Modelos y Optimización I
TP3

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Aclaración:
Perdón si el largo se pasa del esperado, pero a la hora de pasar los engine logs no me terminaba de cerrar la forma que tomaban cuando los copiaba y pegaba del oplide, por eso decidí incluirlos en formato de foto, lo que llevó a que ocuparan más espacio del esperado. eso sumado a que las soluciones normalmente ocupaban 2 páginas, esto alargo notablemente la longitud del informe.

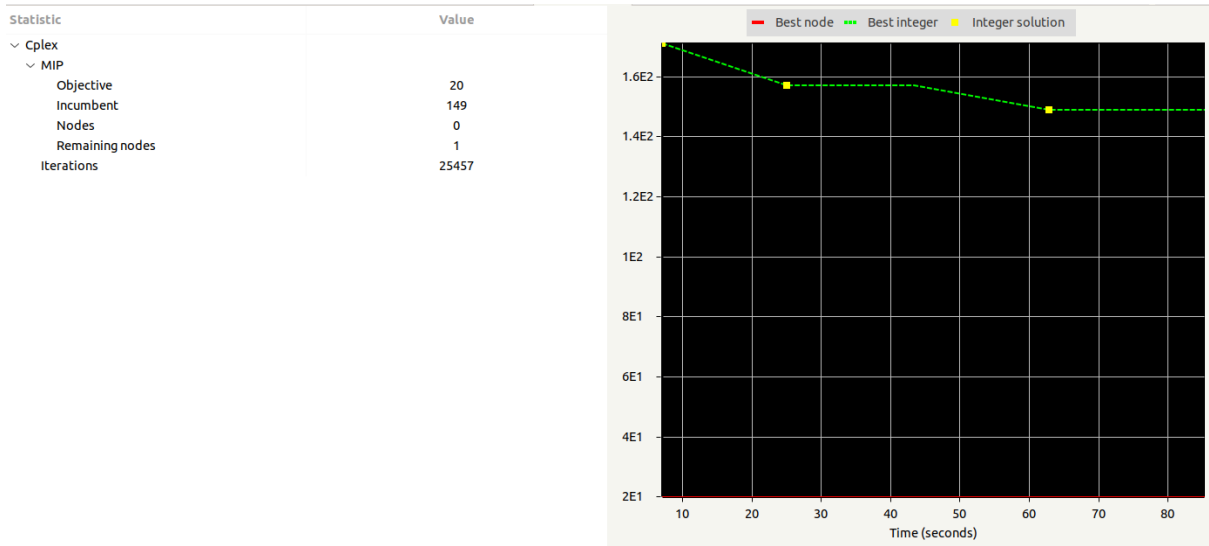1)solución obtenida con una de las heurísticas del tp2:
tiempo: 165

1 2
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126 104
130 104
133 104
136 104
7 106
21 106
25 106
53 106
61 106
62 106
70 106
80 106
84 106
89 106
106 106
115 106
19 19
20 19
32 19
58 19
64 19
65 19
81 19
96 19
100 19
72 127
78 127
83 127
127 127
18 18
54 18
57 138
138 138
45 116
116 116
95 95
36 36
135 135
74 74

2)
Time limit:

```
6⊖ execute {
7      cplex.tilim = 600;
8 }
```

Stats:

Statistic	Value
∨ Cplex	
∨ MIP	
Objective	20
Incumbent	149
Nodes	0
Remaining nodes	1
Iterations	25457

Engine logs:

```
Version identifier: 22.1.1.0 | 2022-11-28 | 9160aff4d
CPXPARAM_TimeLimit                               600
Legacy callback                                  pi
Tried aggregator 1 time.
MIP Presolve eliminated 120467 rows and 0 columns.
MIP Presolve modified 12013 coefficients.
Reduced MIP has 34783 rows, 19182 columns, and 121915 nonzeros.
Reduced MIP has 19044 binaries, 138 generals, 0 SOSs, and 0 indicators.
Presolve time = 0,45 sec. (253,66 ticks)
Found incumbent of value 2760,000000 after 0,63 sec. (403,01 ticks)
Probing time = 0,22 sec. (12,13 ticks)
Tried aggregator 1 time.
Detecting symmetries...
Reduced MIP has 34783 rows, 19182 columns, and 121915 nonzeros.
Reduced MIP has 19044 binaries, 138 generals, 0 SOSs, and 0 indicators.
Presolve time = 0,78 sec. (391,75 ticks)
Probing time = 0,19 sec. (11,35 ticks)
Clique table members: 15739.
MIP emphasis: balance optimality and feasibility.
MIP search method: dynamic search.
Parallel mode: deterministic, using up to 8 threads.
Root relaxation solution time = 2,66 sec. (475,47 ticks)
```

	Nodes					Cuts/		
Node	Left	Objective	IInf	Best Integer	Best Bound	ItCnt	Gap
*	0+	0			2760,0000	0,0000		100,00%
*	0+	0			1467,0000	0,0000		100,00%
*	0+	0			171,0000	0,0000		100,00%
	0	0	20,0000	4286	171,0000	20,0000	11	88,30%
*	0+	0			157,0000	20,0000		87,26%
	0	0	20,0000	2389	157,0000	Cuts: 310	5617	87,26%
	0	0	20,0000	2140	157,0000	Cuts: 1993	11229	87,26%
	0	0	20,0000	2243	157,0000	Cuts: 1933	19205	87,26%
*	0+	0			156,0000	20,0000		87,18%
*	0+	0			153,0000	20,0000		86,93%
*	0+	0			149,0000	20,0000		86,58%
	0	0	-1,00000e+75	0	149,0000	20,0000	19205	86,58%
	0	0	20,0000	1960	149,0000	Cuts: 1852	25457	86,58%
	0	0	20,0000	2146	149,0000	Cuts: 1805	34259	86,58%
	0	2	20,0000	1315	149,0000	20,0000	34259	86,58%
Elapsed time = 133,26 sec. (60514,51 ticks, tree = 0,02 MB, solutions = 7)								
	1	3	37,0000	907	149,0000	20,0000	42352	86,58%
	2	3	20,0000	1498	149,0000	20,0000	40447	86,58%
	3	4	46,2868	778	149,0000	20,0000	51903	86,58%
	4	4	37,0000	1104	149,0000	20,0000	46258	86,58%
	6	8	47,5795	715	149,0000	20,0000	66090	86,58%
	10	12	53,0000	660	149,0000	20,0000	73726	86,58%
	12	5	37,0000	1195	149,0000	20,0000	56690	86,58%
	14	7	37,0000	855	149,0000	20,0000	66785	86,58%
	15	10	56,0000	649	149,0000	20,0000	83501	86,58%

```
     21     19        53,0000    516       149,0000       20,0000   115103   86,58%
Elapsed time = 219,46 sec. (71055,96 ticks, tree = 0,40 MB, solutions = 7)
     27     26        66,0000    444       149,0000       20,0000   159711   86,58%
     34     27        57,0000    430       149,0000       20,0000   165238   86,58%
     41     38        66,0000    388       149,0000       21,3727   206633   85,66%
     53     24        37,0000    690       149,0000       21,3727   157083   85,66%
     65     46        81,0000    621       149,0000       21,3727   224383   85,66%
     79     56        69,0000    436       149,0000       21,3727   279452   85,66%
     91     76        89,0000    342       149,0000       21,3727   310831   85,66%
    109     94        98,0000    304       149,0000       21,3727   363577   85,66%
    130    108        92,0000    432       149,0000       21,3727   429897   85,66%
    154    102        78,2810    685       149,0000       21,3727   408803   85,66%
Elapsed time = 327,45 sec. (81810,87 ticks, tree = 5,57 MB, solutions = 8)
*   156+   138                             148,0000       21,3727            85,56%
*   214+   193                             139,0000       21,3727            84,62%
    218    157       100,0000    469       139,0000       21,3727   540835   84,62%
*   236+   216                             138,0000       21,3727            84,51%
    253    234       117,0000     65       138,0000       21,3727   586442   84,51%
    322    242        83,0000    449       138,0000       21,3727   617845   84,51%
*   324+   276                             137,0000       21,3727            84,40%
*   350+   265                             135,0000       21,3727            84,17%
*   362+   296                             127,0000       21,3727            83,17%
*   412    331       integral      0       126,0000       21,3727   655306   83,04%
    413    333       123,0000     18       126,0000       21,3727   667675   83,04%
*   415    332       integral      0       125,0000       21,3727   667682   82,90%
*   426    315       integral      0       124,0000       21,3727   667688   82,76%
    463    325        94,0000    614       124,0000       21,3727   688821   82,76%
    489    321        96,0000    578       124,0000       21,3727   705302   82,76%
*   513+   371                             123,0000       21,3727            82,62%
*   513+   368                             122,0000       21,3727            82,48%
    513    367       122,0000      0       122,0000       21,3727   755716   82,48%
    523    348        46,2868   1108       122,0000       21,3727   818095   82,48%
    538    334        49,5795   1002       122,0000       21,3727   796286   82,48%
    555    360        52,0000    816       122,0000       21,3727   862028   82,48%
Elapsed time = 432,27 sec. (91745,65 ticks, tree = 7,35 MB, solutions = 21)
    567    361        75,0000    857       122,0000       21,3727   856735   82,48%
    577    388        89,0000    529       122,0000       21,3727   942503   82,48%
    589    392        89,0000    401       122,0000       21,3727   950259   82,48%
    603    397        98,0000    489       122,0000       21,3727   959398   82,48%
    622    418        78,2810    648       122,0000       21,3727  1048126   82,48%
    646    435        72,0000    757       122,0000       21,3727  1082262   82,48%
    675    450       119,0000    122       122,0000       21,3727  1079533   82,48%
    692    471        80,8980    540       122,0000       21,3727  1175878   82,48%
    708    454        59,8750    688       122,0000       21,3727  1141659   82,48%
    732    512        98,0000    387       122,0000       21,3727  1256301   82,48%
Elapsed time = 536,92 sec. (101613,25 ticks, tree = 8,20 MB, solutions = 21)
    755    502        56,0000    731       122,0000       21,3727  1240190   82,48%
    782    529        59,8750    843       122,0000       21,3727  1331157   82,48%

Starting limited solution polishing.
    813    546       101,0000    450       122,0000       21,3727  1357598   82,48%
    845    615       115,4789    225       122,0000       21,3727  1488741   82,48%
    884    559       113,0000    242       122,0000       21,3727  1395028   82,48%
    950    679       120,0000     14       122,0000       21,3727  1544668   82,48%
*   957    675       integral      0       121,0000       21,3727  1544683   82,34%
    978    603       103,0000    333       121,0000       21,3727  1475144   82,34%

Implied bound cuts applied:  8536
Zero-half cuts applied:  433
Gomory fractional cuts applied:  49

Root node processing (before b&c):
  Real time             =  132,97 sec. (60320,92 ticks)
Parallel b&c, 8 threads:
  Real time             =  467,14 sec. (48394,12 ticks)
  Sync time (average)   =   78,99 sec.
  Wait time (average)   =    0,00 sec.
                          ------------
Total (root+branch&cut) =  600,12 sec. (108715,04 ticks)
```

mejor solución encontrada:

solution: 121 /size: 138 /time: 1718480096.781507969

Nodo 1: 123
Nodo 2: 117
Nodo 3: 117
Nodo 4: 28
Nodo 5: 28
Nodo 6: 40
Nodo 7: 40
Nodo 8: 99
Nodo 9: 117
Nodo 10: 117
Nodo 11: 117
Nodo 12: 28
Nodo 13: 28
Nodo 14: 117
Nodo 15: 117
Nodo 16: 117
Nodo 17: 123
Nodo 18: 37
Nodo 19: 117
Nodo 20: 30
Nodo 21: 127
Nodo 22: 20
Nodo 23: 40
Nodo 24: 118
Nodo 25: 117
Nodo 26: 118
Nodo 27: 28
Nodo 28: 118
Nodo 29: 27
Nodo 30: 117
Nodo 31: 40
Nodo 32: 27
Nodo 33: 127
Nodo 34: 28
Nodo 35: 28
Nodo 36: 27
Nodo 37: 37
Nodo 38: 99
Nodo 39: 117
Nodo 40: 40
Nodo 41: 28
Nodo 42: 37
Nodo 43: 20
Nodo 44: 123
Nodo 45: 118
Nodo 46: 117
Nodo 47: 117
Nodo 48: 117
Nodo 49: 117
Nodo 50: 28
Nodo 51: 123
Nodo 52: 127
Nodo 53: 127
Nodo 54: 37
Nodo 55: 28
Nodo 56: 117
Nodo 57: 127
Nodo 58: 118
Nodo 59: 117
Nodo 60: 37
Nodo 61: 37
Nodo 62: 117
Nodo 63: 123
Nodo 64: 20
Nodo 65: 123
Nodo 66: 123
Nodo 67: 123
Nodo 68: 40
Nodo 69: 37
Nodo 70: 118
Nodo 71: 117
Nodo 72: 28
Nodo 73: 123
Nodo 74: 99
Nodo 75: 40
Nodo 76: 28
Nodo 77: 117
Nodo 78: 27
Nodo 79: 117
Nodo 80: 118
Nodo 81: 30
Nodo 82: 117
Nodo 83: 118
Nodo 84: 123
Nodo 85: 117

Nodo 86: 123
Nodo 87: 117
Nodo 88: 117
Nodo 89: 40
Nodo 90: 123
Nodo 91: 117
Nodo 92: 123
Nodo 93: 123
Nodo 94: 123
Nodo 95: 40
Nodo 96: 123
Nodo 97: 118
Nodo 98: 123
Nodo 99: 118
Nodo 100: 117
Nodo 101: 40
Nodo 102: 117
Nodo 103: 117
Nodo 104: 117
Nodo 105: 117
Nodo 106: 117
Nodo 107: 117
Nodo 108: 118
Nodo 109: 37
Nodo 110: 37
Nodo 111: 37
Nodo 112: 40
Nodo 113: 28
Nodo 114: 118
Nodo 115: 127
Nodo 116: 20
Nodo 117: 28
Nodo 118: 118
Nodo 119: 117
Nodo 120: 117
Nodo 121: 27
Nodo 122: 27
Nodo 123: 118
Nodo 124: 28
Nodo 125: 37
Nodo 126: 28
Nodo 127: 117
Nodo 128: 117
Nodo 129: 117
Nodo 130: 127
Nodo 131: 123
Nodo 132: 28
Nodo 133: 40
Nodo 134: 28
Nodo 135: 127
Nodo 136: 28
Nodo 137: 28
Nodo 138: 123

Análisis:

En 10 minutos no encontró la solución óptima, esto se puede ver en el gap que le falta para terminar.

