IMPROVE: A Developed Approach for Solving the Machine Part Cell Formation Problem

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Abstract: ***grouping of machines into cells and parts into families by using incidence matrix formation is equivalent to block diagonalization of the matrix so as to minimize exceptional elements or maximize cell independency. The IMPROVE algorithm tries to make block diagonalization of matrix to minimize exceptional and void elements in an existing initial solution by reassigning machines and parts from cell to another. This paper is an extension for the IMPROVE algorithm in order to solve problems instead of just improving existing solutions. The IMPROVE algorithm can solve problems by using random initial solutions. This study presents many cases for (a 16x43) problem with a comparison with previous approaches for solution. The results showed the superiority of IMPROVE algorithm over other approaches in all test cases.***

Keywords: machine cell formation problem, IMPROVE algorithm, developed IMPROVE algorithm.

1. Introduction

The part family/machine group formation problem can be defined as one of identifying and grouping parts into families and machines into cells, and then assigning families to cells such as to satisfy some objectives. Many models have been developed for machine cell formation. The ROC2 "Rank order clustering algorithm" is an improvement of ROC algorithm [1] which was developed by King and Nakornchai [2]. The algorithm can give a block diagonal form by various trial assignments of the exceptional elements and transfers of parts between machines of the same type, i.e. duplicated bottleneck machines. In the work of Chan and et al [3], a two-phase approach was proposed to tackle the cell formation problem (CFP) with consideration of both intra-cell and inter-cell part movements. In the first phase, a mathematical model with multi objective function is formed to obtain the machine-part cells. Another mathematical model is proposed in the second phase to optimize the total intra and inter cell part movements.

Genetic algorithm (GA) is used to solve this approach. A heuristic approach called MACE that is based on the similarity coefficient of the product type in cell formation with the minimum number of exceptional elements was presented by Waghodekar and Sahu [4]. Askin et al [5] proposed formulating machine and part ordering as a hamiltonian path problem while using similarity coefficients to form a distance measure for machines and parts. The Seifoddini and Wolfe model [6] improves the models based on similarity coefficient method (SCM) by dealing with duplication of bottleneck machines. The duplication process, that is based on the number of intercellular moves starts with the machine generating the largest number of intercellular transfers and continues until no machine generates more intercellular transfers than specified by a threshold value. Boctor [7] formulated the machine part group formation problem as a mixed integer linear program. The objective of his model was to minimize the number of exceptional elements. James et al [8] presented a hybrid grouping genetic algorithm for the cell formation problem that combines this search with a standard grouping genetic algorithm to form machine-part cells. The model introduced by Kusiak [9] considered two classes of clustering models (matrix and integer program "P-median") and showed the relationship between them. Viswanathan [10] developed Kusiak's model [9] to eliminate the weakness of the P-median formulation. This weakness is that the number of cells required has to be specified in advance in the mathematical formulation. He suggested a new measure for similarity coefficient that can take both positive and negative values depending on similarity and dissimilarity between machines or between parts. The development of Kusiak's model in the Viswanathan model aims at determining the optimal number of cells. A new heuristic approach to solve machine cell formation problem by minimizing the number of exceptional and void elements through an IMPROVE algorithm was developed by Elmogassabi [11]. The approach is based on reassignment of bottleneck machines and exceptional parts that resulted from application of any earlier procedure of assignment to reduce number of exceptional and void elements.

In a paper by Jayachitra et al. [12], a mathematical model for virtual manufacturing systems is formulated as binary integer programming, for optimizing the total cost, comprised of fixed machines costs, variable costs of all machines and the logical group movement costs. Part demand and machine's capacity are considered to be fuzzy. Results were compared with solutions obtained using simulated annealing,. SA, algorithm and rank order clustering algorithm, ROC, while reporting results, of comparisons.

The machine-part cell formation problem is tackled using a group genetic algorithm proposed by Arikaran and Jayabalan [13], called (pro-GGA). The pro-GGA is developed for maximizing the total parts flow within cells considering process plans, production volume and cell size. The model is formulated as a 0-1 integer programming The numerical examples and comparisons show that the Pro-GGA is effective and outperforms all the other methods considered.
In a paper by Modak et al. [14] , a number of clustering techniques are quantified to develop part families by utilizing Opitz part coding scheme.. . The C-Linkage method was found to outperform the SCA method and the K-means method in terms of the best solution quality (sum of similarities values).

Tolouei-Rad [15] developed an algorithm for an integrated approach for part classification, cell formation and capacity adjustment. The algorithm is based on group technology code to each part and to each a part family. After forming machine cells for part families, machine tool capacity adjustment is considered with the objective of minimization of the machine purchase and operating costs.

For improving cell utilization, Fallahalipour et al. [16] presented a model for cell formation. The model, nonlinear model, is based on minimizing the number of voids in cells to achieve higher utilization. To reach to a solution, a SA model is developed and tested on problems of different sizes against solutions obtained by Lingo8 software, in terms of objectives of value and processing time, with very promising results.

