



# FACULTAD DE INGENIERÍA

*7114 Modelos y optimización I*

**Cuarta Entrega**

**Informe final**

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## 1.Resultado de mi heurística

```
johana@Johanas-MacBook-Pro modelosTp1 % python3 ./main.py -if laundry/cuarto_problema.txt
-of cuarto_problema.txt
Washes quantity: 11
Washes time: 123
Execution time 0.016057252883911133 seconds
```

### Algoritmo segunda Entrega

```
for i in range(len(self.laundry.clothes)):
    clothe1 = self.laundry.clothes[i]
    if not is_present_in_any_wash(clothe1.id, washes):
        wash = [clothe1.id]

        for j in range(i + 1, len(self.laundry.clothes)):
            clothe2 = self.laundry.clothes[j]
            if are_compatibles(clothe1.id, clothe2.id, self.laundry.incompatibilities,
                               wash) and not is_present_in_any_wash(clothe2.id, washes):
                wash.append(clothe2.id)

        if len(wash) > 0:
            durations = list(
                map(lambda k: k.duration, list(filter(lambda x: x.id in wash, self.laundry.clothes))))
            max_duration = max(durations)
            washes.append([wash, max_duration])
```

A continuación ejecuté mi algoritmo, el cual constaba de los siguientes pasos

1. Guardar en una lista el tiempo de lavado de cada prenda
2. Guardar en otra colección las incompatibilidades de cada prenda de la siguiente manera  
numero\_de\_prenda: [incompatibilidades]  
Ejemplo:  
{1: [36], 6: [74, 45, 136, 36, 21, 18], ...}
3. Ordenar el listado de prendas, con el criterio de mayor duración de lavado.
4. Recorrer el listado de prendas y si esa prenda no está en ningún lavado anterior, creo un nuevo lavado, luego recorro otra vez el listado de lavados y voy agregando prendas primero verificando que sea compatible y que no esté en otro lavado anterior.
5. Una vez que recorrí todos los lavados compatibles con el actual lavado asigno al actual lavado el tiempo que es el máximo de todos los tiempos del lavado actual.

Este algoritmo dió como resultado 11 lavados, y tardó 16 milisegundos en terminar, incluyendo los prints.

## Modelo de programación lineal de la tercer entrega

### Análisis

Lo resolví como un problema de packing sin solapamiento, con incompatibilidades entre prendas donde se debe determinar qué lavados se realizan. Como es sin solapamiento, cada prenda debe estar en un solo lavado.

### Objetivo

Determinar en qué lavado estará cada prenda, la duración de cada lavado para minimizar el tiempo de lavado total en un periodo de tiempo dado.

#### Constantes

$T_i$  = tiempo de lavado de la prenda  $i$

$C_{ik} = 1$  si la prenda  $i$  es compatible con la prenda  $k$

#### Variables

$Y_{ij} = 1$  si la prenda  $i$  se lava en el lavado  $j$ ,

$Y_{ij} = 0$  sino

$X_j = 1$  tiempo de lavado del lavado  $j$

$W_{ij} = 1$  si la prenda  $i$  es la de mayor tiempo en el lavado  $j$

#### Modelo

El tiempo del lavado  $j$  es la de la prenda de mayor tiempo

$$Y_{ij} T_i \leq X_j \leq Y_{ij} + M(1 - W_{ij})$$

$$\sum_{i=1}^{20} W_{ij} = 1 \quad \forall i, j = 1, 2, \dots, 20$$

#### Restricciones de incompatibilidades

Si dos prendas son incompatibles no puede ir en el mismo lavado

$$Y_{ij} + Y_{kj} \leq C_{ik} + 1 \quad \forall i, j = 1, 2, \dots, 20$$

$$Y_{ij} + Y_{kj} \leq C_{ki} + 1 \quad \forall i, j = 1, 2, \dots, 20$$

#### Restricciones de solapamiento

$$\text{Lavado\_k)} \quad \sum_{i=1}^{20} Y_{ij} = 1 \quad \forall i, j = 1, 2, \dots, 20$$

#### Funcional

$$\min \sum_{i=1}^{20} X_j$$

## 2.Resultado del ejemplo de provisto .

A continuación están los gráficos del algoritmos propuesto en clase

Como vemos, al algoritmo le cuesta arrancar, y en principio el resultado es bastante malo, dando 171 como el mejor entero y 37 el valor del mejor nodo, luego del minuto de ejecución recién vemos un resultado que se mantiene constante.

Además, la solución propuesta del mejor nodo y la mejor solución entera, difieren bastante.