Se puede ver que ya encontró una solución mejor que la mía y encontró 19 soluciones enteras como mínimo. Sumado a esto se ve como las primeras soluciones mejoran ampliamente el resultado de las anteriores y mientras más avanza el modelo menos mejoran los resultados, parece que le costó especialmente mejorar los resultados de 149 y 122.

Viendo la columna de **ItCnt** se pueden apreciar conclusiones similares a las del párrafo anterior donde a mejor solución más aumenta el número de interacciones que hace el modelo para encontrar soluciones.

Concusión:

En este caso el modelo está buscando dentro de todas las soluciones posibles, entonces si bien el modelo es válido y seguramente si lo dejo ejecutarse un tiempo ilimitado encuentre la solución cada avance que haga requerirá más **ItCnt** ya que no hay nada que le simplifique a la hora de seleccionar que camino tomar.

3)

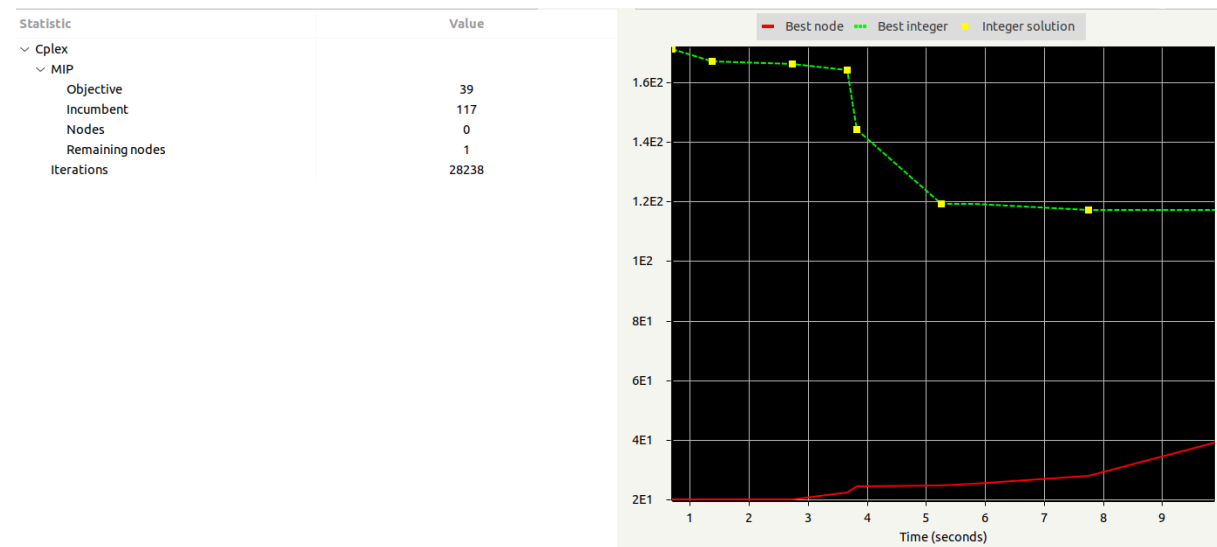**Cambios en el código:**

```
10  int limiteColores = 15;
```

Stats:

Statistic	Value
∨ Cplex	
∨ MIP	
Objective	39
Incumbent	117
Nodes	0
Remaining nodes	1
Iterations	28238

Engine logs:

```
Version identifier: 22.1.1.0 | 2022-11-28 | 9160aff4d
CPXPARAM_TimeLimit                               600
Legacy callback                                  pi
Tried aggregator 1 time.
MIP Presolve eliminated 13053 rows and 0 columns.
MIP Presolve modified 1347 coefficients.
Reduced MIP has 3945 rows, 2085 columns, and 13532 nonzeros.
Reduced MIP has 2070 binaries, 15 generals, 0 SOSs, and 0 indicators.
Presolve time = 0,04 sec. (23,27 ticks)
Found incumbent of value 300,000000 after 0,07 sec. (37,25 ticks)
Probing time = 0,04 sec. (4,04 ticks)
Tried aggregator 1 time.
Detecting symmetries...
Reduced MIP has 3945 rows, 2085 columns, and 13532 nonzeros.
Reduced MIP has 2070 binaries, 15 generals, 0 SOSs, and 0 indicators.
Presolve time = 0,02 sec. (12,94 ticks)
Probing time = 0,07 sec. (4,04 ticks)
Clique table members: 1875.
MIP emphasis: balance optimality and feasibility.
MIP search method: dynamic search.
Parallel mode: deterministic, using up to 8 threads.
Root relaxation solution time = 0,20 sec. (148,88 ticks)
```