2. The IMPROVE Algorithm

The developed IMPROVE algorithm takes a random solution and improves on it by reducing the number of exceptional and void elements. To achieve this improvement, the number of intercellular moves between each bottleneck machine/exceptional part and the machine cells/part families interacting with it are determined. Then, the bottleneck machine is assigned to the cell whose components have the largest number of operations on the machine. Cells containing a single machine may be practically accepted. If not accepted, these machines may be reassigned to other cells with the objective of balancing the workload to minimize the number of exceptional elements. The IMPROVE algorithm for minimizing the number of exceptional and void elements has a higher percentage of success arriving at solutions and results in more cells of uniform size when compared with the case of minimizing the number of exceptional elements only [17]. The number of cells in the initial solution is set as the upper limit of the number of cells in the final solution, therefore, as the number of cells in the initial solution increases, the final solution can reach the near optimal number of cells, so the IMPROVE algorithm may reduce the number of cells [17].

3. Steps of IMPROVE algorithm

The number of intercellular moves between each bottleneck machine/exceptional part and the machine cells/part families interacting with it are determined. Then, the bottleneck machine is assigned to the cell whose components have the largest number of operations on the machine. Cells containing a single machine may be practically accepted. If not accepted machines may be reassigned to other cells with the objective of balancing the workload or as to minimize the number of exceptional elements.

Step 0: Check whether all machines and parts are assigned to cells and calculate the grouping index for the initial solution and enter whether the machines or parts are to be reassigned first.

Step 1: For each machine, calculate the number of ones and zeros in each cell.

Step 2: Assign each machine to the cell that has maximum number of ones. In case of a tie, select the cell that has minimum number of zeros and then calculate the grouping index after the machine assignment.

Step 3: Perform steps 1and 2 for all parts.

Step 4: If the solution resulting from step 3 is not different from the base solution used for steps 2 and 3, go to step5, else repeat steps from 1 to 3.

Step 5: If cells containing a single machine may be practically accepted, go to step7, else go to step6.

Step 6: For cells of a single machine, the machine will be reassigned to another cell with the objective of balancing the workload or as to minimize the number of exceptional elements.

Step 7: Calculate the grouping index for the final solution and stop.

4. Application of the IMPROVE algorithm for Grouping of Parts and Machines

One approach for using the proposed algorithm is to group the machines and parts into cells by assignment of the machines and parts in their cells randomly in the initial solution after deciding upon the number of cells. To explain this use, a numerical example is used, where there are 16 machines and 43 parts as shown in Fig. 1. Twenty five random solutions are obtained by changing the random assignment of machines and parts in their cells and changing the number of cells in each case. Some initial solutions are constructed by the user based on the relationship between machines and parts in each cell. The size of cells within each group of some problems is approximately equal.

The IMPROVE algorithm is applied on the above random solutions under three different conditions to study the effects of the existing solutions, number of cells, order of reassignment of machines or parts and exceptional and void elements on the grouping process. The first condition is grouping machines and parts so as to minimize number of exceptional elements only. The second and third conditions involve grouping machines and parts such as to minimize number of exceptional and void elements, with the second condition reassigning the machines first while the third condition reassigns the parts first. It is noted that solutions of IMPROVE, obtained using second condition, have more output cells than those obtained by other conditions and have mostly the same ratio between number of machines and parts assigned to output cells [17]. The criterion of minimizing number of exceptional and void elements is better than that of minimizing only number of exceptional element, because it is more likely to find solutions, resulting in more number of cells, and with more uniformity on sizes of cells. The approach for reassignment of machines first is better than that of reassignment of parts first. It gave more practical and acceptable solutions, with a large number of cells, and cells of mostly of the same size with less number of void elements [17].

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43
1																																					1					1	
2		1								1																		1				1					1	1		1		1	
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5					1			1	1					1	1	1			1		1		1						1				1								1		1
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7	1												1												1																		
8	1	1	1					1	1		1	1			1				1	1	1		1	1			1	1			1						1	1			1		1
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Figure 1: Machine-part incidence matrix for example [1].

5. Evaluation the IMPROVE algorithm

Different earlier approaches are used to solve example 16x43 to compared their solutions with that obtained from developed IMPROVE algorithm. The performance measures which were used to compare different solutions are number of exceptional elements "e_o", number of void elements "e_v", balance work load and the grouping index "γ". Work balance can be defined as a ratio between cell sizes in each solution [17].

From the results in Table 1, the newly developed IMPROVE algorithm succeeds in reaching to better solutions for all tested cases while IMPROVE algorithm improves all cases except two where it gives the same solutions. In some cases, IMPROVE algorithm [11] minimizes number of exceptional elements by reducing number of cells through merging empty cells where all elements are zeros, and by moving single machine or single part in a cell to other cells. Also, in some unrealistic conditions such as the idle machine or idle part and empty cells, the number of cells resulting after application of IMPROVE algorithm is mostly less than that in the initial solution.

Boctor's model, IMPROVE and the developed IMPROVE algorithm, GA, and HGGA methods give several alternative solutions for a problem. For IMPROVE and the developed IMPROVE algorithm, GA, and HGGA methods, the multiple alternative solutions are created by changing initial solution at each time while Boctor's model creates them by changing upper and lower levels allowable for number of machines and parts in each cell. Kusiak's model, Viswanathan's model, ALC, ROC, and ROC2 give one solution for a problem.