Mejor nodo: 37

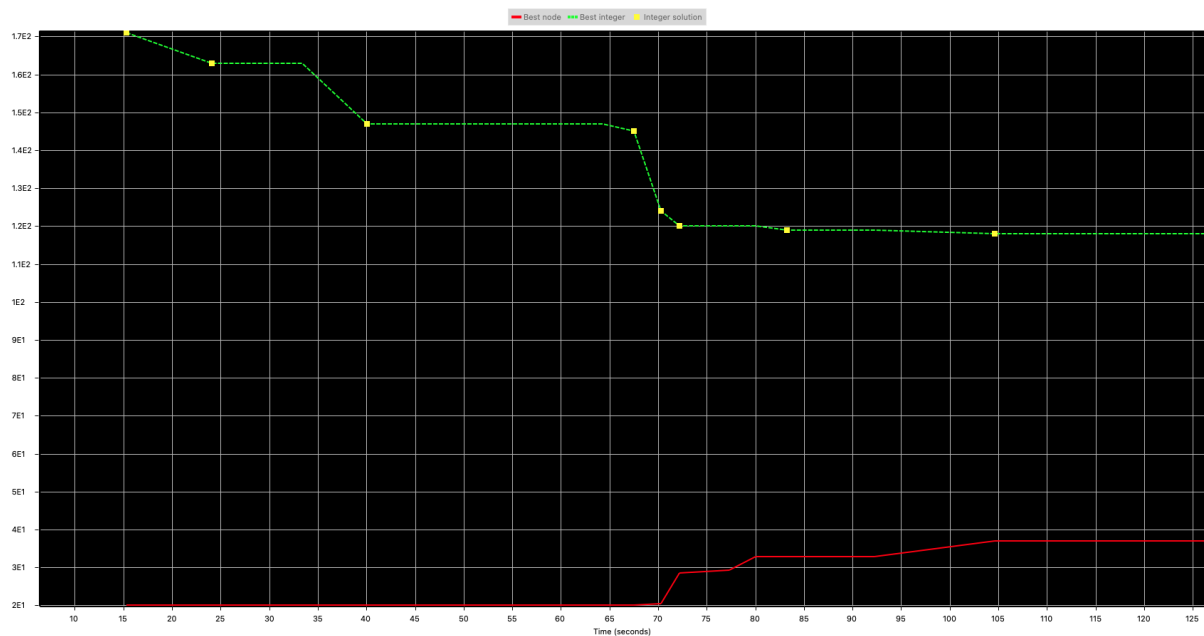
Mejor entero: 118

Luego de dejarlo ejecutándose 10 minutos, puede verse que ambos resultados están más cerca de converger, dando los resultados:

Mejor nodo: 103

Mejor entero: 117

Considero a este valor óptimo, siendo mejor resultado que la heurística propuesta, pero siendo el costo de ejecución muy alto.



Presolve time = 0.78 sec. (253.66 ticks)  
Found incumbent of value 2760.000000 after 1.04 sec. (403.01 ticks)  
Probing time = 0.09 sec. (13.12 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 = 0.47 sec. (391.75 ticks)

Probing time = 0.07 sec. (12.13 ticks)

Clique table members: 15739.

MIP emphasis: balance optimality and feasibility.

MIP search method: dynamic search.

Parallel mode: deterministic, using up to 10 threads.

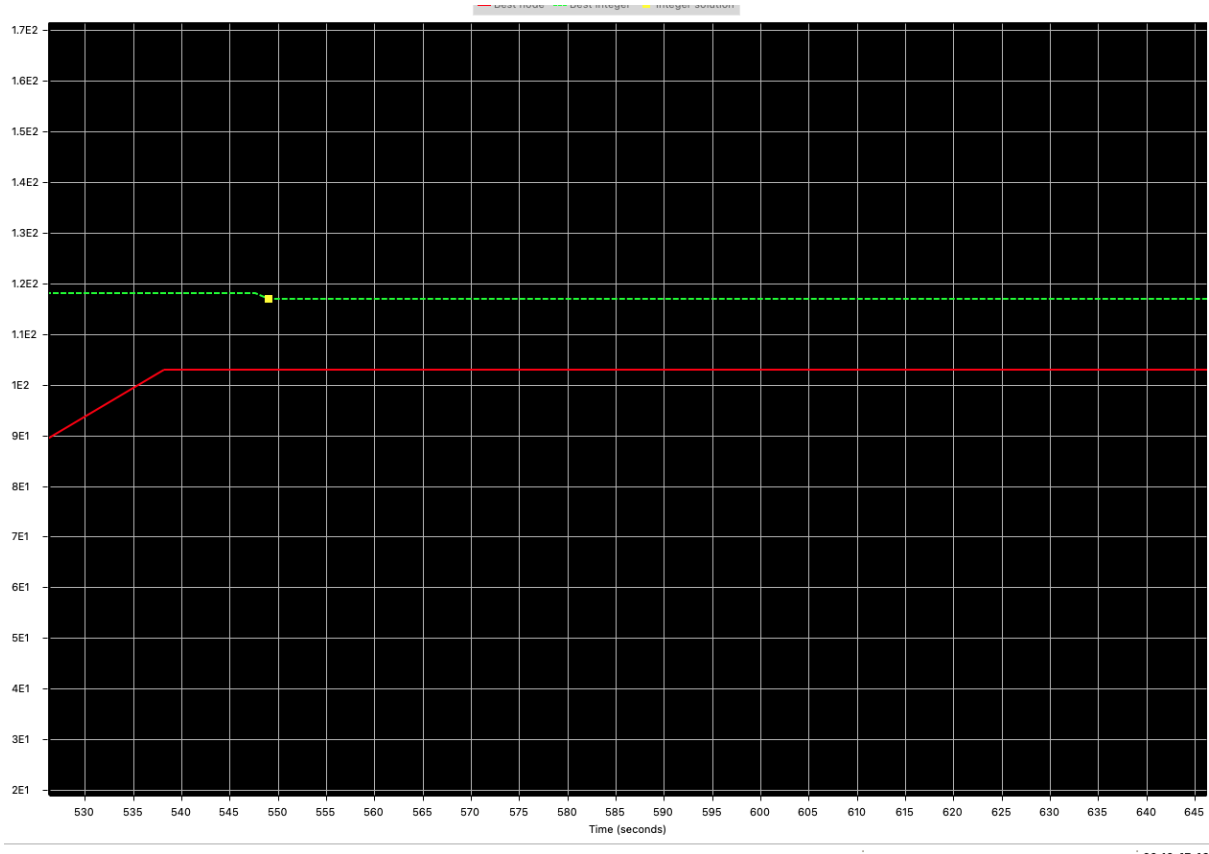
Root relaxation solution time = 12.54 sec. (475.80 ticks)