	Nodes					Cuts/		
	Node	Left	Objective	IInf	Best Integer	Best Bound	ItCnt	Gap
*	0+	0			300,0000	0,0000		100,00%
*	0+	0			171,0000	0,0000		100,00%
	0	0	20,0000	1121	171,0000	20,0000	1890	88,30%
*	0+	0			167,0000	20,0000		88,02%
	0	0	20,0000	1075	167,0000	Cuts: 466	3376	88,02%
*	0+	0			166,0000	20,0000		87,95%
	0	0	22,3129	1075	166,0000	Cuts: 1046	7555	86,56%
*	0+	0			164,0000	22,3129		86,39%
	0	0	24,4000	1000	164,0000	Cuts: 867	10779	85,12%
*	0+	0			162,0000	24,4000		84,94%
*	0+	0			146,0000	24,4000		83,29%
*	0+	0			144,0000	24,4000		83,06%
	0	0	-1,00000e+75	0	144,0000	24,4000	10779	83,06%
*	0+	0			119,0000	24,4000		79,50%
	0	0	24,4190	857	119,0000	Cuts: 685	15477	79,28%
	0	0	24,8376	978	119,0000	Cuts: 668	17933	78,71%
	0	0	25,1408	865	119,0000	Cuts: 705	19017	78,58%
	0	0	25,4164	983	119,0000	Cuts: 582	20016	78,38%
	0	0	25,6319	950	119,0000	Cuts: 570	21211	78,20%
	0	0	25,7120	922	119,0000	Cuts: 488	21877	78,13%
	0	0	25,7848	945	119,0000	Cuts: 466	22531	78,03%
	0	0	25,8287	1029	119,0000	Cuts: 425	23437	77,96%
	0	0	25,8736	1044	119,0000	Cuts: 490	24423	77,94%
*	0+	0			117,0000	26,2563		77,56%
	0	0	25,9381	996	117,0000	Cuts: 518	25444	76,15%

```
      0      0     26,0113  1037     117,0000     Cuts: 502    26842   76,15%
      0      0     26,0693   954     117,0000     Cuts: 363    27469   66,67%
      0      0     26,0946   959     117,0000     Cuts: 584    28238   66,67%
      0      2     26,0946   913     117,0000       39,0000    28238   66,67%
Elapsed time = 10,80 sec. (6438,85 ticks, tree = 0,02 MB, solutions = 10)
      1      3     39,0062   814     117,0000       39,0000    30567   66,67%
      5      5     39,0000   785     117,0000       39,0000    33164   66,67%
     26      8     53,0788   661     117,0000       39,0000    36586   66,67%
     57     27     40,8198   728     117,0000       39,0000    45570   66,67%
     90     76     77,0000   498     117,0000       39,0000    65892   66,67%
    142    111     82,2609   467     117,0000       39,0000    76855   66,67%
    199    166     90,1787   304     117,0000       39,0000    88634   66,67%
    306    221    101,0000   285     117,0000       39,0000    99412   66,67%
    410    339    111,0000   162     117,0000       39,0000   118386   66,67%
    515    443     79,1787   366     117,0000       39,0000   154419   66,67%
Elapsed time = 17,64 sec. (9597,42 ticks, tree = 10,70 MB, solutions = 10)
    618    524    101,0000   240     117,0000       39,0000   196641   66,67%
    808    645     88,0000   354     117,0000       39,0000   233844   66,67%
   1043    813     52,0000   591     117,0000       39,0000   304820   66,67%
   1192    943     78,4170   404     117,0000       39,0000   339595   66,67%
   1413   1186     88,0000   359     117,0000       39,0000   410759   66,67%
   1608   1373     67,9425   565     117,0000       40,7008   454125   65,21%
   1818   1494     65,7252   549     117,0000       41,0894   487108   64,88%
   2121   1773    114,0000   103     117,0000       41,4594   555214   64,56%
   2331   2000     68,4299   526     117,0000       42,0712   611137   64,04%
   2602   2234     53,0857   599     117,0000       42,2470   662616   63,89%
Elapsed time = 41,91 sec. (19175,37 ticks, tree = 65,85 MB, solutions = 10)
   2859   2492     54,7310   583     117,0000       42,3942   717759   63,77%
   3105   2754    infeasible          117,0000       43,0398   781220   63,21%
   3289   2924     61,3061   551     117,0000       43,3413   821628   62,96%


Performing restart 1

Repeating presolve.
Tried aggregator 1 time.
MIP Presolve eliminated 124 rows and 60 columns.
Reduced MIP has 3821 rows, 2025 columns, and 13232 nonzeros.
Reduced MIP has 2010 binaries, 15 generals, 0 SOSs, and 0 indicators.
Presolve time = 0,02 sec. (15,58 ticks)
Tried aggregator 1 time.
Reduced MIP has 3821 rows, 2025 columns, and 13232 nonzeros.
Reduced MIP has 2010 binaries, 15 generals, 0 SOSs, and 0 indicators.
Presolve time = 0,02 sec. (12,70 ticks)
Represolve time = 0,12 sec. (51,54 ticks)
   3308      0     39,3330   811     117,0000     Cuts: 348   867058   62,96%
   3308      0     39,5897   819     117,0000     Cuts: 776   868125   62,96%
   3308      0     40,0026   752     117,0000     Cuts: 506   869454   62,96%
   3308      0     40,0929   722     117,0000     Cuts: 708   871024   62,96%
   3308      0     40,1169   760     117,0000     Cuts: 638   871568   62,96%
   3308      0     40,3326   723     117,0000     Cuts: 420   872498   62,96%
   3308      0     40,7321   705     117,0000     Cuts: 689   874574   62,96%
```

```
  3308      0     41,3623    697    117,0000    Cuts: 726    876072    62,96%
  3308      0     41,8290    694    117,0000    Cuts: 731    876733    62,96%
  3308      0     42,3999    742    117,0000    Cuts: 789    877808    62,96%
  3308      0     42,6213    691    117,0000    Cuts: 824    878788    62,96%
  3308      0     42,7301    742    117,0000    Cuts: 765    879757    62,96%
  3308      0     42,8330    689    117,0000    Cuts: 686    880177    62,96%
  3308      0     42,8814    718    117,0000    Cuts: 701    880861    62,96%
  3308      0     42,8835    715    117,0000    Cuts: 282    881127    62,96%
  3308      2     42,8835    703    117,0000        43,3413    881127    62,96%
  3310      3     53,4872    511    117,0000        43,3709    882478    62,93%
  3320     13     43,6422    654    117,0000        43,6444    887662    62,70%
  3349     34     65,1716    519    117,0000        44,3384    894041    62,10%
  3400     42     52,2177    582    117,0000        44,3384    898985    62,10%
  3504    151     87,9909    363    117,0000        44,3384    935967    62,10%
  3695    196     85,0000    344    117,0000        44,3384    951690    62,10%
Elapsed time = 76,62 sec. (36505,11 ticks, tree = 1,61 MB, solutions = 10)
  4115    527     62,5541    416    117,0000        44,3384   1010485    62,10%
  4350    822     96,2812    393    117,0000        44,3384   1066586    62,10%
  4574   1021     85,0000    388    117,0000        44,3384   1139545    62,10%
  5017   1254     70,5000    477    117,0000        49,8846   1213854    57,36%
  5488   1595     96,5625    332    117,0000        50,8202   1279741    56,56%
  6080   2235     99,0476    378    117,0000        51,2351   1359358    56,21%
  6657   2710    104,7250    287    117,0000        51,7538   1401041    55,77%
  7205   3355    104,1265    336    117,0000        52,2663   1456626    55,33%
  7850   3747     64,8849    519    117,0000        52,5812   1500429    55,06%
  8331   4429     85,0000    377    117,0000        53,3843   1579362    54,37%
Elapsed time = 96,76 sec. (46094,16 ticks, tree = 45,27 MB, solutions = 10)
  8858   4769    101,0000    271    117,0000        53,5040   1635348    54,27%
  9436   5477     99,5989    304    117,0000        53,8692   1712785    53,96%
 10059   5841     97,3889    343    117,0000        54,5127   1747311    53,41%
 10796   6749    108,9000    243    117,0000        54,5838   1835532    53,35%
 11387   7112    111,5484    314    117,0000        54,9038   1865652    53,07%
 11917   7784     97,3889    335    117,0000        55,0153   1936702    52,98%
 12450   8329    101,4105    387    117,0000        55,3142   2004965    52,72%
 13054   8809    112,3529    197    117,0000        55,6679   2050234    52,42%
 13729   9353    101,8211    319    117,0000        55,8806   2111460    52,24%
 14365   9939     97,9444    301    117,0000        56,2505   2180594    51,92%
Elapsed time = 117,38 sec. (55643,19 ticks, tree = 178,08 MB, solutions = 10)
 14991  10610     98,7273    367    117,0000        56,6045   2240476    51,62%
 15676  11104    116,0000    170    117,0000        56,6742   2280411    51,56%
 16244  11838    111,0000    283    117,0000        56,9162   2358083    51,35%
 16958  12189    101,0000    261    117,0000        57,1418   2400985    51,16%
 17613  12626    107,8846    284    117,0000        57,5249   2445865    50,83%
 18291  13468    104,0000    264    117,0000        57,6742   2528342    50,71%
 18933  14138     97,3889    362    117,0000        58,2196   2595287    50,24%
 19626  14685     88,0000    344    117,0000        58,4229   2647474    50,07%
 20252  15311    112,0000    176    117,0000        58,8503   2707306    49,70%
 20792  15454     96,0000    317    117,0000        59,0966   2741150    49,49%
Elapsed time = 139,29 sec. (65192,55 ticks, tree = 332,99 MB, solutions = 10)
 21416  16151    116,0000    218    117,0000        59,2001   2803200    49,40%
 22262  16994     90,0417    335    117,0000        59,4997   2891721    49,15%
```

```
  23029  17777        104,0000     303       117,0000       59,7579   2958661    48,92%
  23729  18484        101,0000     284       117,0000       59,8343   3020295    48,86%
  24262  18968         91,0943     346       117,0000       60,0593   3068548    48,67%
  24825  19574         93,1030     339       117,0000       60,2747   3141531    48,48%
  25552  19938        107,8421     309       117,0000       60,3782   3178534    48,39%
  26104  20718         98,5292     354       117,0000       60,5072   3263711    48,28%
  27063  21197         97,3889     356       117,0000       60,7622   3299280    48,07%
  27661  21977         90,0417     350       117,0000       61,0495   3356790    47,82%
Elapsed time = 161,99 sec. (74738,27 ticks, tree = 528,30 MB, solutions = 10)
  28290  22314        112,0000     251       117,0000       61,1102   3386264    47,77%
  29043  22849        100,9494     353       117,0000       61,3776   3451018    47,54%
  29787  24047          cutoff               117,0000       61,7803   3554288    47,20%
  30587  24486         97,3889     360       117,0000       61,7912   3597999    47,19%
  31283  25001        100,0318     344       117,0000       62,0467   3648412    46,97%
  31947  25809          cutoff               117,0000       62,0738   3716277    46,95%
  32710  26654         77,5467     421       117,0000       62,2051   3812788    46,83%
  33517  27168         86,5040     446       117,0000       62,3991   3855811    46,67%
  34162  28141         79,4307     350       117,0000       62,4637   3942797    46,61%
  34838  28696        116,0000     167       117,0000       62,7522   3993916    46,37%
Elapsed time = 185,64 sec. (84285,66 ticks, tree = 710,62 MB, solutions = 10)
  35416  29301        106,4156     283       117,0000       62,8336   4057874    46,30%
  36075  29736         86,8630     358       117,0000       62,8336   4101295    46,30%
  36517  30559         86,0602     465       117,0000       63,1456   4183772    46,03%
  37061  30788        114,5625     275       117,0000       63,1456   4205065    46,03%
  37798  31236        101,0000     331       117,0000       63,1456   4250248    46,03%
  38520  31714         80,4002     382       117,0000       63,3622   4285666    45,84%
  39313  32205        103,7851     355       117,0000       63,5153   4332525    45,71%
  39887  32608         97,3889     356       117,0000       63,5831   4364424    45,66%
  40469  33830        106,9444     268       117,0000       63,6873   4484520    45,57%
  41076  34391         85,0000     325       117,0000       63,8228   4550558    45,45%
Elapsed time = 210,60 sec. (93834,52 ticks, tree = 854,59 MB, solutions = 10)
  41750  34597         96,0000     299       117,0000       63,8472   4582133    45,43%
  42554  35354        105,1706     274       117,0000       63,9791   4657004    45,32%
  43153  36283        110,5545     321       117,0000       64,0000   4739027    45,30%
  43651  36777        106,6542     307       117,0000       64,0000   4785044    45,30%
  44265  36917         96,0000     316       117,0000       64,0000   4800322    45,30%
  44980  37772        103,0417     362       117,0000       64,2028   4905299    45,13%
  45679  38229        115,2500     230       117,0000       64,3284   4948213    45,02%
  46461  39573        112,0000     208       117,0000       64,4375   5066021    44,93%
  47243  40061         91,1319     359       117,0000       64,6055   5115939    44,78%
  49722  41924         91,0968     387       117,0000       65,0000   5299584    44,44%
Elapsed time = 246,17 sec. (106248,62 ticks, tree = 1087,63 MB, solutions = 10)
  52675  44916         82,0417     420       117,0000       65,2927   5595559    44,19%
  55761  47226         92,0186     327       117,0000       65,7054   5796533    43,84%
  58412  50071         78,8920     499       117,0000       65,9395   6070042    43,64%
  61163  52715         92,5851     351       117,0000       66,1670   6323756    43,45%
  64076  55118         92,0186     310       117,0000       66,5000   6532861    43,16%
  66720  57527        107,0000     339       117,0000       66,7719   6755471    42,93%

Performing restart 2
```

```
Repeating presolve.
Tried aggregator 1 time.
MIP Presolve eliminated 130 rows and 0 columns.
Reduced MIP has 3691 rows, 2025 columns, and 19179 nonzeros.
Reduced MIP has 2010 binaries, 15 generals, 0 SOSs, and 0 indicators.
Presolve time = 0,03 sec. (19,74 ticks)
Tried aggregator 1 time.
Reduced MIP has 3691 rows, 2025 columns, and 19179 nonzeros.
Reduced MIP has 2010 binaries, 15 generals, 0 SOSs, and 0 indicators.
Presolve time = 0,02 sec. (17,13 ticks)
Represolve time = 0,24 sec. (90,11 ticks)
  68780       0    104,0000   245      117,0000      Cuts: 45    7062407   11,11%
  68780       0    104,0000   319      117,0000      Cuts: 447   7062791   11,11%
  68780       0    104,0000   274      117,0000      Cuts: 130   7063103   11,11%
  68780       0    104,0000   315      117,0000      Cuts: 364   7063524   11,11%
  68780       0    104,0000   322      117,0000      Cuts: 159   7063709   11,11%
  68780       0    104,0000   248      117,0000      Cuts: 19    7063910   11,11%
  68780       0    104,0000   362      117,0000      Cuts: 607   7064576   11,11%
  68780       0    104,0000   344      117,0000      Cuts: 142   7064889   11,11%
  68780       0    104,0000   391      117,0000      Cuts: 490   7065256   11,11%
  68780       0    104,0000   235      117,0000      Cuts: 82    7065560   11,11%
  68780       0    104,0000   340      117,0000      Cuts: 442   7066086   11,11%
  68780       2    104,0000   308      117,0000      104,0000    7066086   11,11%
  68820      26    107,0000   308      117,0000      104,0000    7073784   11,11%
  68916      72    110,1818   307      117,0000      104,0000    7094194   11,11%
  69534     446    105,0000   333      117,0000      104,0000    7142817   11,11%
Elapsed time = 365,73 sec. (148980,77 ticks, tree = 8,55 MB, solutions = 10)
  71542    2103    104,7909   323      117,0000      104,0000    7325289   11,11%
  73759    3728    112,6667   290      117,0000      104,2347    7488604   10,91%
  76262    6309    114,2135   273      117,0000      104,6404    7701872   10,56%
  79502    8669    112,0000   142      117,0000      104,8684    7866643   10,37%
  82121   11377    112,0000   266      117,0000      105,0000    8087761   10,26%
  84467   13008    111,0000   293      117,0000      105,0000    8241228   10,26%
  86377   14769    109,3846   280      117,0000      105,0000    8415850   10,26%
  88124   16274    114,0000   243      117,0000      105,0000    8592873   10,26%
  89964   17979    116,0000   235      117,0000      105,0000    8773916   10,26%
  91742   19810    114,1026   316      117,0000      105,0000    8968366   10,26%
Elapsed time = 478,84 sec. (187147,17 ticks, tree = 609,07 MB, solutions = 10)
  93285   20689    110,0000   426      117,0000      105,0000    9093519   10,26%
  94970   22148    107,6986   429      117,0000      105,0000    9266152   10,26%
  96666   23741    114,0000   294      117,0000      105,0500    9470959   10,21%
  99167   25429    107,8810   329      117,0000      105,1264    9628204   10,15%
 100756   27148    108,0000   300      117,0000      105,1602    9805180   10,12%
Starting limited solution polishing.
 102087   28185    116,0000   270      117,0000      105,1864    9931192   10,10%
 103584   29632    cutoff              117,0000      105,2069   10066199   10,08%
 104710   30478    cutoff              117,0000      105,2318   10182748   10,06%
 105867   31635    108,0000   399      117,0000      105,2858   10311066   10,01%
 106650   32413    112,2500   358      117,0000      105,3321   10406777    9,97%
Elapsed time = 596,48 sec. (225364,56 ticks, tree = 1051,84 MB, solutions = 10)
```

```
Clique cuts applied:  20
Implied bound cuts applied:  267
Flow cuts applied:  206
Mixed integer rounding cuts applied:  963
Zero-half cuts applied:  19
Gomory fractional cuts applied:  46

Root node processing (before b&c):
  Real time              =   10,78 sec. (6430,21 ticks)
Parallel b&c, 8 threads:
  Real time              =  589,25 sec. (220426,67 ticks)
  Sync time (average)    =   44,98 sec.
  Wait time (average)    =    0,06 sec.
                            ------------
Total (root+branch&cut) =  600,02 sec. (226856,88 ticks)
```

mejor solución encontrada:

solution: 117 /size: 138 /time: 1718488482.227885008
Nodo 1: 15
Nodo 2: 15
Nodo 3: 13
Nodo 4: 12
Nodo 5: 8
Nodo 6: 13
Nodo 7: 13
Nodo 8: 4
Nodo 9: 15
Nodo 10: 12
Nodo 11: 12
Nodo 12: 12
Nodo 13: 12
Nodo 14: 12
Nodo 15: 13
Nodo 16: 15
Nodo 17: 9
Nodo 18: 9
Nodo 19: 15
Nodo 20: 4
Nodo 21: 1
Nodo 22: 1
Nodo 23: 13
Nodo 24: 2
Nodo 25: 12
Nodo 26: 15
Nodo 27: 12
Nodo 28: 13
Nodo 29: 14
Nodo 30: 15
Nodo 31: 15
Nodo 32: 13
Nodo 33: 12
Nodo 34: 12
Nodo 35: 12
Nodo 36: 2
Nodo 37: 15
Nodo 38: 4
Nodo 39: 13
Nodo 40: 14
Nodo 41: 15
Nodo 42: 14
Nodo 43: 9
Nodo 44: 13
Nodo 45: 14
Nodo 46: 12
Nodo 47: 15
Nodo 48: 15
Nodo 49: 15
Nodo 50: 12
Nodo 51: 12
Nodo 52: 15
Nodo 53: 5
Nodo 54: 9
Nodo 55: 15
Nodo 56: 13
Nodo 57: 1
Nodo 58: 9

Nodo 59: 13
Nodo 60: 9
Nodo 61: 5
Nodo 62: 12
Nodo 63: 15
Nodo 64: 1
Nodo 65: 9
Nodo 66: 12
Nodo 67: 15
Nodo 68: 15
Nodo 69: 5
Nodo 70: 8
Nodo 71: 9
Nodo 72: 5
Nodo 73: 15
Nodo 74: 10
Nodo 75: 12
Nodo 76: 15
Nodo 77: 12
Nodo 78: 2
Nodo 79: 8
Nodo 80: 13
Nodo 81: 4
Nodo 82: 15
Nodo 83: 14
Nodo 84: 12
Nodo 85: 15
Nodo 86: 14
Nodo 87: 15
Nodo 88: 12
Nodo 89: 13
Nodo 90: 15
Nodo 91: 15
Nodo 92: 14
Nodo 93: 15
Nodo 94: 15
Nodo 95: 13
Nodo 96: 15
Nodo 97: 2
Nodo 98: 15
Nodo 99: 14
Nodo 100: 8
Nodo 101: 9
Nodo 102: 15
Nodo 103: 15
Nodo 104: 15
Nodo 105: 12
Nodo 106: 12
Nodo 107: 12
Nodo 108: 14
Nodo 109: 9
Nodo 110: 14
Nodo 111: 15
Nodo 112: 14
Nodo 113: 12
Nodo 114: 8
Nodo 115: 8
Nodo 116: 1
Nodo 117: 15
Nodo 118: 12
Nodo 119: 15
Nodo 120: 15
Nodo 121: 8
Nodo 122: 2
Nodo 123: 12
Nodo 124: 12
Nodo 125: 8
Nodo 126: 14
Nodo 127: 12
Nodo 128: 15
Nodo 129: 13
Nodo 130: 14
Nodo 131: 14
Nodo 132: 2
Nodo 133: 4
Nodo 134: 12
Nodo 135: 5
Nodo 136: 12
Nodo 137: 12
Nodo 138: 8

Análisis:

En 10 minutos no encontró la solución óptima, parece que está cerca por el gap pero al yo poner el límite de 10 minutos terminó la ejecución.