In most cases, the developed IMPROVE algorithm gives several solutions that are better than those solutions resulting from other methods. Viswanathan's model and HGGA give eight cells in their results where Viswanathan model gives 8 part families and 5 machine cells, an infeasible solution as given in the appendix, case No. 19. HGGA method has one empty cell which means that number of cells resulting is 7. The maximum number of cells that the developed IMPROVE algorithm can get is 7 cells.

As shown from the results in the appendix, methods that have two stages to solve the machine part cell formation problem like Kusiak's model and Viswanathan's model probably give infeasible solution. The problem that happened in these methods results from ignoring the relationships between parts and machines especially in the first stage where they used the relationship between part to part or machine to machine, i.e. the similarity coefficients. Also parts or machines are grouped to cells in the first stage then others are grouped to cells. this may cause unequal number of cells in the first and second stages.

Table 1: Comparison between IMPROVE algorithm, developed IMPROVE algorithm with other earlier approaches

Case	Solution source	Approach	Performance measures of Methods				Performance measures of IMPROVE algorithm				Performance measures of the developed IMPROVE algorithm			
			# Cell	# exceptional element	# void element	Grouping index	# Cell	# exceptional element	# void element	Grouping index	# Cell	# exceptional element	# void element	Grouping index
1	Kusiak	With p=2	2	19	246	0.65^{b}	2^{e}	13	232	0.67	2	13	232	0.67
2	Boctor	With p=2	2	15	233	0.66^{b}	2^{e}	13	232	0.67	2	13	232	0.67
3	Kusiak	With p=3	3	28	139	0.62	3	23	127	0.65	3	17	157	0.67
4	Boctor	With p=3	3^{e}	17	181	0.67	3^{e}	17	181	0.67	3	17	157	0.67
5	Chan et al. (2008)	GA	3	30	116	0.61^{b}	3	24	131	0.64	3	17	157	0.67
6	Askin et al.(1991)	ROC2	3	31	161	0.6^{b}	3	17	186	0.67	3	17	157	0.67
7	King and Nakornchai, (1982)	ROC2	4	36	83	0.57	4^{e}	23	96	0.66	4	17	159	0.67
8	King(1980)	ROC	4	66	116	0.38^{b}	4	26	77	0.64	4	17	159	0.67
9	Chan et al.(2008)	GA	4	29	76	0.62^{b}	4	26	77	0.64	4	17	159	0.67

10	Kusiak	With p=4	4	36	103	0.57[a]	4	36	103	0.57	4	17	159	0.67
11	Boctor	With p=4	4	24	100	0.65	4[e]	21	108	0.67	4	17	159	0.67
12	Boctor	With p=4	4	23	119	0.65[b]	4	21	126	0.66[a]	4	17	159	0.67
13	Seifoddini (1989)	ALC	5	27	77	0.63	4[e]	21	108	0.67	4	17	159	0.67
14	Askin et al.(1991)	HPH	5	31	51	0.6	5	28	54	0.63	5	23	104	0.65
15	Chan et al.(2008)	GA	5	29	54	0.62[b]	5[e]	27	56	0.64	5	23	104	0.65
16	Kusiak	With p=5	5	42	83	0.52[a]	3[e]	21	139	0.66	3	17	157	0.67
17	Boctor	With p=5	5	27	58	0.64	5[e]	27	56	0.64	5	23	104	0.65
18	Viswanathan	Similarity[S1]	7	44	23	0.46[a,b]	7	42	30	0.49[a]	7	32	44	0.60[a]
19	Viswanathan	Similarity[S2]	8	38	38	0.54[d]	5[e]	27	56	0.64	5	23	104	0.65
20	James,et al	HGGA	8	42	20	0.48[a,b]	6[e]	30	48	0.61[a]	6	29	52	0.62[a]

a: The solution has a cell or more of a single machine or a single part or both.
b: The solution has some machines or parts that are not active in their cell (idle machines or idle parts).
c: The solution has unbalanced work load.
d: The solution has unequal part families and machine cells (infeasible solution).
e: Same solution obtained by developed IMPROVE algorithm
S1: Similarity coefficient between machines
S2: Similarity coefficient between parts

6. Conclusions

The IMPROVE algorithm brought about the best possible block diagonal structure in a zero-one and formed the machine-part groups by reassigning them from an improper cell to another cell without restriction on the cell size and number of cells. In this paper, the developed IMPROVE algorithm has the ability to create machine-part groups based on an initial solution that is randomly generated. This study shows the weakness for some methods.

- The results show that the developed IMPROVE algorithm is better than other approaches on all test cases.
- The IMPROVE algorithm and Boctor's model are close to the developed IMPROVE algorithm. Also, the developed IMPROVE algorithm has the ability to give several alternative solutions with different number of groups for a problem as Boctor's model. However, Boctor's model has one drawback when compared with IMPROVE and the developed IMPROVE algorithms where it does not minimize void elements.
- The developed IMPROVE algorithm can give a maximum number of groups for any problem.
- The methods that solve part machine formation problem in two stages do not use the relationship between parts and machines thus have the likelihood of not reaching to feasible solutions.
- The empty cells, idle machines, and idle parts never happen in the solutions for IMPROVE and developed IMPROVE algorithm.