| Nodes  |      | Cuts/     |              |              |            |            |        |        |        |
|--|------|-----------|--------------|--------------|------------|------------|--------|--------|--------|
| Node   | Left | Objective | Inf          | 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      | 4592         | 171.0000   | 20.0000    | 11     | 88.30% |        |
| *  | 0+   | 0         |              | 163.0000     | 20.0000    | 87.73%     |        |        |        |
|  | 0    | 0         | 20.0000      | 1722         | 163.0000   | Cuts: 231  | 7483   | 87.73% |        |
|  | 0    | 0         | 20.0000      | 2445         | 163.0000   | Cuts: 1531 | 15635  | 87.73% |        |
|  | 0    | 0         | 20.0000      | 1930         | 163.0000   | Cuts: 158  | 20534  | 87.73% |        |
| *  | 0+   | 0         |              | 158.0000     | 20.0000    | 87.34%     |        |        |        |
| *  | 0+   | 0         |              | 157.0000     | 20.0000    | 87.26%     |        |        |        |
| *  | 0+   | 0         |              | 147.0000     | 20.0000    | 86.39%     |        |        |        |
|  | 0    | 0         | -1.00000e+75 | 0            | 147.0000   | 20.0000    |        | 20534  | 86.39% |
|  | 0    | 0         | 20.0000      | 2192         | 147.0000   | Cuts: 1845 | 26262  | 86.39% |        |
|  | 0    | 2         | 20.0000      | 1742         | 147.0000   | 20.0000    | 26262  | 86.39% |        |
| Elapsed time = 48.70 sec. (54094.97 ticks, tree = 0.02 MB, solutions = 7)  |      |           |              |              |            |            |        |        |        |
|  | 1    | 3         | 37.0000      | 1270         | 147.0000   | 20.0000    | 35668  | 86.39% |        |
|  | 2    | 3         | 20.0000      | 2087         | 147.0000   | 20.0000    | 30045  | 86.39% |        |
|  | 3    | 4         | 46.2868      | 1169         | 147.0000   | 20.0000    | 42290  | 86.39% |        |
|  | 4    | 6         | 46.2868      | 1171         | 147.0000   | 20.0000    | 47875  | 86.39% |        |
|  | 6    | 8         | 53.0000      | 1112         | 147.0000   | 20.0000    | 50937  | 86.39% |        |
|  | 10   | 10        | 52.0000      | 876          | 147.0000   | 20.0000    | 54281  | 86.39% |        |
|  | 15   | 11        | 57.0000      | 732          | 147.0000   | 20.0000    | 57381  | 86.39% |        |
|  | 18   | 18        | 57.0000      | 665          | 147.0000   | 20.0000    | 72621  | 86.39% |        |
|  | 22   | 20        | 70.0000      | 533          | 147.0000   | 20.0000    | 81878  | 86.39% |        |
|  | 26   | 23        | 52.0000      | 570          | 147.0000   | 20.0000    | 100567 | 86.39% |        |
| Elapsed time = 55.54 sec. (61718.57 ticks, tree = 0.65 MB, solutions = 7)  |      |           |              |              |            |            |        |        |        |
|  | 33   | 28        | 67.9387      | 561          | 147.0000   | 20.0000    | 111660 | 86.39% |        |
|  | 42   | 42        | 78.0000      | 385          | 147.0000   | 20.0000    | 167128 | 86.39% |        |
|  | 51   | 42        | 70.0000      | 512          | 147.0000   | 20.0000    | 177047 | 86.39% |        |
|  | 61   | 53        | 70.0000      | 486          | 147.0000   | 20.0000    | 223329 | 86.39% |        |
|  | 73   | 62        | 97.0000      | 598          | 147.0000   | 20.0000    | 240858 | 86.39% |        |
|  | 93   | 81        | 106.2411     | 360          | 147.0000   | 20.0000    | 307710 | 86.39% |        |
|  | 117  | 106       | 65.0000      | 818          | 147.0000   | 20.0000    | 413360 | 86.39% |        |
|  | 149  | 135       | 123.0000     | 129          | 147.0000   | 20.0000    | 451598 | 86.39% |        |
| *  | 176+ | 152       |              | 146.0000     | 20.0000    | 86.30%     |        |        |        |
| *  | 193+ | 169       |              | 145.0000     | 20.0000    | 86.21%     |        |        |        |
|  | 198  | 137       | 84.0491      | 552          | 145.0000   | 20.4583    | 478565 | 85.89% |        |
| *  | 217+ | 186       |              | 144.0000     | 20.4583    | 85.79%     |        |        |        |
| *  | 225+ | 185       |              | 141.0000     | 20.4583    | 85.49%     |        |        |        |
| *  | 241+ | 224       |              | 140.0000     | 20.4583    | 85.39%     |        |        |        |
|  | 241  | 174       | 96.0000      | 391          | 140.0000   | 20.4583    | 511355 | 85.39% |        |
| Elapsed time = 65.72 sec. (71810.72 ticks, tree = 3.95 MB, solutions = 11) |      |           |              |              |            |            |        |        |        |
| *  | 263+ | 236       |              | 139.0000     | 20.4583    | 85.28%     |        |        |        |
| *  | 302+ | 276       |              | 138.0000     | 20.4583    | 85.18%     |        |        |        |
|  | 305  | 240       | 101.0000     | 388          | 138.0000   | 28.5000    | 630515 | 79.35% |        |