Encontró 10 soluciones enteras. A diferencia del punto anterior los primeros incrementos fueron abruptos (la foto del stats es realizada antes de tiempo para evidenciar esto) hasta que se estancó en 117.

Se puede apreciar que el límite de 15 lavados mejoró la velocidad de la solución ya que no solo la primera solución encontrada es mejor que en el caso anterior sino que también se estancó menos (exceptuando en 117 que podría ser el óptimo). También se ve en la columna **ItCnt** aumenta más paulatinamente que sin la limitación de los lavados

Concusión:

Limitar la cantidad de lavados le facilita al modelo tomar ejecutarse ya que desde un principio puede descartar soluciones que en el caso anterior tuvo que analizar.De todas formas y a pesar de achicar bastante el gap, hay muchas formas de generar el valor 117 y modelo probará todas las soluciones hasta confirmar que esta es la óptima

4)

Stats:

Statistic	Value
⌄ Cplex	
⌄ MIP	
Objective	48.860202
Incumbent	122
Nodes	0
Remaining nodes	1
Iterations	52845
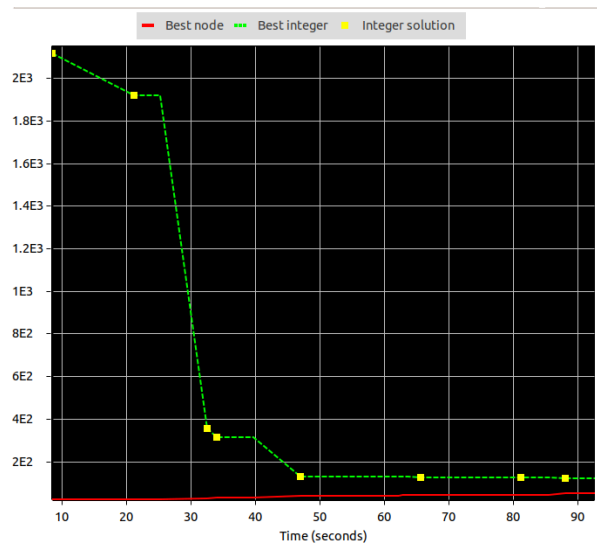
Engine logs:

```
Version identifier: 22.1.1.0 | 2022-11-28 | 9160aff4d
CPXPARAM_TimeLimit                               600
Legacy callback                                  pi
Tried aggregator 1 time.
MIP Presolve eliminated 120489 rows and 0 columns.
MIP Presolve modified 11991 coefficients.
Reduced MIP has 34898 rows, 19182 columns, and 122062 nonzeros.
Reduced MIP has 19044 binaries, 138 generals, 0 SOSs, and 0 indicators.
Presolve time = 0,46 sec. (253,34 ticks)
Found incumbent of value 2760,000000 after 0,68 sec. (465,00 ticks)
Probing time = 0,21 sec. (12,14 ticks)
Tried aggregator 1 time.
Detecting symmetries...
Reduced MIP has 34898 rows, 19182 columns, and 122062 nonzeros.
Reduced MIP has 19044 binaries, 138 generals, 0 SOSs, and 0 indicators.
Presolve time = 0,19 sec. (144,06 ticks)
Probing time = 0,18 sec. (11,37 ticks)
Clique table members: 15717.
MIP emphasis: balance optimality and feasibility.
MIP search method: dynamic search.
Parallel mode: deterministic, using up to 8 threads.
Root relaxation solution time = 5,02 sec. (1168,99 ticks)
```

	Nodes					Cuts/		
	Node	Left	Objective	IInf	Best Integer	Best Bound	ItCnt	Gap
*	0+	0			2760,0000	0,0000		100,00%
*	0+	0			2631,0000	0,0000		100,00%
*	0+	0			2442,0000	0,0000		100,00%
*	0+	0			2298,0000	0,0000		100,00%
*	0+	0			2201,0000	0,0000		100,00%
*	0+	0			2126,0000	0,0000		100,00%
*	0+	0			2116,0000	0,0000		100,00%
	0	0	20,0000	10405	2116,0000	20,0000	12	99,05%
*	0+	0			2008,0000	20,0000		99,00%
*	0+	0			1917,0000	20,0000		98,96%
	0	0	21,2797	9863	1917,0000	Cuts: 1866	2673	98,89%
	0	0	26,0577	8520	1917,0000	Cuts: 1406	7115	98,64%
*	0+	0			356,0000	26,0577		92,68%
	0	0	28,3956	7861	356,0000	Cuts: 846	16167	92,02%
*	0+	0			313,0000	28,3956		90,93%
	0	0	-1,00000e+75	0	313,0000	28,3956	16167	90,93%
*	0+	0			178,0000	28,3956		84,05%
*	0+	0			177,0000	28,3956		83,96%
*	0+	0			154,0000	28,3956		81,56%
*	0+	0			147,0000	28,3956		80,68%
*	0+	0			145,0000	28,3956		80,42%
*	0+	0			143,0000	28,3956		80,14%
*	0+	0			133,0000	28,3956		78,65%
*	0+	0			130,0000	28,3956		78,16%
	0	0	-1,00000e+75	0	130,0000	28,3956	23311	78,16%

```
Repeating presolve.
Tried aggregator 1 time.
MIP Presolve eliminated 10456 rows and 5898 columns.
MIP Presolve modified 1719 coefficients.
Reduced MIP has 24442 rows, 13284 columns, and 83876 nonzeros.
Reduced MIP has 13146 binaries, 138 generals, 0 SOSs, and 0 indicators.
Presolve time = 0,13 sec. (97,13 ticks)
Probing time = 0,30 sec. (23,00 ticks)
Tried aggregator 1 time.
Detecting symmetries...
Reduced MIP has 24442 rows, 13284 columns, and 83876 nonzeros.
Reduced MIP has 13146 binaries, 138 generals, 0 SOSs, and 0 indicators.
Presolve time = 0,12 sec. (92,94 ticks)
Represolve time = 0,72 sec. (408,19 ticks)
Probing time = 0,29 sec. (22,97 ticks)
Clique table members: 11159.
MIP emphasis: balance optimality and feasibility.
MIP search method: dynamic search.
Parallel mode: deterministic, using up to 8 threads.
Root relaxation solution time = 1,50 sec. (663,91 ticks)
```

	Nodes		Objective	IInf	Best Integer	Cuts/ Best Bound	ItCnt	Gap
	Node	Left						
*	0+	0			130,0000	28,3956		78,16%
	0	0	37,0000	816	130,0000	37,0000	23328	71,54%
	0	0	40,1892	2276	130,0000	Cuts: 366	36353	69,09%
*	0+	0			126,0000	40,1892		68,10%
	0	0	40,9753	487	126,0000	Cuts: 235	38246	67,48%
	0	0	41,0829	534	126,0000	Cuts: 222	39893	67,39%
*	0+	0			124,0000	41,0829		66,87%
	0	0	41,2142	518	124,0000	Cuts: 203	42269	66,76%
	0	0	41,4277	510	124,0000	Cuts: 183	42777	66,59%
	0	0	41,5220	514	124,0000	Cuts: 182	43500	66,51%
	0	0	41,5605	520	124,0000	Cuts: 148	44902	66,48%
*	0+	0			122,0000	41,5605		65,93%
	0	0	41,6074	496	122,0000	Cuts: 191	48311	59,95%
	0	0	41,6857	547	122,0000	Cuts: 233	50712	59,95%
	0	0	41,7083	483	122,0000	Cuts: 43	51586	59,95%
	0	0	41,7400	497	122,0000	Cuts: 239	52845	59,95%

```
Detecting symmetries...
```

	Nodes		Objective	IInf	Best Integer	Cuts/ Best Bound	ItCnt	Gap
	0	2	41,7400	488	122,0000	48,8602	52860	59,95%

```
Elapsed time = 116,74 sec. (45180,45 ticks, tree = 0,02 MB, solutions = 22)
```

	Nodes		Objective	IInf	Best Integer	Cuts/ Best Bound	ItCnt	Gap
	1	3	42,9291	490	122,0000	48,8602	54142	59,95%
	4	5	55,7370	436	122,0000	48,8602	55572	59,95%
	22	17	66,9710	450	122,0000	48,8602	60363	59,95%
	69	46	cutoff		122,0000	48,8602	68402	59,95%
	180	81	66,0851	437	122,0000	48,8602	79156	59,95%
	324	157	68,4377	363	122,0000	54,2784	93390	55,51%
	472	235	112,2695	241	122,0000	55,3386	103635	54,64%
	620	374	104,7946	256	122,0000	55,3386	115227	54,64%

```
*   749+   424                         120,0000      55,3386               53,88%
     805    501     96,2636    290      120,0000      55,3386    126481    53,88%
    1257    764    117,7600    233      120,0000      59,4320    157603    50,47%
Elapsed time = 129,20 sec. (48352,51 ticks, tree = 5,86 MB, solutions = 23)
    2026   1142    110,8126    214      120,0000      73,0000    198890    39,17%
    2541   1569    105,9260    238      120,0000      78,4556    247405    34,62%
*   2752   1667    integral      0      119,0000      78,7389    254563    33,83%
    3169   1790    109,5372    220      119,0000      81,5908    272333    31,44%

Performing restart 1

Repeating presolve.
Tried aggregator 4 times.
MIP Presolve eliminated 20017 rows and 10600 columns.
MIP Presolve modified 212 coefficients.
Aggregator did 12 substitutions.
Reduced MIP has 4413 rows, 2672 columns, and 13814 nonzeros.
Reduced MIP has 2552 binaries, 120 generals, 0 SOSs, and 0 indicators.
Presolve time = 0,04 sec. (35,22 ticks)
Tried aggregator 1 time.
Reduced MIP has 4413 rows, 2672 columns, and 13814 nonzeros.
Reduced MIP has 2553 binaries, 119 generals, 0 SOSs, and 0 indicators.
Presolve time = 0,01 sec. (12,90 ticks)
Represolve time = 0,22 sec. (337,24 ticks)
    3402      0     43,7979    640      119,0000    Cuts: 592    302027    30,54%
    3402      0     43,9889    641      119,0000    Cuts: 638    302509    30,54%
    3402      0     44,1070    571      119,0000    Cuts: 221    302955    30,54%
    3402      0     44,5811    548      119,0000    Cuts: 589    303907    30,54%
    3402      0     45,9928    559      119,0000    Cuts: 559    305427    30,54%
    3402      0     46,1294    594      119,0000    Cuts: 568    306182    30,54%
    3402      0     46,2152    548      119,0000    Cuts: 512    306555    30,54%
    3402      0     46,2884    548      119,0000    Cuts: 528    306875    30,54%
    3402      2     46,2884    513      119,0000      82,6614    306875    30,54%
    3410      3     46,5885    512      119,0000      82,6614    311498    30,54%
    3416      4     46,6753    507      119,0000      82,6614    312833    30,54%
    3431      5     46,9235    544      119,0000      82,6614    319940    30,54%
    3451      5     85,8496    364      119,0000      82,6614    325665    30,54%
    3500     11     85,9876    335      119,0000      82,6614    337306    30,54%
    3734     25     83,3750    319      119,0000      82,6614    362858    30,54%
Elapsed time = 160,03 sec. (62583,14 ticks, tree = 0,04 MB, solutions = 24)
    3969     25     90,9914    288      119,0000      82,6614    396285    30,54%
    4606    211    104,3158    254      119,0000      82,6614    439659    30,54%
    5202    632    117,0000     92      119,0000      82,6614    518113    30,54%
*   6021    901    integral      0      118,0000      98,5705    567856    16,47%
*   6150    951    integral      0      117,0000      98,5705    578164    15,75%
    6265    936    113,0000    171      117,0000     100,6960    591652    13,94%
```

```
Clique cuts applied:  10
Implied bound cuts applied:  37
Flow cuts applied:  70
Mixed integer rounding cuts applied:  111
Zero-half cuts applied:  57
Lift and project cuts applied:  1
Gomory fractional cuts applied:  21

Root node processing (before b&c):
  Real time             =  116,47 sec. (44836,29 ticks)
Parallel b&c, 8 threads:
  Real time             =   55,12 sec. (22392,96 ticks)
  Sync time (average)   =   12,41 sec.
  Wait time (average)   =    0,02 sec.
                           ------------
Total (root+branch&cut) = 171,58 sec. (67229,25 ticks)
```

mejor solución encontrada:

solution: 117 /size: 138 /time: 1718491001.44904089

Nodo 1: 2
Nodo 2: 1
Nodo 3: 1
Nodo 4: 3
Nodo 5: 3
Nodo 6: 5
Nodo 7: 3
Nodo 8: 1
Nodo 9: 1
Nodo 10: 2
Nodo 11: 2
Nodo 12: 2
Nodo 13: 2
Nodo 14: 2
Nodo 15: 1
Nodo 16: 3
Nodo 17: 3
Nodo 18: 4
Nodo 19: 1
Nodo 20: 9
Nodo 21: 3
Nodo 22: 5
Nodo 23: 1
Nodo 24: 1
Nodo 25: 2
Nodo 26: 1
Nodo 27: 2
Nodo 28: 3
Nodo 29: 8
Nodo 30: 1
Nodo 31: 3
Nodo 32: 8
Nodo 33: 2
Nodo 34: 2
Nodo 35: 5
Nodo 36: 8
Nodo 37: 2
Nodo 38: 1
Nodo 39: 1
Nodo 40: 7
Nodo 41: 2
Nodo 42: 6
Nodo 43: 6
Nodo 44: 1
Nodo 45: 7
Nodo 46: 3
Nodo 47: 1
Nodo 48: 1
Nodo 49: 3
Nodo 50: 1
Nodo 51: 1
Nodo 52: 3
Nodo 53: 8
Nodo 54: 8
Nodo 55: 1
Nodo 56: 3