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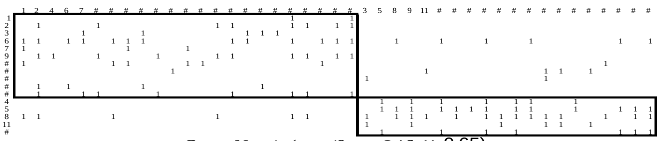
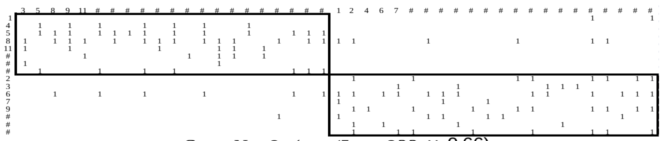
I. Appendix

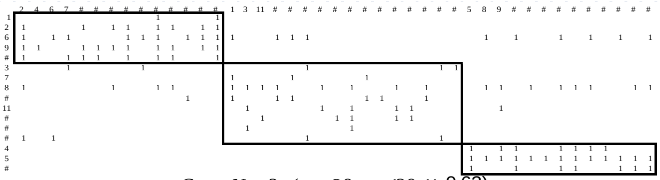
CASES SOLUTIONS,IMPROVEMENTS FOR ALL CASES AND DEVELOPED IMPROVE SOLUTIONS



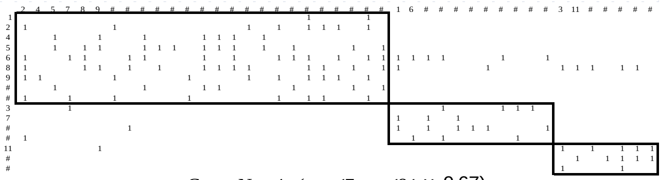
Case No. 1 (eo=19 ev=246 γ=0.65)



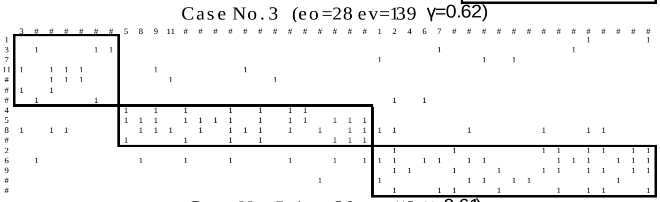
Case No. 2 (eo=15 ev=233 γ=0.66)



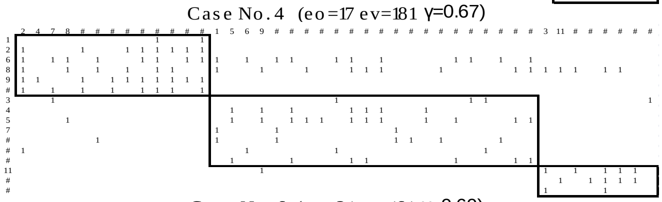
Case No. 3 (eo=28 ev=139 γ=0.62)



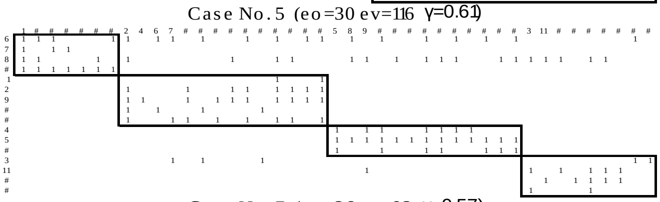
Case No. 4 (eo=17 ev=181 γ=0.67)



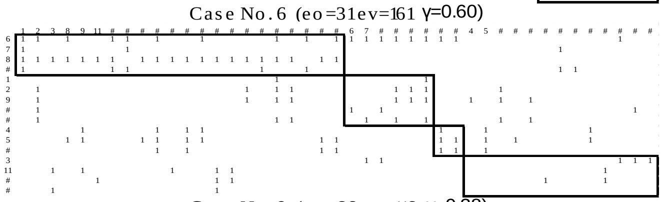
Case No. 5 (eo=30 ev=116 γ=0.61)



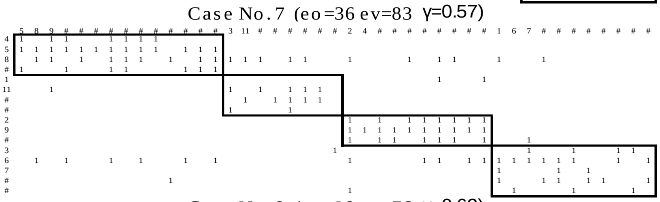
Case No. 6 (eo=31 ev=161 γ=0.60)