|   |       |      |            |          |          |          |         |                |
|---|-------|------|------------|----------|----------|----------|---------|----------------|
| *   | 307+  | 276  |            |          | 137.0000 | 28.5000  |         | 79.20%         |
| *   | 320+  | 288  |            |          | 132.0000 | 28.5000  |         | 78.41%         |
| *   | 335+  | 268  |            |          | 128.0000 | 28.5000  |         | 77.73%         |
| *   | 349+  | 259  |            |          | 127.0000 | 28.5000  |         | 77.56%         |
| *   | 361   | 262  | integral 0 |          | 124.0000 | 28.5000  | 671560  | 77.02%         |
|   |       | 376  | 233        | 50.0000  | 1145     | 124.0000 | 28.5000 | 624030 77.02%  |
|   |       | 461  | 298        | 112.0000 | 127      | 124.0000 | 28.5000 | 722535 77.02%  |
| *   | 467+  | 299  |            |          | 123.0000 | 28.5000  |         | 76.83%         |
| *   | 509+  | 305  |            |          | 122.0000 | 28.5000  |         | 76.64%         |
| *   | 511+  | 301  |            |          | 121.0000 | 28.5000  |         | 76.45%         |
| *   | 518   | 336  | integral 0 |          | 120.0000 | 28.5000  | 770556  | 76.25%         |
|   |       | 527  | 294        | 84.0000  | 657      | 120.0000 | 28.5000 | 774736 76.25%  |
|   |       | 553  | 298        | 84.0000  | 752      | 120.0000 | 28.5000 | 782141 76.25%  |
|   |       | 582  | 344        | 94.0000  | 500      | 120.0000 | 28.5000 | 861841 76.25%  |
|   |       | 608  | 348        | 111.0000 | 251      | 120.0000 | 28.5000 | 856713 76.25%  |
|   |       | 641  | 353        | 65.1439  | 1033     | 120.0000 | 29.2868 | 904746 75.59%  |
|   |       | 662  | 377        | 69.0000  | 965      | 120.0000 | 29.2868 | 958239 75.59%  |
|   |       | 699  | 433        | 50.0000  | 901      | 120.0000 | 32.8621 | 1087487 72.61% |
| Elapsed time = 75.91 sec. (81610.38 ticks, tree = 5.25 MB, solutions = 27)    |       |      |            |          |          |          |         |                |
|   |       | 721  | 452        | 97.0000  | 520      | 120.0000 | 32.8621 | 1117544 72.61% |
|   |       | 745  | 460        | 77.0000  | 405      | 120.0000 | 32.8621 | 1136059 72.61% |
| *   | 779+  | 466  |            |          | 119.0000 | 32.8621  |         | 72.38%         |
|   |       | 787  | 482        | 70.9836  | 756      | 119.0000 | 32.8621 | 1177825 72.38% |
|   |       | 824  | 507        | 56.0000  | 1070     | 119.0000 | 32.8621 | 1255674 72.38% |
|   |       | 848  | 519        | 104.0000 | 320      | 119.0000 | 32.8621 | 1329362 72.38% |
|   |       | 868  | 577        | 112.0000 | 129      | 119.0000 | 32.8621 | 1434551 72.38% |
|   |       | 930  | 583        | 63.1470  | 848      | 119.0000 | 32.8621 | 1465316 72.38% |
|   |       | 941  | 562        | 56.0000  | 964      | 119.0000 | 32.8621 | 1423637 72.38% |
|   |       | 956  | 604        | 101.0000 | 764      | 119.0000 | 32.8621 | 1538948 72.38% |
|   |       | 977  | 608        | 117.0000 | 208      | 119.0000 | 32.8621 | 1547006 72.38% |
| Elapsed time = 87.95 sec. (91844.69 ticks, tree = 7.80 MB, solutions = 28)    |       |      |            |          |          |          |         |                |
|   |       | 1001 | 655        | 37.0000  | 1085     | 119.0000 | 32.8621 | 1625403 72.38% |
|   |       | 1014 | 668        | 76.9695  | 682      | 119.0000 | 32.8621 | 1663612 72.38% |
|   |       | 1030 | 675        | 71.7204  | 579      | 119.0000 | 32.8621 | 1696590 72.38% |
|   |       | 1052 | 701        | 102.0000 | 617      | 119.0000 | 32.8621 | 1765584 72.38% |
|   |       | 1070 | 708        | 89.0000  | 681      | 119.0000 | 32.8621 | 1792569 72.38% |
|   |       | 1097 | 744        | 118.0000 | 153      | 119.0000 | 32.8621 | 1886200 72.38% |
| *   | 1112+ | 745  |            |          | 118.0000 | 32.8621  |         | 72.15%         |
|   |       | 1125 | 744        | 85.0000  | 747      | 118.0000 | 32.8621 | 1915548 72.15% |
|   |       | 1147 | 749        | 85.0000  | 530      | 118.0000 | 32.8621 | 1923341 72.15% |
|   |       | 1165 | 751        | 94.8849  | 456      | 118.0000 | 32.8621 | 1931697 72.15% |
|   |       | 1184 | 776        | 113.0000 | 298      | 118.0000 | 32.8621 | 1991979 72.15% |
| Elapsed time = 98.89 sec. (101725.48 ticks, tree = 9.29 MB, solutions = 29)   |       |      |            |          |          |          |         |                |
|   |       | 1206 | 788        | 109.0000 | 385      | 118.0000 | 32.8621 | 2063242 72.15% |
|   |       | 1234 | 802        | 113.0000 | 128      | 118.0000 | 32.8621 | 2085874 72.15% |
|   |       | 1247 | 805        | 46.2868  | 1053     | 118.0000 | 32.8621 | 2125422 72.15% |
|   |       | 1258 | 714        | 57.0000  | 625      | 118.0000 | 37.0000 | 1827765 68.64% |
|   |       | 1274 | 878        | 59.9816  | 770      | 118.0000 | 37.0000 | 2319287 68.64% |
|   |       | 1283 | 897        | 59.0000  | 869      | 118.0000 | 37.0000 | 2388806 68.64% |
|   |       | 1297 | 908        | 58.4625  | 711      | 118.0000 | 37.0000 | 2436341 68.64% |
|   |       | 1310 | 882        | 62.9321  | 897      | 118.0000 | 37.0000 | 2338629 68.64% |
|   |       | 1322 | 901        | 63.3333  | 799      | 118.0000 | 37.0000 | 2401662 68.64% |
|   |       | 1331 | 941        | 72.0000  | 746      | 118.0000 | 37.0000 | 2561681 68.64% |
| Elapsed time = 110.87 sec. (112081.86 ticks, tree = 12.65 MB, solutions = 29) |       |      |            |          |          |          |         |                |
|   |       | 1347 | 960        | 72.0395  | 883      | 118.0000 | 37.0000 | 2622888 68.64% |
|   |       | 1376 | 956        | 49.7436  | 1222     | 118.0000 | 37.0000 | 2610825 68.64% |
|   |       | 1406 | 948        | 95.0000  | 681      | 118.0000 | 37.0000 | 2578845 68.64% |
|   |       | 1436 | 989        | 70.0000  | 653      | 118.0000 | 37.0000 | 2709050 68.64% |
|   |       | 1458 | 1023       | 50.0000  | 919      | 118.0000 | 37.0000 | 2807171 68.64% |