Nodo 57: 11
Nodo 58: 7
Nodo 59: 3
Nodo 60: 1
Nodo 61: 6
Nodo 62: 2
Nodo 63: 1
Nodo 64: 6
Nodo 65: 6
Nodo 66: 2
Nodo 67: 2
Nodo 68: 6
Nodo 69: 7
Nodo 70: 6
Nodo 71: 2
Nodo 72: 7
Nodo 73: 2
Nodo 74: 10
Nodo 75: 1
Nodo 76: 2
Nodo 77: 1
Nodo 78: 11
Nodo 79: 1
Nodo 80: 3
Nodo 81: 11
Nodo 82: 2
Nodo 83: 6
Nodo 84: 2
Nodo 85: 1
Nodo 86: 1
Nodo 87: 1
Nodo 88: 2
Nodo 89: 3
Nodo 90: 1
Nodo 91: 1
Nodo 92: 8
Nodo 93: 1
Nodo 94: 8
Nodo 95: 3
Nodo 96: 2
Nodo 97: 6
Nodo 98: 1
Nodo 99: 6
Nodo 100: 5
Nodo 101: 3
Nodo 102: 1
Nodo 103: 1
Nodo 104: 1
Nodo 105: 1
Nodo 106: 1
Nodo 107: 1
Nodo 108: 6
Nodo 109: 2
Nodo 110: 1
Nodo 111: 1
Nodo 112: 6
Nodo 113: 1
Nodo 114: 3
Nodo 115: 11
Nodo 116: 9
Nodo 117: 4
Nodo 118: 6
Nodo 119: 2
Nodo 120: 1
Nodo 121: 2
Nodo 122: 1
Nodo 123: 7
Nodo 124: 2
Nodo 125: 3
Nodo 126: 4
Nodo 127: 1
Nodo 128: 3
Nodo 129: 3
Nodo 130: 8
Nodo 131: 1
Nodo 132: 5
Nodo 133: 4
Nodo 134: 2
Nodo 135: 7
Nodo 136: 2
Nodo 137: 1
Nodo 138: 5

Análisis:

En 2:54 minutos aproximadamente encontró la solución óptima, a pesar de que falta gap el hecho de que la ejecución termine por su cuenta me hace llegar a esta conclusión aunque esto puede deberse a las restricciones que agregue la simetría.

Encontró 27 soluciones enteras. A diferencia del punto anterior este modelo parece no haberse estancado, el avance es continuo.

Se puede ver que la simetría mejoró la velocidad de la solución, si bien las primeras soluciones encontradas son bastante peores que en el caso anterior, este modelo terminó antes de llegar al límite de los 10 minutos. Sumado a esto, se ve que la columna **ItCnt** aumenta más paulatinamente y nunca pasando los 1,000,000 lo que podría explicar la velocidad de su resolución

Conclusión:

Por lo que entendí, la simetría garantiza que los primeros lavados tienen que ser los que más tiempo demoran, esto descarta soluciones que se componen de los mismos lavados en diferente orden. Esta restricción parece simplificar el problema de forma tal que no necesita utilizar los 10 minutos que tiene disponible para encontrar una solución ,a pesar de comenzar con una solución inicial tan alta.

5)
Stats:

Statistic	Value
∨ Cplex	
∨ MIP	
Objective	114.967059
Incumbent	117
Nodes	7831
Remaining nodes	548
Iterations	466667
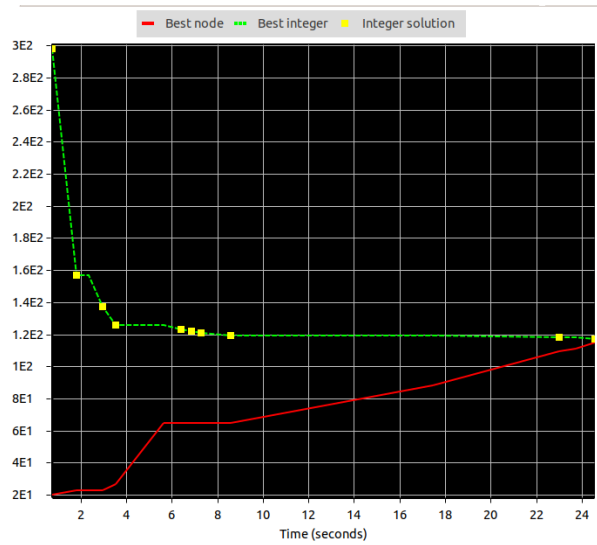
Engine logs:

```
Version identifier: 22.1.1.0 | 2022-11-28 | 9160aff4d
CPXPARAM_TimeLimit                               600
Legacy callback                                  pi
Tried aggregator 1 time.
MIP Presolve eliminated 13050 rows and 0 columns.
MIP Presolve modified 1350 coefficients.
Reduced MIP has 3962 rows, 2085 columns, and 13578 nonzeros.
Reduced MIP has 2070 binaries, 15 generals, 0 SOSs, and 0 indicators.
Presolve time = 0,04 sec. (23,33 ticks)
Found incumbent of value 300,000000 after 0,07 sec. (53,08 ticks)
Probing time = 0,04 sec. (4,05 ticks)
Tried aggregator 1 time.
Detecting symmetries...
Reduced MIP has 3962 rows, 2085 columns, and 13578 nonzeros.
Reduced MIP has 2070 binaries, 15 generals, 0 SOSs, and 0 indicators.
Presolve time = 0,01 sec. (12,66 ticks)
Probing time = 0,05 sec. (4,28 ticks)
Clique table members: 1878.
MIP emphasis: balance optimality and feasibility.
MIP search method: dynamic search.
Parallel mode: deterministic, using up to 8 threads.
Root relaxation solution time = 0,18 sec. (136,45 ticks)
```

	Nodes				Cuts/		
Node	Left	Objective	IInf	Best Integer	Best Bound	ItCnt	Gap
* 0+	0			300,0000	0,0000		100,00%
* 0+	0			298,0000	0,0000		100,00%
0	0	20,0000	1178	298,0000	20,0000	1809	93,29%
* 0+	0			157,0000	20,0000		87,26%
0	0	22,1429	1150	157,0000	Cuts: 1090	5659	85,30%
* 0+	0			137,0000	23,0769		83,16%
0	0	26,5726	918	137,0000	Cuts: 705	10322	80,60%
* 0+	0			126,0000	26,5726		78,91%
0	0	27,6682	880	126,0000	Cuts: 604	12939	78,04%
0	0	28,0280	830	126,0000	Cuts: 567	14015	77,76%
0	0	28,3486	909	126,0000	Cuts: 571	15032	55,29%
0	0	28,6811	878	126,0000	Cuts: 246	15754	48,41%
0	0	28,8796	858	126,0000	Cuts: 474	16675	48,41%
0	0	29,0391	855	126,0000	Cuts: 442	17266	48,41%
0	2	30,2595	626	126,0000	65,0000	17826	48,41%

```
Elapsed time = 6,18 sec. (3429,67 ticks, tree = 0,02 MB, solutions = 5)
```

14	10	cutoff		126,0000	65,0000	21718	48,41%
* 54+	31			125,0000	65,0000		48,00%
* 55+	31			124,0000	65,0000		47,58%
* 69	36	integral	0	123,0000	65,0000	26815	47,15%
* 91+	7			122,0000	65,0000		46,72%
139	74	110,3783	199	122,0000	65,0000	31143	46,72%
344	151	74,4525	360	122,0000	65,0000	42850	46,72%
* 456	190	integral	0	121,0000	65,0000	49902	46,28%
645	286	117,6174	218	121,0000	65,0000	61763	46,28%
1007	487	110,3488	213	121,0000	65,0000	72254	46,28%

```
*  1091+   573                        119,0000     65,0000             45,38%
   1182     538      92,3401    298    119,0000     65,0000    87536    45,38%
   1610     812     117,5000     91    119,0000     65,0000   111218    45,38%
   1955     994      90,8062    299    119,0000     66,2313   121030    44,34%
   2412    1216     116,1853    173    119,0000     77,2786   139699    35,06%

Performing restart 1

Repeating presolve.
Tried aggregator 1 time.
MIP Presolve eliminated 1093 rows and 592 columns.
MIP Presolve modified 122 coefficients.
Reduced MIP has 2869 rows, 1493 columns, and 9535 nonzeros.
Reduced MIP has 1478 binaries, 15 generals, 0 SOSs, and 0 indicators.
Presolve time = 0,02 sec. (12,47 ticks)
Tried aggregator 1 time.
MIP Presolve eliminated 127 rows and 0 columns.
MIP Presolve modified 14 coefficients.
Reduced MIP has 2742 rows, 1493 columns, and 9281 nonzeros.
Reduced MIP has 1478 binaries, 15 generals, 0 SOSs, and 0 indicators.
Presolve time = 0,01 sec. (8,67 ticks)
Represolve time = 0,09 sec. (69,86 ticks)
   3323       0      83,0494    397    119,0000   Cuts: 288   176144    27,62%
   3323       0      83,5233    384    119,0000   Cuts: 379   176776    27,62%
   3323       0      83,6841    389    119,0000   Cuts: 328   177358    27,62%
   3323       0      83,9896    379    119,0000   Cuts: 201   177714    27,62%
   3323       0      84,8441    390    119,0000   Cuts: 335   178369    27,62%
   3323       0      85,4492    360    119,0000   Cuts: 270   178716    27,62%
   3323       0      85,7775    359    119,0000   Cuts: 316   178981    27,62%
   3323       0      86,0926    375    119,0000   Cuts: 249   179202    27,62%
   3323       0      86,3619    384    119,0000   Cuts: 272   179562    27,43%
   3323       0      86,6843    373    119,0000   Cuts: 255   180263    27,16%
   3323       0      86,7097    381    119,0000   Cuts: 263   180417    27,13%
   3323       0      86,8842    402    119,0000   Cuts: 245   180753    26,99%
   3323       0      86,9422    385    119,0000   Cuts: 255   181066    26,94%
   3323       0      87,4680    382    119,0000   Cuts: 219   181479    26,50%
   3323       0      87,6540    405    119,0000   Cuts: 218   181780    26,34%
   3323       0      87,8680    387    119,0000   Cuts: 264   182135    26,16%
   3323       0      88,0371    378    119,0000   Cuts: 224   182329    26,02%
   3323       0      88,0857    381    119,0000   Cuts: 247   182636    25,98%
   3323       0      88,1048    401    119,0000   Cuts: 238   182904    25,96%
   3323       0      88,2111    391    119,0000   Cuts: 176   183168    25,87%
   3323       0      88,2547    419    119,0000   Cuts: 227   183429    25,84%
   3323       0      88,2594    428    119,0000   Cuts: 173   183575    25,83%
   3323       0      88,2926    403    119,0000    Cuts: 59   183699    25,80%
   3323       0      88,2926    412    119,0000   Cuts: 227   183815    25,80%
   3323       0      88,3281    403    119,0000    Cuts: 94   183986    25,77%
   3323       0      88,3572    404    119,0000   Cuts: 203   184125    25,75%
   3323       0      88,4176    409    119,0000   Cuts: 193   184303    25,70%
   3323       0      88,4292    417    119,0000   Cuts: 184   184420    25,69%
   3323       2      88,4292    413    119,0000     88,4292   184421    25,69%
```

```
Elapsed time = 19,04 sec. (9355,56 ticks, tree = 0,02 MB, solutions = 14)
     3431     18      117,5417    206      119,0000       89,4617   203788   24,82%
     4033    301      116,2500    189      119,0000       96,1830   279347   19,17%
     5539    803      110,5917    199      119,0000      107,6201   372218    9,56%
*    6300    935       integral     0      118,0000      109,5919   399201    7,13%
     7699    715      infeasible           118,0000      114,1179   458711    3,29%
*    7845    579       integral     0      117,0000      114,9671   462658    1,74%

Clique cuts applied:  11
Implied bound cuts applied:  20
Flow cuts applied:  57
Mixed integer rounding cuts applied:  201
Zero-half cuts applied:  34
Gomory fractional cuts applied:  12

Root node processing (before b&c):
  Real time            =     6,11 sec. (3345,32 ticks)
Parallel b&c, 8 threads:
  Real time            =    21,57 sec. (10000,29 ticks)
  Sync time (average)  =     3,67 sec.
  Wait time (average)  =     0,02 sec.
                          ------------
Total (root+branch&cut) =   27,68 sec. (13345,61 ticks)
```

mejor solución encontrada:

solution: 117 /size: 138 /time: 1718568970.898525953

Nodo 1: 1
Nodo 2: 1
Nodo 3: 1
Nodo 4: 1
Nodo 5: 1
Nodo 6: 3
Nodo 7: 3
Nodo 8: 2
Nodo 9: 1
Nodo 10: 2
Nodo 11: 1
Nodo 12: 2
Nodo 13: 3
Nodo 14: 1
Nodo 15: 1
Nodo 16: 2
Nodo 17: 1
Nodo 18: 4
Nodo 19: 1
Nodo 20: 9
Nodo 21: 6
Nodo 22: 1
Nodo 23: 1
Nodo 24: 2
Nodo 25: 1
Nodo 26: 5
Nodo 27: 2
Nodo 28: 1
Nodo 29: 8
Nodo 30: 1
Nodo 31: 1
Nodo 32: 8
Nodo 33: 1
Nodo 34: 1
Nodo 35: 2
Nodo 36: 8
Nodo 37: 2
Nodo 38: 2
Nodo 39: 1
Nodo 40: 2
Nodo 41: 2
Nodo 42: 3
Nodo 43: 1
Nodo 44: 1
Nodo 45: 9
Nodo 46: 1
Nodo 47: 1
Nodo 48: 1
Nodo 49: 4
Nodo 50: 2