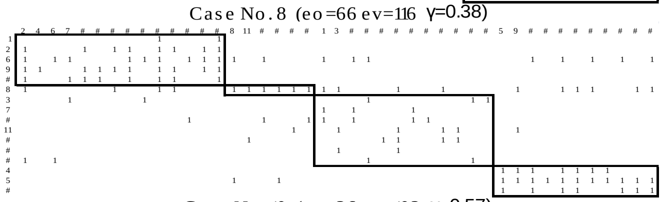
Case No. 7 (eo=36 ev=83 γ=0.57)



Case No. 8 (eo=66 ev=116 γ=0.38)



Case No. 9 (eo=29 ev=76 γ=0.62)



Case No. 10 (eo=36 ev=103 γ=0.57)

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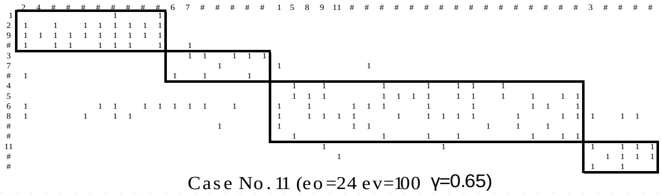
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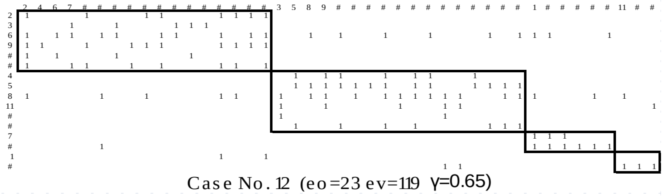
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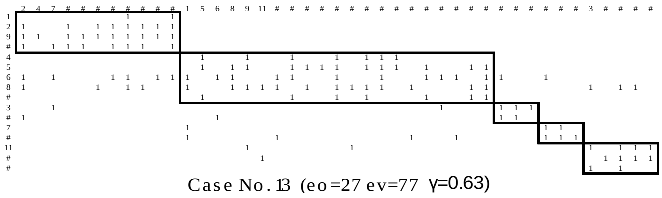
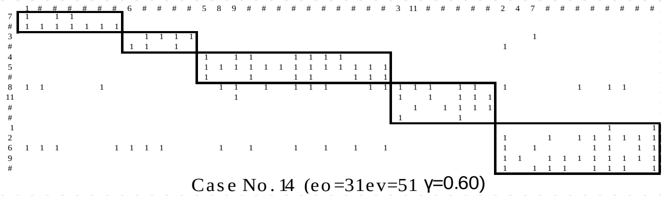

Case No. 13 (eo=27 ev=77 γ=0.63)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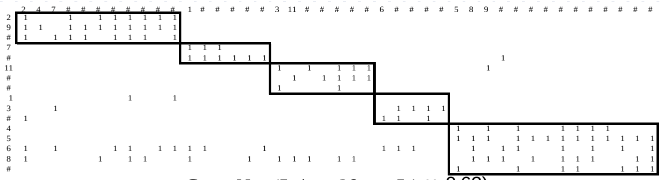
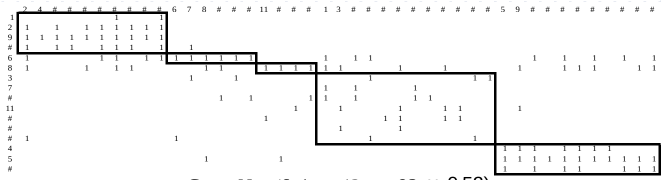
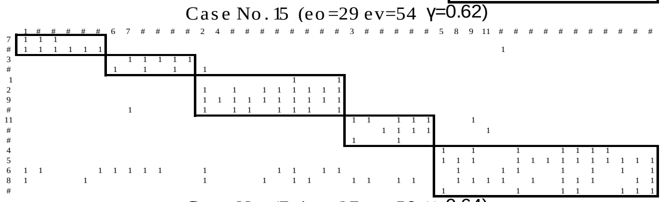
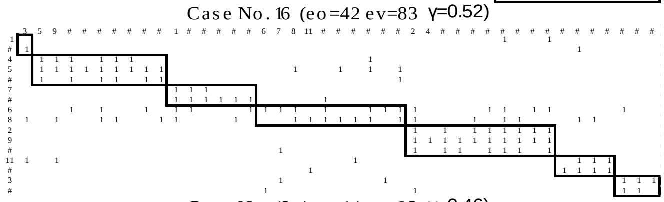
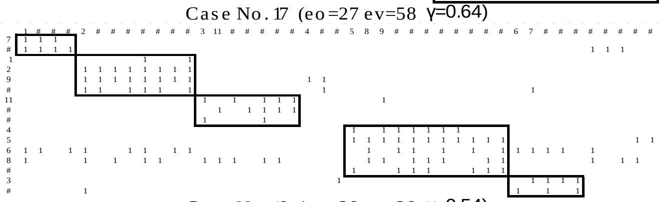
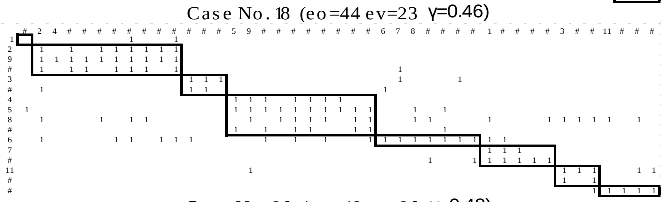