|   |      |          |      |          |         |         |        |
|---|------|----------|------|----------|---------|---------|--------|
| 1474  | 993  | 75.6839  | 796  | 118.0000 | 37.0000 | 2720334 | 68.64% |
| 1489  | 1026 | 54.4196  | 823  | 118.0000 | 37.0000 | 2819334 | 68.64% |
| 1518  | 1091 | 98.6296  | 612  | 118.0000 | 37.0000 | 2985290 | 68.64% |
| 1545  | 1112 | 77.9752  | 629  | 118.0000 | 37.0000 | 3043884 | 68.64% |
| 1568  | 1053 | 46.2868  | 1177 | 118.0000 | 37.0000 | 2884378 | 68.64% |
| Elapsed time = 121.37 sec. (121815.20 ticks, tree = 13.94 MB, solutions = 29) |      |          |      |          |         |         |        |
| 1598  | 1089 | 115.0000 | 500  | 118.0000 | 37.0000 | 2979247 | 68.64% |
| 1634  | 1032 | 63.4196  | 896  | 118.0000 | 37.0000 | 2836044 | 68.64% |
| 1656  | 1128 | 83.0000  | 653  | 118.0000 | 37.0000 | 3115024 | 68.64% |
| 1672  | 1175 | 90.4444  | 443  | 118.0000 | 37.0000 | 3240548 | 68.64% |
| 1687  | 1163 | 46.2868  | 902  | 118.0000 | 37.0000 | 3202411 | 68.64% |
| 1702  | 1183 | 102.5263 | 455  | 118.0000 | 37.0000 | 3254633 | 68.64% |
| 1718  | 1187 | 109.3684 | 466  | 118.0000 | 37.0000 | 3260933 | 68.64% |
| 1736  | 1198 | 57.0000  | 964  | 118.0000 | 37.0000 | 3306433 | 68.64% |
| 1751  | 1259 | 76.0000  | 766  | 118.0000 | 37.0000 | 3459872 | 68.64% |
| 1765  | 1304 | 57.0000  | 817  | 118.0000 | 37.0000 | 3609275 | 68.64% |