Nodo 51: 2
Nodo 52: 1
Nodo 53: 3
Nodo 54: 8
Nodo 55: 1
Nodo 56: 2
Nodo 57: 6
Nodo 58: 2
Nodo 59: 1
Nodo 60: 2
Nodo 61: 8
Nodo 62: 1
Nodo 63: 1
Nodo 64: 6
Nodo 65: 2
Nodo 66: 1
Nodo 67: 2
Nodo 68: 3
Nodo 69: 2
Nodo 70: 5
Nodo 71: 1
Nodo 72: 7
Nodo 73: 2
Nodo 74: 10
Nodo 75: 1
Nodo 76: 1
Nodo 77: 1
Nodo 78: 11
Nodo 79: 2
Nodo 80: 1
Nodo 81: 11
Nodo 82: 1
Nodo 83: 6
Nodo 84: 2
Nodo 85: 1
Nodo 86: 1
Nodo 87: 1
Nodo 88: 1
Nodo 89: 3
Nodo 90: 1
Nodo 91: 1
Nodo 92: 7
Nodo 93: 1
Nodo 94: 2
Nodo 95: 3
Nodo 96: 1
Nodo 97: 2
Nodo 98: 1
Nodo 99: 6
Nodo 100: 5
Nodo 101: 3
Nodo 102: 1
Nodo 103: 1
Nodo 104: 1
Nodo 105: 1
Nodo 106: 2
Nodo 107: 1
Nodo 108: 6
Nodo 109: 2
Nodo 110: 4
Nodo 111: 3
Nodo 112: 1
Nodo 113: 1
Nodo 114: 1
Nodo 115: 10
Nodo 116: 9
Nodo 117: 1
Nodo 118: 2
Nodo 119: 1
Nodo 120: 2
Nodo 121: 1
Nodo 122: 2
Nodo 123: 8
Nodo 124: 2
Nodo 125: 1
Nodo 126: 4
Nodo 127: 1
Nodo 128: 3
Nodo 129: 1
Nodo 130: 2
Nodo 131: 2
Nodo 132: 1
Nodo 133: 1
Nodo 134: 4
Nodo 135: 7
Nodo 136: 2
Nodo 137: 1
Nodo 138: 5

Análisis:

En 27 segundos aproximadamente encontró la solución óptima, a pesar de que falta gap el hecho de que la ejecución termine por su cuenta me hace llegar a esta conclusión.
Encontró 13 soluciones enteras.En su mayoría el avance fue continuo, con algunas demoras en la solución de valor 119 .

Se puede ver que la combinación de la simetría con el límite de lavados mejoró la velocidad de la solución, esté incluso comenzando en un mejor punto de partida que en el punto anterior y similar al de punto 3. Este modelo terminó antes de llegar al límite de los 10 minutos. La columna **ItCnt** nunca pasando los 500,000 y se mantiene la mayor parte de su ejecución entre los 100,000 y los 200,000 lo que podría explicar la velocidad de su resolución
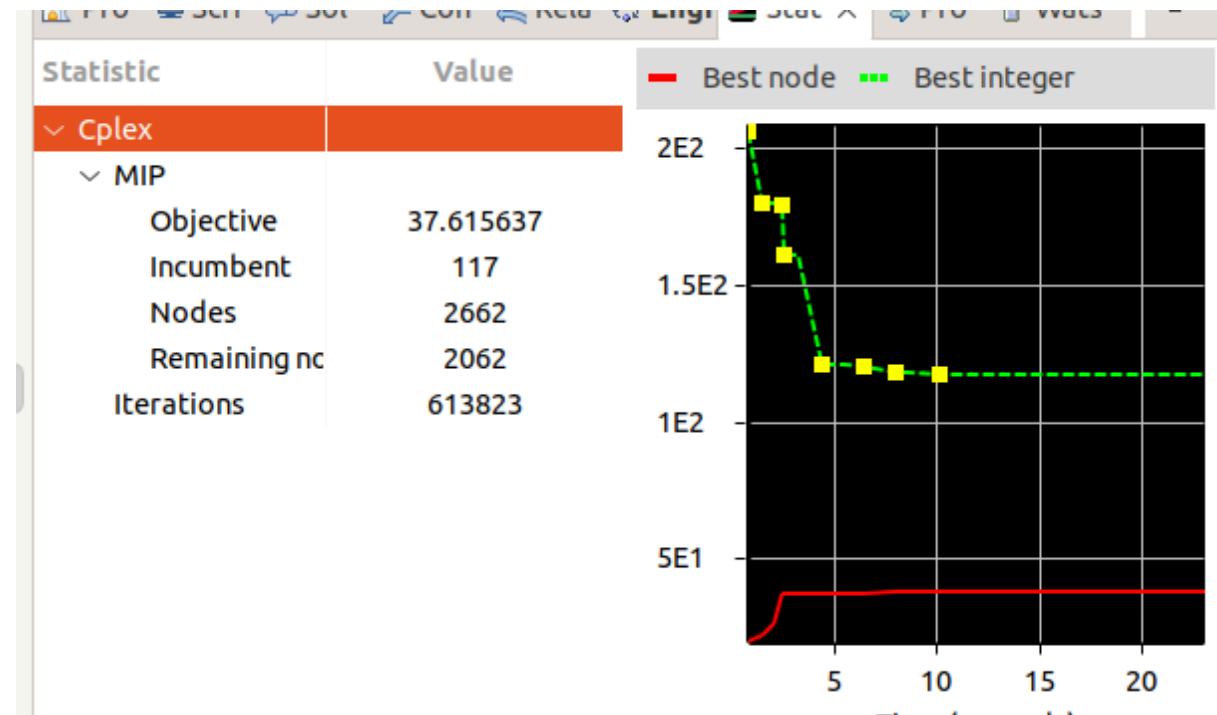
Conclusión:

La combinación de ambas restricciones limita la modelo de tal forma que su resolución se realiza en menos de 30 segundos. Es la que por ahora parece ser el mejor modelo ya que la respuesta no empeoro y el tiempo de resolución es ampliamente mejorado.

6)
Caso 11 lavados sin simetría:

Stats

Statistic	Value
Cplex	
MIP	
Objective	37.615637
Incumbent	117
Nodes	2662
Remaining nc	2062
Iterations	613823

Engine logs:

```
Version identifier: 22.1.1.0 | 2022-11-28 | 9160aff4d
CPXPARAM_TimeLimit                               600
Legacy callback                                  pi
Tried aggregator 1 time.
MIP Presolve eliminated 9579 rows and 0 columns.
MIP Presolve modified 981 coefficients.
Reduced MIP has 2923 rows, 1529 columns, and 9881 nonzeros.
Reduced MIP has 1518 binaries, 11 generals, 0 SOSs, and 0 indicators.
Presolve time = 0,03 sec. (16,78 ticks)
Found incumbent of value 220,000000 after 0,06 sec. (27,90 ticks)
Probing time = 0,01 sec. (3,01 ticks)
Tried aggregator 1 time.
Detecting symmetries...
Reduced MIP has 2923 rows, 1529 columns, and 9881 nonzeros.
Reduced MIP has 1518 binaries, 11 generals, 0 SOSs, and 0 indicators.
Presolve time = 0,01 sec. (9,31 ticks)
Probing time = 0,01 sec. (3,01 ticks)
Clique table members: 1405.
MIP emphasis: balance optimality and feasibility.
MIP search method: dynamic search.
Parallel mode: deterministic, using up to 8 threads.
Root relaxation solution time = 0,19 sec. (125,83 ticks)
```

	Nodes		Objective	IInf	Best Integer	Cuts/Best Bound	ItCnt	Gap
	Node	Left						
*	0+	0			220,0000	0,0000		100,00%
*	0+	0			206,0000	0,0000		100,00%
	0	0	20,0000	944	206,0000	20,0000	1700	90,29%
*	0+	0			180,0000	20,0000		88,89%
	0	0	26,2697	815	180,0000	Cuts: 626	4108	85,41%
	0	0	37,0000	724	180,0000	Cuts: 820	5820	79,44%
*	0+	0			179,0000	37,0000		79,33%
	0	0	37,0000	787	179,0000	Cuts: 640	6978	79,33%
*	0+	0			170,0000	37,0000		78,24%
*	0+	0			161,0000	37,0000		77,02%
	0	0	-1,00000e+75	0	161,0000	37,0000	6978	77,02%
	0	0	37,0000	619	161,0000	Cuts: 169	7454	77,02%
	0	0	37,0000	690	161,0000	Cuts: 564	8278	77,02%
*	0+	0			159,0000	37,0000		76,73%
*	0+	0			122,0000	37,0000		69,67%
*	0+	0			121,0000	37,0000		69,42%
	0	0	-1,00000e+75	0	121,0000	37,0000	8278	69,42%
	0	2	37,0000	512	121,0000	37,0000	8278	69,42%

```
Elapsed time = 4,02 sec. (2413,33 ticks, tree = 0,02 MB, solutions = 9)
```