Case No. 15 (eo=29 ev=54 γ=0.62)

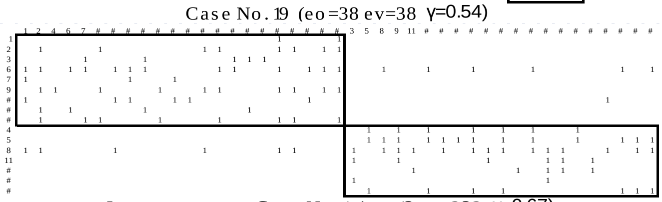

Case No. 16 (eo=42 ev=83 γ=0.52)

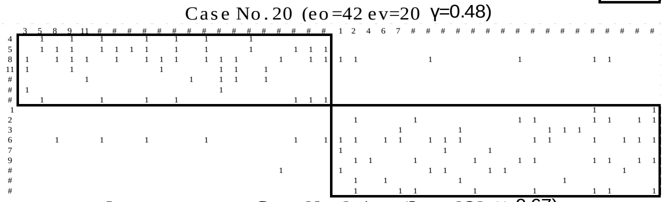

Case No. 17 (eo=27 ev=58 γ=0.64)

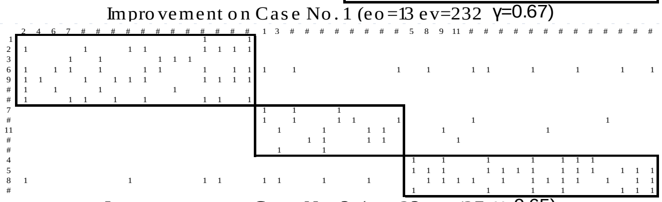

Case No. 18 (eo=44 ev=23 γ=0.46)

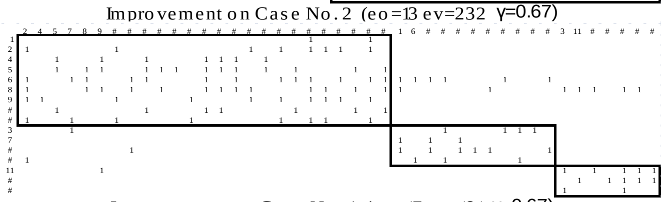

Case No. 19 (eo=38 ev=38 γ=0.54)

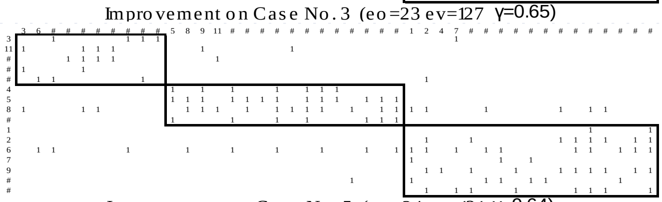

Case No. 20 (eo=42 ev=20 γ=0.48)

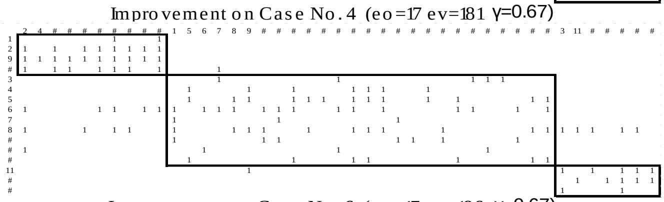

Improvement on Case No. 1 (eo=13 ev=232 γ=0.67)

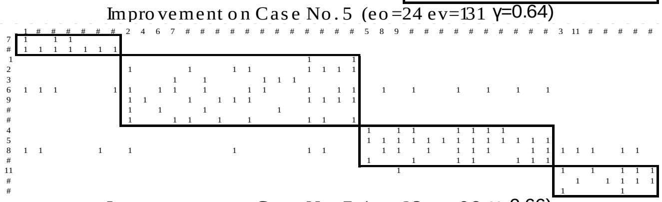

Improvement on Case No. 2 (eo=13 ev=232 γ=0.67)

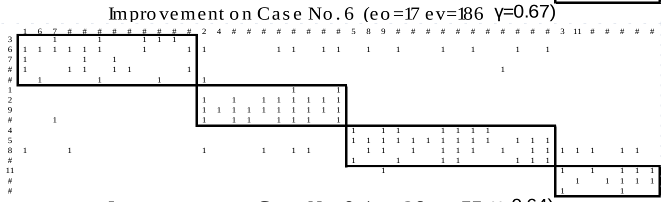

Improvement on Case No. 3 (eo=23 ev=127 γ=0.65)

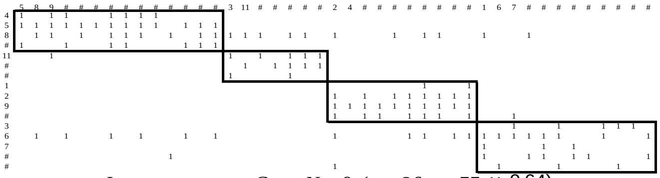

Improvement on Case No. 4 (eo=17 ev=181 γ=0.67)