Luego de 10 minutos



Engine log

Repeating presolve.  
Tried aggregator 1 time.  
MIP Presolve eliminated 1034 rows and 0 columns.  
Reduced MIP has 32641 rows, 18630 columns, and 160840 nonzeros.  
Reduced MIP has 18492 binaries, 138 generals, 0 SOSs, and 0 indicators.  
Presolve time = 0.37 sec. (191.43 ticks)  
Tried aggregator 1 time.  
Reduced MIP has 32641 rows, 18630 columns, and 160840 nonzeros.  
Reduced MIP has 18492 binaries, 138 generals, 0 SOSs, and 0 indicators.



```

Presolve time = 0.37 sec. (168.56 ticks)
Represolve time = 0.96 sec. (489.26 ticks)
 8214 0      103.0000 438      118.0000      Cuts: 282 14571777 12.71%
 8214 0      103.0000 522      118.0000      Cuts: 525 14575883 12.71%
 8214 0      103.0000 340      118.0000      Cuts: 64 14578299 12.71%
 8214 0      103.0000 394      118.0000      Cuts: 485 14581850 12.71%
 8214 0      103.0000 330      118.0000      Cuts: 65 14584270 12.71%
 8214 0      103.0000 444      118.0000      Cuts: 546 14587397 12.71%
 8214 0      103.0000 224      118.0000      Cuts: 45 14588791 12.71%
 8214 0      103.0000 350      118.0000      Cuts: 472 14591729 12.71%
 8214 0      103.0000 300      118.0000      Cuts: 32 14594665 12.71%
 8214 0      103.0000 367      118.0000      Cuts: 508 14597621 12.71%
 8214 0      103.0000 298      118.0000      Cuts: 222 14600855 12.71%
 8214 0      103.0000 369      118.0000      Cuts: 460 14604789 12.71%
 8214 2      103.0000 152      118.0000      103.0000 14604789 12.71%
 8246 18     103.0000 216      118.0000      103.0000 14632653 12.71%
 8380 116    104.0000 275      118.0000      103.0000 14728332 12.71%
* 8712 390   integral 0      117.0000      103.0000 14931302 11.97%
 8829 397    103.0000 305      117.0000      103.0000 14938521 11.97%
 9358 878    106.2500 245      117.0000      103.0000 15234762 11.97%
Elapsed time = 552.17 sec. (576557.59 ticks, tree = 8.86 MB, solutions = 30)
10114 1369   114.0000      78      117.0000      103.0000 15470098 11.97%
10595 1694   104.0000 348      117.0000      103.0000 15588806 11.97%
11285 2384   105.0000 370      117.0000      103.0000 15818875 11.97%
12310 3363   107.0000 260      117.0000      103.0000 15987259 11.97%
12864 3852   105.0000 369      117.0000      103.0000 16182725 11.97%
13638 4621   106.0000 245      117.0000      103.0000 16351777 11.97%
14484 5361   106.0000 267      117.0000      103.0000 16529704 11.97%
15187 6048   108.0000 169      117.0000      103.0000 16721816 11.97%
15975 6757   107.0000 388      117.0000      103.0000 16911273 11.97%
16615 7375   112.0000      62      117.0000      103.0000 17132788 11.97%
Elapsed time = 587.64 sec. (614743.56 ticks, tree = 81.44 MB, solutions = 30)
17352 8112   104.0000 229      117.0000      103.0000 17369010 11.97%
18320 8815   107.0000 202      117.0000      103.0000 17535304 11.97%
19190 9731   108.0000 228      117.0000      103.0000 17733709 11.97%
19987 10629   106.0000 316      117.0000      103.0000 17956023 11.97%
20764 11277   114.0000      91      117.0000      103.0000 18107943 11.97%
21655 12413   104.0000 293      117.0000      103.0000 18325903 11.97%
22365 12950   infeasible      117.0000      103.0000 18484380 11.97%
23293 13888   106.0000 295      117.0000      103.0000 18685856 11.97%
24006 14689   105.0000 268      117.0000      103.0000 18891404 11.97%
24661 15011   107.0000 332      117.0000      103.0000 18978411 11.97%
Elapsed time = 622.43 sec. (652948.94 ticks, tree = 164.50 MB, solutions = 30)
25379 15998   107.0000 294      117.0000      103.0000 19253830 11.97%
26072 16538   106.0000 228      117.0000      103.0000 19410258 11.97%
26941 17164   116.0000 143      117.0000      103.0000 19622007 11.97%
27701 17868   105.0000 237      117.0000      103.0000 19845630 11.97%
28284 18487   105.0000 278      117.0000      103.0000 20037565 11.97%
28737 18777   107.0000 140      117.0000      103.0000 20103672 11.97%
29405 19350   106.0000 308      117.0000      103.0000 20275042 11.97%
30428 20050   106.0000 285      117.0000      103.0000 20427173 11.97%
31478 20897   108.0000 137      117.0000      103.0000 20566406 11.97%
32338 22249   108.0000 363      117.0000      103.0000 20817979 11.97%
Elapsed time = 655.36 sec. (691138.09 ticks, tree = 244.60 MB, solutions = 30)
33069 23037   107.0000 218      117.0000      103.0000 21021054 11.97%
33925 23508   106.0000 329      117.0000      103.0000 21156051 11.97%
34757 24729   105.0000 351      117.0000      103.0000 21461708 11.97%
35547 25386   106.0000 345      117.0000      103.0000 21641253 11.97%
36257 26004   106.0000 256      117.0000      103.0000 21798598 11.97%