	Nodes		Objective	IInf	Best Integer	Cuts/Best Bound	ItCnt	Gap
	3	5	49,3191	493	121,0000	37,0000	11073	69,42%
	29	22	77,7283	336	121,0000	37,0000	16570	69,42%
	77	64	90,1862	317	121,0000	37,0000	33130	69,42%
	159	129	119,0000	44	121,0000	37,0000	49104	69,42%
*	161+	128			120,0000	37,0000		69,17%
	252	144	69,8539	397	120,0000	37,0000	54511	69,17%

```
    285    228       72,7532   396      120,0000        37,5963    83258    68,67%
    340    260       92,2394   303      120,0000        37,5963    93996    68,67%
*   393    315       integral    0      119,0000        37,5963   103477    68,41%
*   401    323       integral    0      118,0000        37,5963   105052    68,14%
    461    331       89,0000   318      118,0000        37,5963   106613    68,14%
    531    379       62,6830   357      118,0000        37,5963   116755    68,14%
*   795    514       integral    0      117,0000        37,6156   147732    67,85%
    953    673      116,0000    72      117,0000        37,6156   179862    67,85%
Elapsed time = 9,97 sec. (5576,93 ticks, tree = 8,68 MB, solutions = 13)
   1285    952       57,0755   442      117,0000        37,6156   244749    67,85%
   1546   1120       63,2325   409      117,0000        37,6156   296944    67,85%
   1829   1413       69,1856   441      117,0000        37,6156   372964    67,85%
   2053   1633      103,1826   311      117,0000        37,6156   435863    67,85%
   2265   1794       58,5861   455      117,0000        37,6156   503373    67,85%
   2554   2089       57,7381   473      117,0000        37,6156   583279    67,85%
   2933   2259       66,0600   456      117,0000        37,6156   623699    67,85%
   3299   2713       67,3014   449      117,0000        44,5774   721670    61,90%

Performing restart 1

Repeating presolve.
Tried aggregator 1 time.
MIP Presolve eliminated 92 rows and 44 columns.
Reduced MIP has 2831 rows, 1485 columns, and 9661 nonzeros.
Reduced MIP has 1474 binaries, 11 generals, 0 SOSs, and 0 indicators.
Presolve time = 0,04 sec. (11,19 ticks)
Tried aggregator 1 time.
Reduced MIP has 2831 rows, 1485 columns, and 9661 nonzeros.
Reduced MIP has 1474 binaries, 11 generals, 0 SOSs, and 0 indicators.
Presolve time = 0,01 sec. (9,14 ticks)
Represolve time = 0,11 sec. (41,02 ticks)
   3412      0      104,0000   285      117,0000      Cuts: 31    762124    11,11%
   3412      0      104,0000   345      117,0000      Cuts: 410   762670    11,11%
   3412      0      104,0000   269      117,0000      Cuts: 59    762873    11,11%
   3412      0      104,0000   354      117,0000      Cuts: 373   763180    11,11%
   3412      0      104,0000   235      117,0000      Cuts: 33    763416    11,11%
   3412      0      104,0000   337      117,0000      Cuts: 347   763922    11,11%
   3412      0      104,0000   285      117,0000      Cuts: 112   764247    11,11%
   3412      0      104,0000   332      117,0000      Cuts: 241   764589    11,11%
   3412      2      104,0000   181      117,0000       104,0000   764589    11,11%
   3414      3      104,0000   269      117,0000       104,0000   765676    11,11%
Elapsed time = 33,94 sec. (18589,67 ticks, tree = 0,02 MB, solutions = 13)
   3420      6      104,0000   277      117,0000       104,0000   766703    11,11%
   3432     17      104,0000   280      117,0000       104,0000   769673    11,11%
   3494     27      104,0000   276      117,0000       104,0000   772340    11,11%
   3865    223      106,1000   184      117,0000       104,0000   783734    11,11%
   6011   1632      108,3593   185      117,0000       104,0000   819891    11,11%
   7960   3082      107,1818   255      117,0000       104,0000   877458    11,11%
   9584   4423      116,0000   149      117,0000       104,0000   943846    11,11%
```

```
 10847  5392       113,0080  308       117,0000       104,0000  1002686  11,11%
 12015  6366       106,1246  294       117,0000       104,0000  1067321  11,11%
 13253  7317       107,1818  281       117,0000       104,0000  1125270  11,11%
Elapsed time = 52,00 sec. (28413,11 ticks, tree = 174,27 MB, solutions = 13)
 14350  8086       112,3500  158       117,0000       104,0000  1175702  11,11%
 15276  9149       111,3720  296       117,0000       104,0000  1253510  11,11%
 16513 10064       115,0000  108       117,0000       104,0000  1310305  11,11%
 17500 10767       113,0893  195       117,0000       104,0000  1366791  11,11%
 18478 11561       110,8750  272       117,0000       104,0000  1424490  11,11%
 19345 12291       111,9342  311       117,0000       104,0000  1480197  11,11%
 20326 12940       116,0000  183       117,0000       104,0000  1527827  11,11%
 20874 13589       109,0000  314       117,0000       104,0000  1587351  11,11%
 21630 14144       106,6290  329       117,0000       104,0000  1647291  11,11%
 22492 14816       112,8096  233       117,0000       104,0000  1706183  11,11%
Elapsed time = 70,44 sec. (37962,26 ticks, tree = 372,47 MB, solutions = 13)
 23571 15698       111,0000  209       117,0000       104,0000  1776764  11,11%
 24485 16346       110,8457  291       117,0000       104,0000  1829754  11,11%
 25253 17032       104,0000  316       117,0000       104,0000  1900300  11,11%
 26147 17491       111,8500  242       117,0000       104,0000  1931854  11,11%
 26803 18243       110,8500  292       117,0000       104,0000  2001938  11,11%
 27685 18958       116,0000  202       117,0000       104,0000  2067002  11,11%
 28290 19472       110,8235  238       117,0000       104,0000  2109017  11,11%
 29014 20126       105,0986  367       117,0000       104,0000  2177023  11,11%
 29663 20553       108,7500  294       117,0000       104,0000  2228094  11,11%
 30333 21015       111,0846  292       117,0000       104,0000  2274225  11,11%
Elapsed time = 89,38 sec. (47526,87 ticks, tree = 537,98 MB, solutions = 13)
 31140 21301       111,6100  266       117,0000       104,0000  2305284  11,11%
 31816 22200       111,5237  308       117,0000       104,0000  2399848  11,11%
 32298 22662       112,2308  356       117,0000       104,0000  2463299  11,11%
 33024 22947       114,0000  190       117,0000       104,0000  2501267  11,11%
 33697 23547       115,1429  224       117,0000       104,0000  2560845  11,11%
 34361 24260       115,7500  248       117,0000       104,0000  2624177  11,11%
 34951 24754       115,5000  286       117,0000       104,0000  2681953  11,11%
 35651 25399       109,6932  263       117,0000       104,0000  2741178  11,11%
 36234 25724       116,0000  223       117,0000       104,0000  2769215  11,11%
 36924 25991       104,0000  377       117,0000       104,0000  2803812  11,11%
Elapsed time = 108,70 sec. (57084,57 ticks, tree = 686,36 MB, solutions = 13)
 37558 26542       115,6000  236       117,0000       104,0000  2875455  11,11%
 38225 27042       109,0000  326       117,0000       104,0000  2917432  11,11%
 38986 27864       108,6154  347       117,0000       104,0000  2997964  11,11%
 39653 28389       109,0000  328       117,0000       104,0000  3049136  11,11%
 40376 28734       108,2346  316       117,0000       104,0000  3096196  11,11%
 40991 29040       112,0000  172       117,0000       104,0000  3130521  11,11%
 41657 29757       105,1547  339       117,0000       104,0000  3205957  11,11%
 42440 30248       114,0000  246       117,0000       104,0000  3250113  11,11%
 43201 30768       112,0000  153       117,0000       104,0000  3299648  11,11%
 43958 31476       108,7500  327       117,0000       104,0000  3365949  11,11%
Elapsed time = 128,71 sec. (66646,32 ticks, tree = 834,13 MB, solutions = 13)
 44783 32082       107,7160  350       117,0000       104,0000  3416158  11,11%
 45811 32989       114,7955  160       117,0000       104,0000  3494173  11,11%
 46531 33410       108,7500  329       117,0000       104,0000  3535800  11,11%
```

```
46531 33410      108,7500   329      117,0000      104,0000   3535800   11,11%
47046 34521      112,0000   247      117,0000      104,0000   3637042   11,11%
47738 34966      113,9259   192      117,0000      104,0000   3686838   11,11%
48372 35182      110,5000   276      117,0000      104,0000   3710212   11,11%
48954 36046      106,7778   259      117,0000      104,0000   3800489   11,11%
49614 36179      109,6000   325      117,0000      104,0000   3822425   11,11%
50384 36793      115,6500   252      117,0000      104,0000   3877014   11,11%
51074 37689      112,0000   171      117,0000      104,0000   3963602   11,11%
Elapsed time = 150,10 sec. (76212,51 ticks, tree = 1015,79 MB, solutions = 13)
51785 37650      111,2376   382      117,0000      104,0000   3961027   11,11%
52373 38718      112,8571   243      117,0000      104,0000   4049475   11,11%
52895 39145      112,0000   255      117,0000      104,0000   4108332   11,11%
53439 39914      112,5000   292      117,0000      104,0000   4206076   11,11%
53852 40157      111,0893   268      117,0000      104,0000   4246758   11,11%
54509 40154      104,8571   368      117,0000      104,0000   4237352   11,11%
55022 40975      112,0000   266      117,0000      104,0000   4336547   11,11%
55533 41452      112,0000   228      117,0000      104,0000   4391531   11,11%
56140 41979      106,7778   342      117,0000      104,0000   4459543   11,11%
56645 42030      115,3869   290      117,0000      104,0000   4466620   11,11%
Elapsed time = 172,79 sec. (85773,99 ticks, tree = 1128,79 MB, solutions = 13)
57163 42870      109,0000   262      117,0000      104,0000   4568538   11,11%
57606 43151      111,9709   284      117,0000      104,0000   4605401   11,11%
58231 43453      109,0000   263      117,0000      104,0000   4657276   11,11%
58742 43763        cutoff            117,0000      104,0000   4690395   11,11%
59107 44181      112,4239   258      117,0000      104,0000   4746942   11,11%
59565 44507      109,6000   228      117,0000      104,0000   4785026   11,11%
60052 45098      109,0000   359      117,0000      104,0000   4867954   11,11%
60604 45475      113,0000   229      117,0000      104,0000   4931001   11,11%
61061 45515      112,0000   204      117,0000      104,0000   4937585   11,11%
62923 47278        cutoff            117,0000      104,0000   5188688   11,11%
Elapsed time = 203,86 sec. (98207,27 ticks, tree = 1268,05 MB, solutions = 13)
64891 49006      112,0000   260      117,0000      104,0000   5414046   11,11%
66579 50473      107,1818   356      117,0000      104,0000   5622716   11,11%
67935 51400      112,0000   301      117,0000      104,0000   5777014   11,11%
69723 52738      111,4375   203      117,0000      104,0000   6009279   11,11%
72585 54567      113,8194   202      117,0000      104,1434   6219002   10,99%
75406 56586      115,3158   192      117,0000      104,3500   6430476   10,81%
78039 59183      108,8291   284      117,0000      104,7098   6726397   10,50%
81253 61217      112,0000   160      117,0000      104,8571   6905553   10,38%
84122 63287      109,0000   270      117,0000      104,8571   7096697   10,38%
87106 65430      109,6000   200      117,0000      104,8571   7308290   10,38%
Elapsed time = 311,08 sec. (136363,71 ticks, tree = 1817,77 MB, solutions = 13)
89837 67882      108,3273   238      117,0000      104,8571   7560729   10,38%
92680 70164      111,0000   331      117,0000      104,8571   7762860   10,38%
94642 71945      112,9275   302      117,0000      104,8571   7982429   10,38%
96522 73474      106,1687   277      117,0000      104,8571   8210942   10,38%
98504 74963      109,0000   271      117,0000      104,8571   8412651   10,38%
100423 76624       cutoff            117,0000      104,8571   8651451   10,38%
102425 78070     112,0000   291      117,0000      104,8571   8831867   10,38%
104354 79692     106,4583   300      117,0000      104,8571   9047551   10,38%
106302 81261     107,2258   366      117,0000      104,8571   9276322   10,38%
```

```
 107942 82832       105,5281    364        117,0000    104,8571  9524539   10,38%
Elapsed time = 419,99 sec. (174561,81 ticks, tree = 2337,00 MB, solutions = 13)
Nodefile size = 284,89 MB (258,43 MB after compression)
 109738 84075       113,6531    284        117,0000    104,8571  9709395   10,38%
 111375 85342       116,0000    180        117,0000    104,8571  9887780   10,38%
 113336 86748       111,1000    256        117,0000    104,8571 10095937   10,38%
 115204 88738       108,2308    331        117,0000    104,8571 10385337   10,38%
 116987 89380       112,0000    265        117,0000    104,8571 10502425   10,38%
 118654 90917       107,2697    346        117,0000    104,8571 10716293   10,38%
 120535 92826          cutoff              117,0000    104,8571 10990664   10,38%
 122404 94059       116,0000    223        117,0000    104,8571 11165827   10,38%
 124165 95569       112,0000    242        117,0000    104,8571 11381770   10,38%
 125870 96742       107,2258    348        117,0000    104,8571 11558264   10,38%
Elapsed time = 529,25 sec. (212738,57 ticks, tree = 2744,56 MB, solutions = 13)
Nodefile size = 692,22 MB (629,90 MB after compression)
 127813 98562       106,7778    343        117,0000    104,8571 11821220   10,38%
Starting limited solution polishing.
 129782 99559       112,0000    298        117,0000    104,8571 11955571   10,38%

Performing restart 2

Repeating presolve.
Tried aggregator 1 time.
MIP Presolve eliminated 94 rows and 0 columns.
Reduced MIP has 2737 rows, 1485 columns, and 17393 nonzeros.
Reduced MIP has 1474 binaries, 11 generals, 0 SOSs, and 0 indicators.
Presolve time = 0,02 sec. (15,23 ticks)
Tried aggregator 1 time.
Reduced MIP has 2737 rows, 1485 columns, and 17393 nonzeros.
Reduced MIP has 1474 binaries, 11 generals, 0 SOSs, and 0 indicators.
Presolve time = 0,02 sec. (15,72 ticks)
Represolve time = 0,37 sec. (95,02 ticks)
 130788      0      107,0000    234        117,0000    Cuts: 67 12194575    8,55%
 130788      0      107,0000    317        117,0000   Cuts: 480 12195257    8,55%
 130788      0      107,0000    245        117,0000    Cuts: 67 12195414    8,55%
 130788      0      107,0000    316        117,0000   Cuts: 424 12195766    8,55%
 130788      0      107,0000    278        117,0000   Cuts: 113 12196147    8,55%
 130788      0      107,0000    382        117,0000   Cuts: 328 12196700    8,55%
 130788      0      107,0000    171        117,0000    Cuts: 17 12196851    8,55%
 130788      0      107,0000    311        117,0000   Cuts: 449 12197255    8,55%
 130788      0      107,0000    288        117,0000   Cuts: 138 12197621    8,55%
 130788      0      107,0000    338        117,0000   Cuts: 389 12197914    8,55%
 130788      0      107,0000    180        117,0000    Cuts: 64 12198058    8,55%
 130788      0      107,0000    301        117,0000   Cuts: 354 12198443    8,55%
 130788      2      107,0000    165        117,0000    107,0000 12198443    8,55%
 130823     29      109,0000    252        117,0000    107,0000 12206908    8,55%
 131088    128         cutoff              117,0000    107,0000 12242823    8,55%
 133584   1938      116,0000    149        117,0000    107,0000 12386046    8,55%

Clique cuts applied:  5
```

```
Cover cuts applied:  1
Implied bound cuts applied:  3
Flow cuts applied:  32
Mixed integer rounding cuts applied:  232
Zero-half cuts applied:  7
Gomory fractional cuts applied:  12

Root node processing (before b&c):
  Real time            =    3,99 sec. (2407,55 ticks)
Parallel b&c, 8 threads:
  Real time            =  596,04 sec. (239062,28 ticks)
  Sync time (average)  =   67,42 sec.
  Wait time (average)  =    0,06 sec.
                          ------------
Total (root+branch&cut) =  600,03 sec. (241469,84 ticks)
```

mejor solución encontrada:

solution: 117 /size: 138 /time: 1718589295.283252954

Nodo 1: 7
Nodo 2: 7
Nodo 3: 1
Nodo 4: 1
Nodo 5: 7
Nodo 6: 3
Nodo 7: 8
Nodo 8: 7
Nodo 9: 7
Nodo 10: 1
Nodo 11: 7
Nodo 12: 1
Nodo 13: 7
Nodo 14: 7
Nodo 15: 7
Nodo 16: 7
Nodo 17: 7
Nodo 18: 11
Nodo 19: 7
Nodo 20: 6
Nodo 21: 7
Nodo 22: 11
Nodo 23: 7
Nodo 24: 2
Nodo 25: 1
Nodo 26: 2
Nodo 27: 1
Nodo 28: 8
Nodo 29: 5
Nodo 30: 7
Nodo 31: 1
Nodo 32: 3
Nodo 33: 1
Nodo 34: 7
Nodo 35: 10
Nodo 36: 5
Nodo 37: 3
Nodo 38: 3
Nodo 39: 7
Nodo 40: 10
Nodo 41: 7
Nodo 42: 7
Nodo 43: 2
Nodo 44: 1
Nodo 45: 2
Nodo 46: 7
Nodo 47: 7
Nodo 48: 7
Nodo 49: 7
Nodo 50: 1
Nodo 51: 7
Nodo 52: 1
Nodo 53: 5
Nodo 54: 5
Nodo 55: 7
Nodo 56: 7
Nodo 57: 6
Nodo 58: 4
Nodo 59: 8

