0.7222	0.7222	0.7222
B9	0.01	0.01	0.7576	0.7576	0.7576
B10	0.01	0.01	0.9000	0.9000	0.9000
B11	0.01	0.02	0.7273	0.7273	0.7297
B12	0.01	0.01	0.8276	0.8276	0.8276
B13	0.36	0.80	0.5962	0.5962	0.6042
B14	0.25	0.30	0.6405	0.6405	0.6405
B15	0.01	0.01	0.8333	0.8333	0.8333
B16	0.16	0.06	0.7391	0.7391	0.7444
B17	0.98	0.26	0.6552	0.6552	0.6842
B18	1.82	1.65	0.6027	0.6129	0.6129
B19	0.03	0.06	0.8000	0.8000	0.8113
B20	0.05	0.03	0.8710	0.8710	0.8710
B21	0.03	0.04	0.8333	0.8333	0.8333
B22	0.05	0.01	0.7258	0.7258	0.7258
B23	0.05	0.06	0.8111	0.8111	0.8111
B24	4.79	7.80	0.5673	0.5673	0.5728
B25	0.20	0.10	0.7600	0.7600	0.8000
B26	13.81	25.75	0.6068	0.6068	0.6078
B27	0.25	0.28	0.7248	0.7248	0.7248
B28	0.83	1.04	0.6729	0.6729	0.6729
B29	33.82	51.76	0.5730	0.5730	0.5745
B30	4.76	8.67	0.7308	0.7308	0.7325
B31	19.69	17.50	0.6798	0.6798	0.6798
B32	*	*	0.6193	*	*

Computational experiments

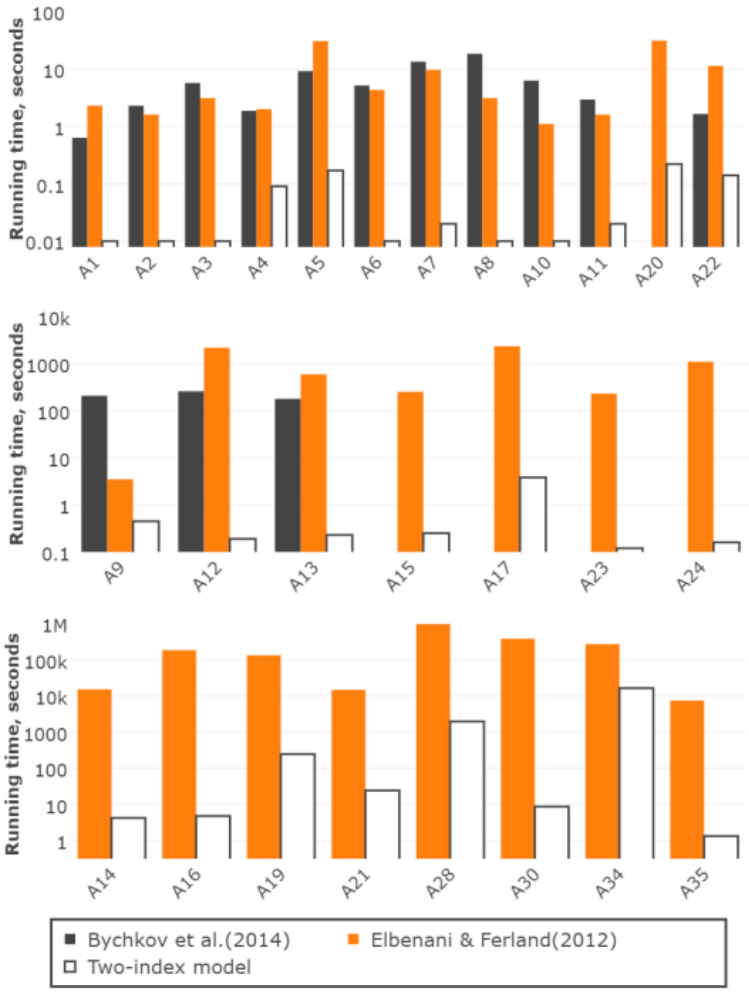


Figure 1: Testset A - No residual cells. Running times comparison.