```

|  |       |          |        |          |          |          |                 |
|--|-------|----------|--------|----------|----------|----------|-----------------|
| 36997  | 26752 | 116.0000 | 111    | 117.0000 | 103.0000 | 21995939 | 11.97%          |
| 37744  | 27555 | 116.0000 |        | 26       | 117.0000 | 103.0000 | 22299741 11.97% |
| 38451  | 28315 | 106.0000 | 318    |          | 117.0000 | 103.0000 | 22508180 11.97% |
| 39495  | 29155 | 104.0000 | 299    |          | 117.0000 | 103.0000 | 22694960 11.97% |
| 40523  | 30287 | 116.0000 |        | 48       | 117.0000 | 103.0000 | 22855993 11.97% |
| Elapsed time = 689.22 sec. (729332.52 ticks, tree = 332.67 MB, solutions = 30) |       |          |        |          |          |          |                 |
| 41437  | 30623 | 104.0000 | 255    |          | 117.0000 | 103.0000 | 22924601 11.97% |
| 42295  | 31842 | 116.0000 |        | 61       | 117.0000 | 103.0000 | 23152481 11.97% |
| 42954  | 32555 | 105.0000 | 336    |          | 117.0000 | 103.0000 | 23308349 11.97% |
| 43762  | 33125 | 105.0000 | 279    |          | 117.0000 | 103.0000 | 23470935 11.97% |
| 44449  | 34143 | 107.0000 | 256    |          | 117.0000 | 103.0000 | 23736833 11.97% |
| 45260  | 34534 | 112.0000 | 125    | 117.0000 |          | 103.0000 | 23824652 11.97% |
| 45770  | 34927 | 114.0000 |        | 65       | 117.0000 | 103.0000 | 23980160 11.97% |
| 46210  | 36105 | 110.0000 | 142    | 117.0000 |          | 103.0000 | 24384274 11.97% |
| 46463  | 36325 | 106.2500 | 253    |          | 117.0000 | 103.0000 | 24534140 11.97% |
| 46711  | 36532 |          | cutoff |          | 117.0000 | 103.0000 | 24681710 11.97% |
| Elapsed time = 729.35 sec. (767617.80 ticks, tree = 405.29 MB, solutions = 30) |       |          |        |          |          |          |                 |
| 46815  | 36702 | 105.0000 | 477    |          | 117.0000 | 103.0000 | 24801537 11.97% |
| 47035  | 36840 | 106.0000 | 312    |          | 117.0000 | 103.0000 | 24988908 11.97% |
| 47261  | 37082 | 107.0000 | 215    |          | 117.0000 | 103.0000 | 25161761 11.97% |
| 47554  | 37268 | 116.0000 |        | 95       | 117.0000 | 103.0000 | 25183907 11.97% |
| 47964  | 37242 | 108.0000 | 214    |          | 117.0000 | 103.0000 | 25297785 11.97% |
| 48401  | 37586 | 108.2922 | 137    |          | 117.0000 | 103.0000 | 25432266 11.97% |
| 48894  | 38259 | 105.0000 | 362    |          | 117.0000 | 103.0000 | 25778982 11.97% |
| 49290  | 38544 | 116.0000 | 151    | 117.0000 |          | 103.0000 | 25878851 11.97% |
| 49546  | 39136 | 105.0000 | 243    |          | 117.0000 | 103.0000 | 26166620 11.97% |
| 49748  | 39362 | 108.0000 | 173    |          | 117.0000 | 103.0000 | 26295374 11.97% |
| Elapsed time = 774.31 sec. (805923.90 ticks, tree = 437.48 MB, solutions = 30) |       |          |        |          |          |          |                 |
| 50016  | 39557 | 104.0000 | 427    |          | 117.0000 | 103.0000 | 26398735 11.97% |
| 50226  | 39737 | 109.7554 | 160    |          | 117.0000 | 103.0000 | 26515482 11.97% |
| 50558  | 40033 | 106.0000 | 305    |          | 117.0000 | 103.0000 | 26668294 11.97% |
| 50690  | 40168 | 105.2500 | 241    |          | 117.0000 | 103.0000 | 26841315 11.97% |
| 50783  | 40167 | 106.0000 | 278    |          | 117.0000 | 103.0000 | 26773679 11.97% |
| 50939  | 40628 | 104.0000 | 335    |          | 117.0000 | 103.0000 | 27133341 11.97% |
| 51295  | 40689 | 105.0000 | 285    |          | 117.0000 | 103.0000 | 27251793 11.97% |
| 51472  | 41079 | 107.0000 | 263    |          | 117.0000 | 103.0000 | 27449011 11.97% |
| 51624  | 41084 | 105.0000 | 588    |          | 117.0000 | 103.0000 | 27532003 11.97% |
| 51789  | 41536 | 105.1667 | 267    |          | 117.0000 | 103.0000 | 27783820 11.97% |
| Elapsed time = 822.76 sec. (844240.47 ticks, tree = 461.52 MB, solutions = 30) |       |          |        |          |          |          |                 |
| 52191  | 41562 | 105.0000 | 415    |          | 117.0000 | 103.0000 | 27868349 11.97% |
| 52790  | 42131 | 107.0000 | 290    |          | 117.0000 | 103.0000 | 28205637 11.97% |
| 53267  | 42159 | 106.0000 | 284    |          | 117.0000 | 103.0000 | 28188328 11.97% |
| 53826  | 42532 | 115.0000 | 169    | 117.0000 |          | 103.0000 | 28350740 11.97% |
| 54109  | 42914 | 106.0000 | 336    |          | 117.0000 | 103.0000 | 28525762 11.97% |
| 54525  | 44086 | 108.0000 | 234    |          | 117.0000 | 103.0000 | 28993591 11.97% |
| 54748  | 44066 | 104.0000 | 365    |          | 117.0000 | 103.0000 | 29113708 11.97% |
| 55016  | 44141 | 107.0000 | 313    |          | 117.0000 | 103.0000 | 29166217 11.97% |
| 55307  | 44908 | 106.0000 | 306    |          | 117.0000 | 103.0000 | 29625486 11.97% |
| 55954  | 45129 | 109.0000 | 260    |          | 117.0000 | 103.0000 | 29837078 11.97% |
| Elapsed time = 866.87 sec. (882464.21 ticks, tree = 499.93 MB, solutions = 30) |       |          |        |          |          |          |                 |
| 56385  | 45609 | 105.0000 | 301    |          | 117.0000 | 103.0000 | 30089249 11.97% |