Improvement on Case No. 5 (eo=24 ev=131 γ=0.64)

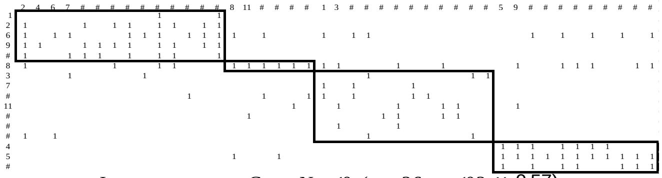

Improvement on Case No. 6 (eo=17 ev=186 γ=0.67)


Improvement on Case No. 7 (eo=23 ev=96 γ=0.66)

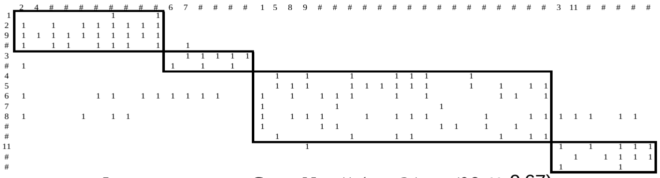

Improvement on Case No. 8 (eo=26 ev=77 γ=0.64)



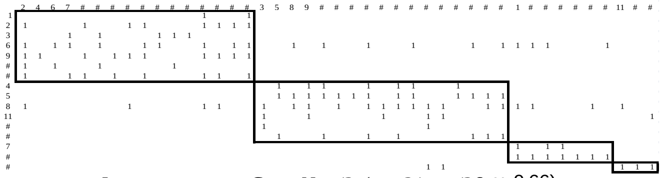
Improvement on Case No. 9 (eo=26 ev=77 γ=0.64)



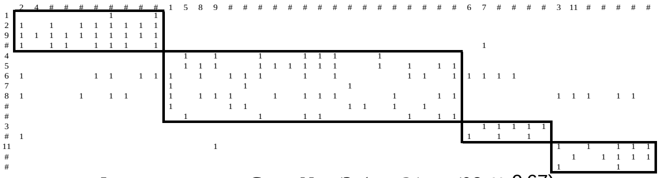
Improvement on Case No. 10 (eo=36 ev=103 γ=0.57)



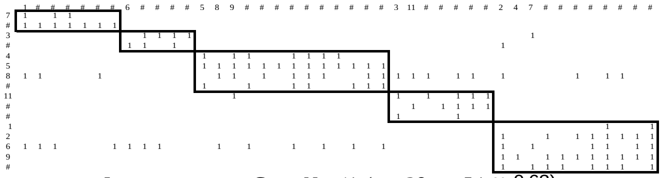
Improvement on Case No. 11 (eo=21 ev=108 γ=0.67)



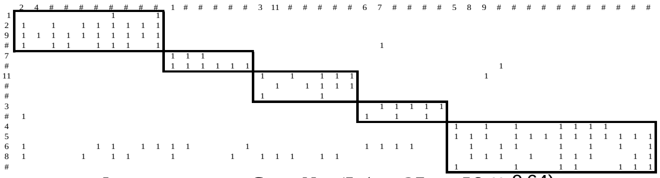
Improvement on Case No. 12 (eo=21 ev=126 γ=0.66)



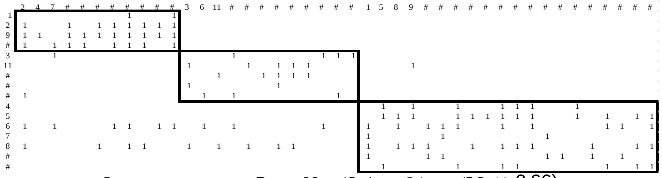
Improvement on Case No. 13 (eo=21 ev=108 γ=0.67)



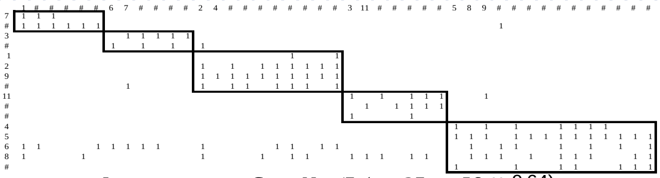
Improvement on Case No. 14 (eo=28 ev=54 γ=0.63)



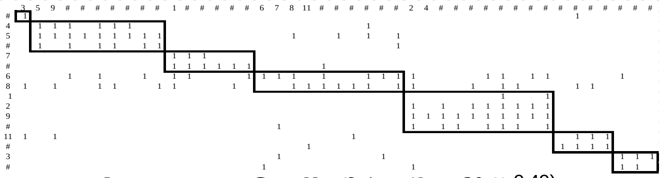
Improvement on Case No. 15 (eo=27 ev=56 γ=0.64)