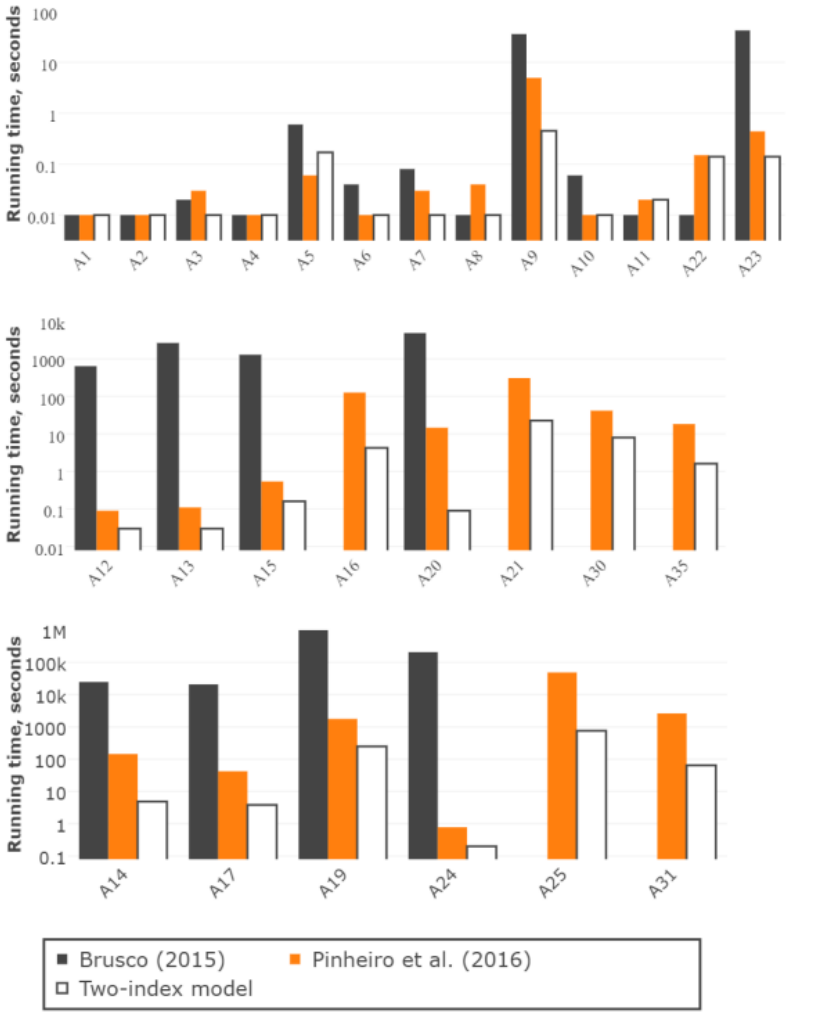


Figure 2: Testset A - Allowed residual cells. Running times comparison.

Contributions

Bychkov et al.(2014) Exact model for the Cell Formation Problem // *Optimization Letters*. 2014. Vol. 8. No. 8. P. 2203-2210.

- A new exact model for the cell formation problem has been suggested (**three-index model**)
- For many existing manufacturing cell formation problem instances global optimality of existing solutions has been probed

Bychkov & Batsyn (2017) An efficient exact model for the cell formation problem with variable number of production cells // Computers & Operations Research (On review)

- A new efficient simple exact model without direct machine-to-cell or part-to-cell relations for the manufacturing cell formation has been suggested (**two-index model**)
- Almost all the existing problem instances are solved exactly with respect to variable number of production cells
- One new dataset collected from the literature and the corrected classical 35GT dataset are provided for future research