Nodo 60: 1
Nodo 61: 10
Nodo 62: 1
Nodo 63: 7
Nodo 64: 7
Nodo 65: 1
Nodo 66: 7
Nodo 67: 1
Nodo 68: 1
Nodo 69: 11
Nodo 70: 11
Nodo 71: 7
Nodo 72: 10
Nodo 73: 1
Nodo 74: 9
Nodo 75: 7
Nodo 76: 1
Nodo 77: 7
Nodo 78: 5
Nodo 79: 7
Nodo 80: 7
Nodo 81: 4
Nodo 82: 1
Nodo 83: 2
Nodo 84: 1
Nodo 85: 7
Nodo 86: 8
Nodo 87: 7
Nodo 88: 7
Nodo 89: 8
Nodo 90: 1
Nodo 91: 7
Nodo 92: 2
Nodo 93: 7
Nodo 94: 1
Nodo 95: 8
Nodo 96: 7
Nodo 97: 1
Nodo 98: 7
Nodo 99: 2
Nodo 100: 3
Nodo 101: 8
Nodo 102: 7
Nodo 103: 1
Nodo 104: 7
Nodo 105: 1
Nodo 106: 7
Nodo 107: 7
Nodo 108: 2
Nodo 109: 7
Nodo 110: 2
Nodo 111: 2
Nodo 112: 8
Nodo 113: 1
Nodo 114: 1
Nodo 115: 11
Nodo 116: 6
Nodo 117: 7
Nodo 118: 1
Nodo 119: 11
Nodo 120: 11
Nodo 121: 7
Nodo 122: 7
Nodo 123: 1
Nodo 124: 1
Nodo 125: 8
Nodo 126: 10
Nodo 127: 1
Nodo 128: 1
Nodo 129: 7
Nodo 130: 10
Nodo 131: 1
Nodo 132: 5
Nodo 133: 11
Nodo 134: 1
Nodo 135: 10
Nodo 136: 1
Nodo 137: 1
Nodo 138: 3

Análisis:
El resultado de este intento es muy similar a del punto 3 ambos tardan los 10 minutos disponibles en ejecutarse y encuentran de forma rápida la solución 117, donde se estancan disminuyendo en el resto de tiempo que tienen disponible en buscar mejores soluciones alternativas o probar que es la óptima. En este intento mejorar un poco más el gap acercándose a más al cero pero también aumenta más el **ItCnt.** Otra diferencia la primera solución encontrada, en el punto 3 es 300 y en este 220 . Este intento también encontró más soluciones enteras.

Conclusión:
El cambio de 15 a 11 lavados no parece afectar demasiado en este caso, no mejora ni la velocidad ni el rendimiento

Caso 11 lavados con simetría:
Stats:

Statistic	Value
Cplex	
MIP	
Objective	108.95614
Incumbent	117
Nodes	1415
Remaining no	541
Iterations	81829
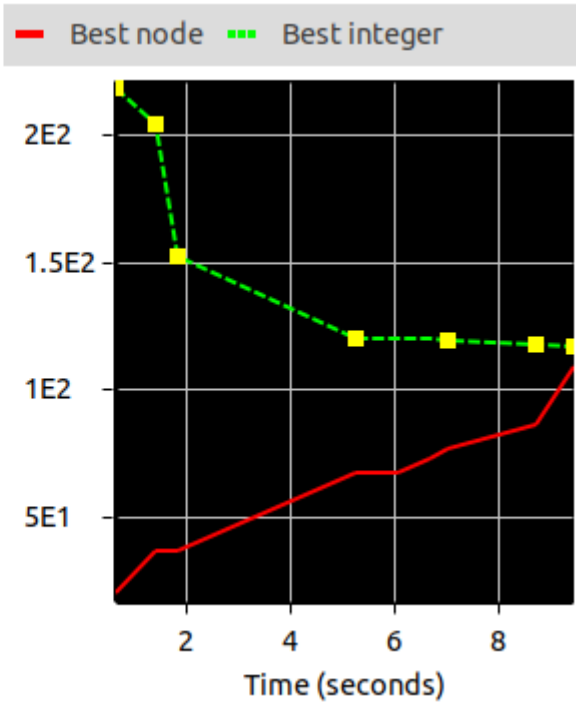
Engine logs:

```
Version identifier: 22.1.1.0 | 2022-11-28 | 9160aff4d
CPXPARAM_TimeLimit                               600
Legacy callback                                  pi
Tried aggregator 1 time.
MIP Presolve eliminated 9577 rows and 0 columns.
MIP Presolve modified 983 coefficients.
Reduced MIP has 2935 rows, 1529 columns, and 9909 nonzeros.
Reduced MIP has 1518 binaries, 11 generals, 0 SOSs, and 0 indicators.
Presolve time = 0,03 sec. (16,79 ticks)
Found incumbent of value 220,000000 after 0,07 sec. (50,34 ticks)
Probing time = 0,01 sec. (3,02 ticks)
Tried aggregator 1 time.
Detecting symmetries...
Reduced MIP has 2935 rows, 1529 columns, and 9909 nonzeros.
Reduced MIP has 1518 binaries, 11 generals, 0 SOSs, and 0 indicators.
Presolve time = 0,01 sec. (9,08 ticks)
Probing time = 0,01 sec. (3,06 ticks)
Clique table members: 1407.
MIP emphasis: balance optimality and feasibility.
MIP search method: dynamic search.
Parallel mode: deterministic, using up to 8 threads.
Root relaxation solution time = 0,14 sec. (98,28 ticks)
```

	Nodes					Cuts/		
Node	Left	Objective	IInf	Best Integer	Best Bound	ItCnt	Gap
*	0+	0			220,0000	0,0000		100,00%
*	0+	0			218,0000	0,0000		100,00%
	0	0	20,0000	914	218,0000	20,0000	1394	90,83%
*	0+	0			204,0000	20,0000		90,20%
	0	0	29,5206	794	204,0000	Cuts: 833	3326	82,03%
*	0+	0			152,0000	36,6667		75,88%
	0	0	37,0000	753	152,0000	Cuts: 557	4300	75,66%
*	0+	0			120,0000	37,0000		69,17%
	0	0	41,7808	637	120,0000	Cuts: 833	15438	43,62%
	0	0	48,4557	595	120,0000	Cuts: 833	18167	43,62%
	0	0	62,8621	503	120,0000	Cuts: 833	20925	39,19%
*	0+	0			119,0000	72,9675		38,68%
	0	0	65,0000	479	119,0000	Cuts: 560	21715	35,29%
	0	0	65,0152	573	119,0000	Cuts: 421	22478	35,29%
	0	0	65,1373	442	119,0000	Cuts: 166	22774	30,93%
	0	0	65,1373	506	119,0000	Cuts: 459	23156	30,93%
	0	2	65,9507	375	119,0000	86,4800	23544	27,33%

```
Elapsed time = 7,66 sec. (3656,12 ticks, tree = 0,02 MB, solutions = 6)
```

	Node	Left	Objective	IInf	Best Integer	Best Bound	ItCnt	Gap
	125	5	66,2602	418	119,0000	86,4800	33868	27,33%
*	211	24	integral	0	118,0000	86,4800	42726	26,71%
*	227+	18			118,0000	86,4800		26,71%
	513	119	108,4746	243	118,0000	86,4800	50753	26,71%
*	1322	560	integral	0	117,0000	106,2035	73840	9,23%
	1454	536	117,0000	20	117,0000	108,9561	76852	6,88%

```
Clique cuts applied:  3
Implied bound cuts applied:  648
Mixed integer rounding cuts applied:  106
Zero-half cuts applied:  28
Multi commodity flow cuts applied:  11

Root node processing (before b&c):
  Real time              =     7,63 sec. (3626,68 ticks)
Parallel b&c, 8 threads:
  Real time              =     1,63 sec. (844,68 ticks)
  Sync time (average)    =     0,48 sec.
  Wait time (average)    =     0,00 sec.
                              ------------
Total (root+branch&cut) =     9,25 sec. (4471,35 ticks)
```

Mejor solución encontrada:

solution: 117 /size: 138 /time: 1718590554.381311893
Nodo 1: 1
Nodo 2: 1
Nodo 3: 1
Nodo 4: 1
Nodo 5: 1
Nodo 6: 5
Nodo 7: 4
Nodo 8: 11
Nodo 9: 1
Nodo 10: 2
Nodo 11: 1
Nodo 12: 2
Nodo 13: 1
Nodo 14: 2
Nodo 15: 2
Nodo 16: 1
Nodo 17: 2
Nodo 18: 3
Nodo 19: 1
Nodo 20: 11
Nodo 21: 7
Nodo 22: 5
Nodo 23: 4
Nodo 24: 1
Nodo 25: 1
Nodo 26: 6
Nodo 27: 2
Nodo 28: 5
Nodo 29: 8
Nodo 30: 1
Nodo 31: 2
Nodo 32: 6
Nodo 33: 6
Nodo 34: 1
Nodo 35: 4
Nodo 36: 8
Nodo 37: 3
Nodo 38: 2
Nodo 39: 1
Nodo 40: 4
Nodo 41: 1
Nodo 42: 2
Nodo 43: 1
Nodo 44: 4
Nodo 45: 11
Nodo 46: 2
Nodo 47: 1
Nodo 48: 1
Nodo 49: 1
Nodo 50: 1
Nodo 51: 2
Nodo 52: 6
Nodo 53: 4
Nodo 54: 3
Nodo 55: 2
Nodo 56: 2
Nodo 57: 9
Nodo 58: 9
Nodo 59: 1
Nodo 60: 4

Nodo 61: 8
Nodo 62: 2
Nodo 63: 1
Nodo 64: 1
Nodo 65: 5
Nodo 66: 1
Nodo 67: 1
Nodo 68: 6
Nodo 69: 2
Nodo 70: 5
Nodo 71: 1
Nodo 72: 7
Nodo 73: 1
Nodo 74: 10
Nodo 75: 2
Nodo 76: 1
Nodo 77: 2
Nodo 78: 9
Nodo 79: 2
Nodo 80: 1
Nodo 81: 11
Nodo 82: 1
Nodo 83: 6
Nodo 84: 2
Nodo 85: 1
Nodo 86: 6
Nodo 87: 1
Nodo 88: 1
Nodo 89: 4
Nodo 90: 2
Nodo 91: 1
Nodo 92: 8
Nodo 93: 1
Nodo 94: 2
Nodo 95: 4
Nodo 96: 2
Nodo 97: 2
Nodo 98: 1
Nodo 99: 6
Nodo 100: 5
Nodo 101: 3
Nodo 102: 1
Nodo 103: 2
Nodo 104: 1
Nodo 105: 2
Nodo 106: 2
Nodo 107: 1
Nodo 108: 6
Nodo 109: 1
Nodo 110: 2
Nodo 111: 5
Nodo 112: 6
Nodo 113: 1
Nodo 114: 1
Nodo 115: 3
Nodo 116: 9
Nodo 117: 6
Nodo 118: 2
Nodo 119: 2
Nodo 120: 2
Nodo 121: 8
Nodo 122: 2
Nodo 123: 11
Nodo 124: 2
Nodo 125: 1
Nodo 126: 3
Nodo 127: 2
Nodo 128: 1
Nodo 129: 3
Nodo 130: 9
Nodo 131: 5
Nodo 132: 1
Nodo 133: 4
Nodo 134: 2
Nodo 135: 7
Nodo 136: 2
Nodo 137: 2
Nodo 138: 5

Análisis:

Tanto este caso como con 15 lavados llega a la solución de 117, pero en mi opinión hay tres grandes diferencias el tiempo, el gap y **ItCnt.** Si bien ambas soluciones son rápidas a comparación del resto de las probadas en el modelo este caso demora 9 segundos. Esto está altamente relacionado al **ItCnt** que se puede apreciar que nunca supera los 100,000, siendo el único de todos los intentos en lograrlo. Lo más interesante es que el gap es mejor el en punto 5, si bien ambos tienen la misma solución en el punto 5 se está más cerca de probar la optima.

Conclusión:

El rendimiento mejora, pero por alguna razón está más seguro de su solución en el punto 5. El cambio de 15 a 11 no parece ser tan significativo como el de simetría.

7)

Si bien en cuanto a tiempo la heurística no está tan mal, el resultado dista mucho del obtenido con plc. Mientras la heurística arroja una sola solución plc varía e intenta mejorar su solución en cada uno de los casos probado y según el tiempo que se disponga se lograrán mejores resultados, cosa que por lo menos en la heurística no pasa.

En común, ambos parecen priorizar los lavados largos primeros (en plc cuanto se descomenta la restricción de simetría) y esto parece ser de lo más importante a la hora de limitar el tiempo de ejecución.