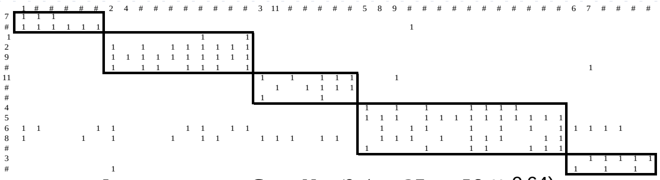
Improvement on Case No. 16 (eo=21 ev=139 γ=0.66)



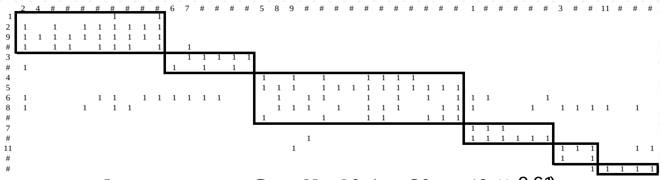
Improvement on Case No. 17 (eo=27 ev=56 γ=0.64)



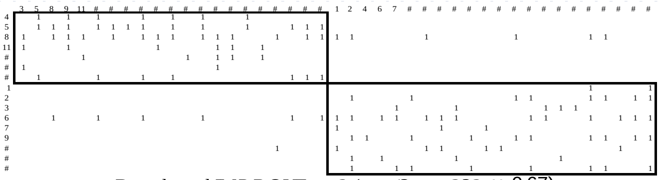
Improvement on Case No. 18 (eo=42 ev=30 γ=0.49)



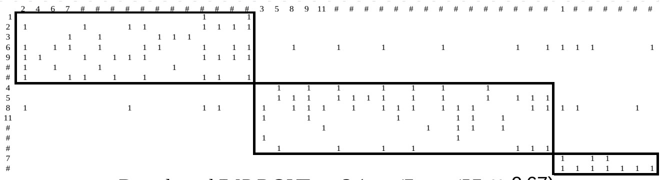
Improvement on Case No. 19 (eo=27 ev=56 γ=0.64)



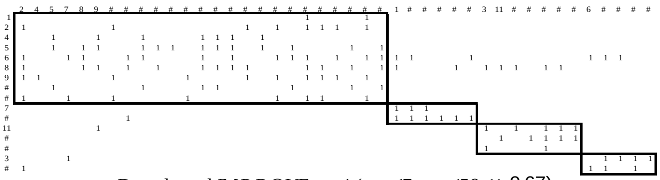
Improvement on Case No. 20 (eo=30 ev=48 γ=0.61)



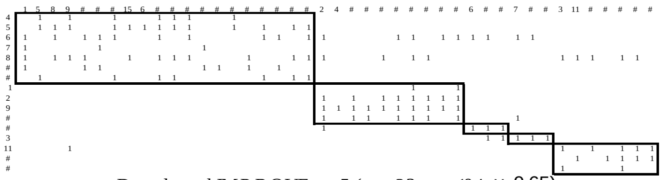
Developed IMPROVE, p=2 (eo=13, ev=232, γ=0.67)



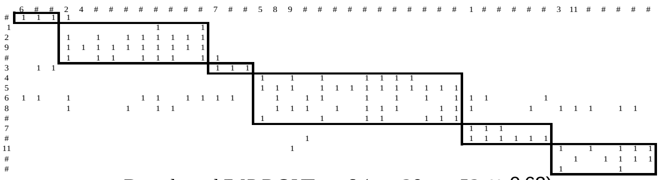
Developed IMPROVE, p=3 (eo=17, ev=157, γ=0.67)



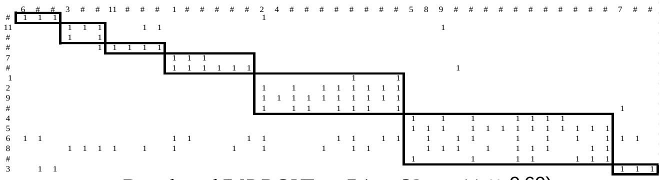
Developed IMPROVE, p=4 (eo=17, ev=159, γ=0.67)



Developed IMPROVE, p=5 (eo=23, ev=104, γ=0.65)



Developed IMPROVE, p=6 (eo=29 ev=52 γ=0.62)



Developed IMPROVE, p=7 (eo=32 ev=44 γ=0.60)

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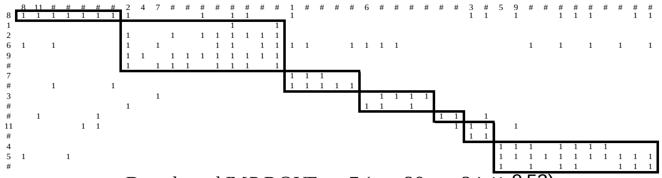
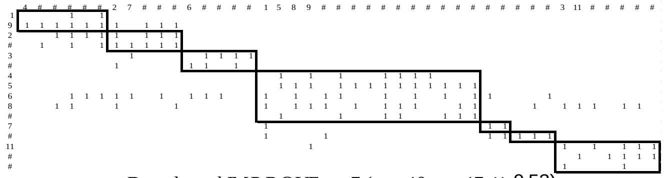


Developed IMPROVE, p=7 (eo=39 ev=34 γ=0.52)



Developed IMPROVE, p=7 (eo=40 ev=47 γ=0.52)