Contributions

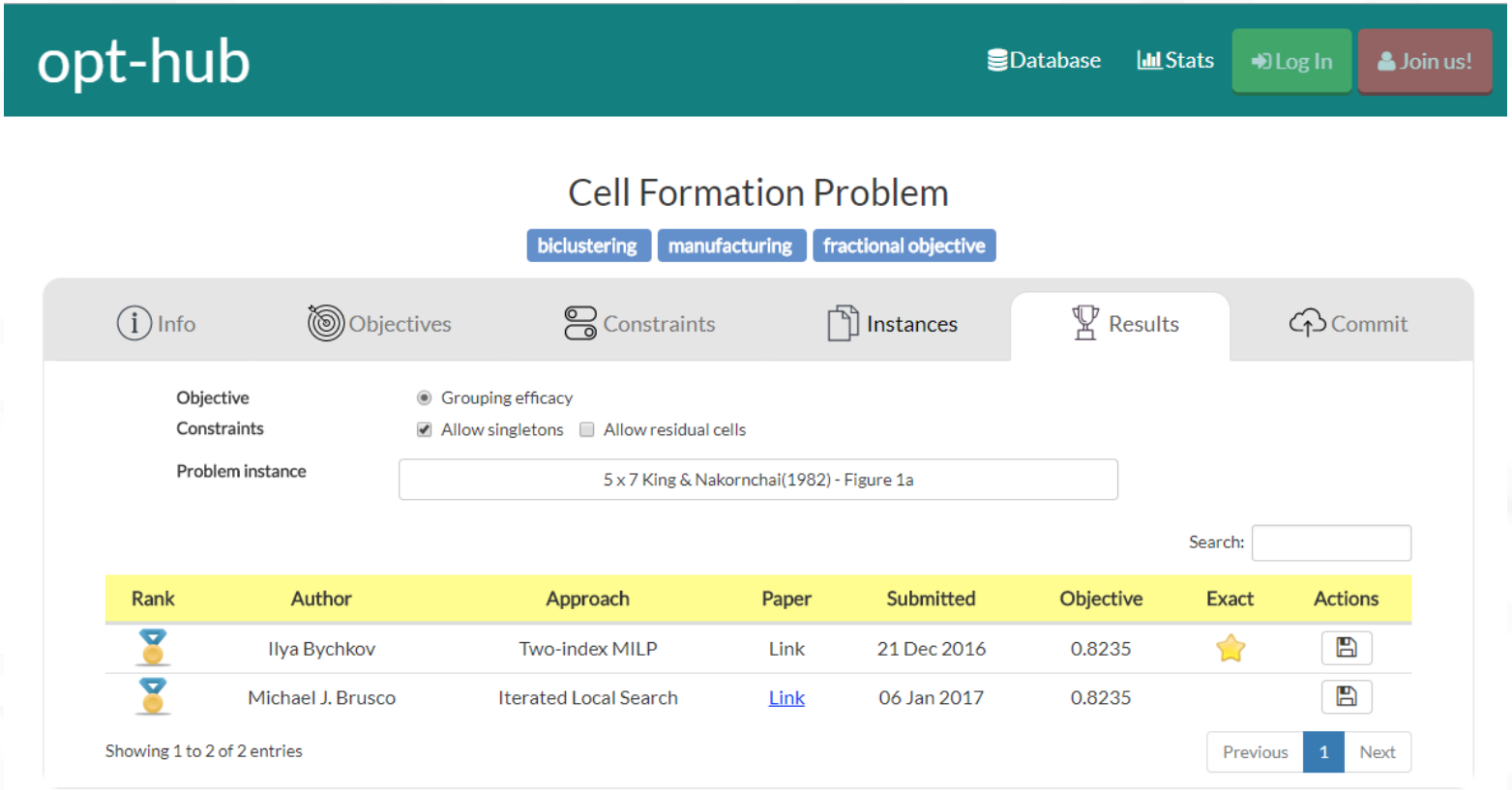
- Batsyn, M., Bychkov, I., Goldengorin, B., Pardalos, P., & Sukhov, P. (2013). Pattern-based heuristic for the cell formation problem in group technology. In *Models, Algorithms, and Technologies for Network Analysis* (pp. 11-50). Springer, New York, NY.

- Bychkov, I., Batsyn, M., Sukhov, P., & Pardalos, P. M. (2013). Heuristic algorithm for the cell formation problem. In *Models, Algorithms, and Technologies for Network Analysis* (pp. 43-69). Springer, New York, NY.

- Bychkov I., Batsyn M., & Pardalos P.M. (2017). Heuristic for Maximizing Grouping Efficiency in the Cell Formation Problem. In *Models, Algorithms, and Technologies for Network Analysis: NET 2016, Nizhny Novgorod, Russia, Springer Proceedings in Mathematics and Statistics, Springer International Publishing*. Springer International Publishing.

Contributions

One new dataset collected from the literature and the corrected classical 35GT dataset are provided for future research



Thank you