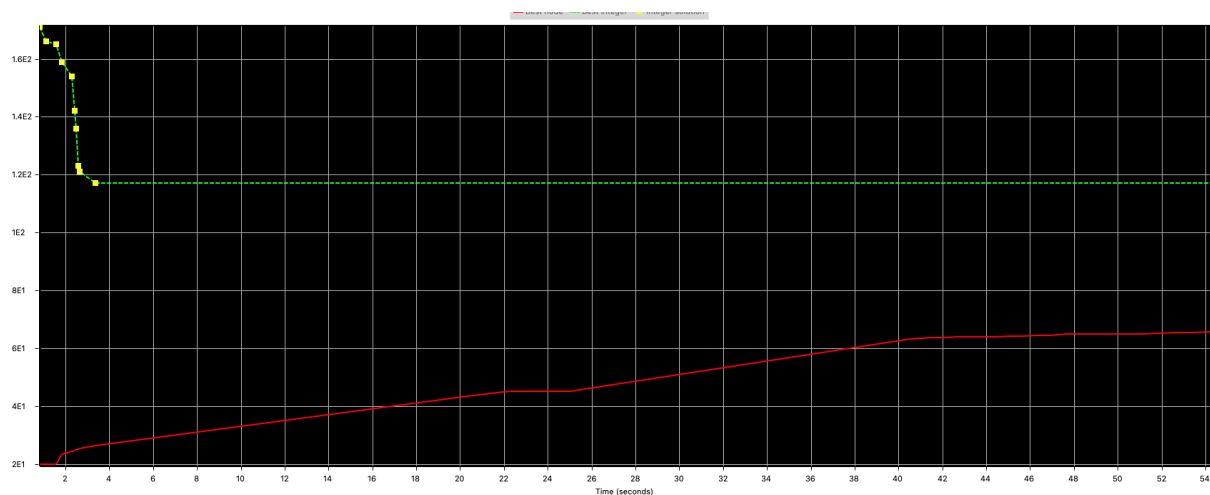
### 3.Resultado con cota de 15 lavados

Como puede verse en el gráfico, el óptimo del mejor entero vuelve a dar 117 pero esta vez tarda solo 6 segundos en arrojar dicho resultado. En este caso los resultados del mejor entero y el mejor nodo difieren bastante, pero luego de 8 minutos de ejecución empiezan a parecerse un poco más.

Dejé este modelo corriendo por 10 minutos y el resultados fue el siguiente:

Óptimo del mejor entero: 117

Óptimo del mejor nodo: 107



Engine log

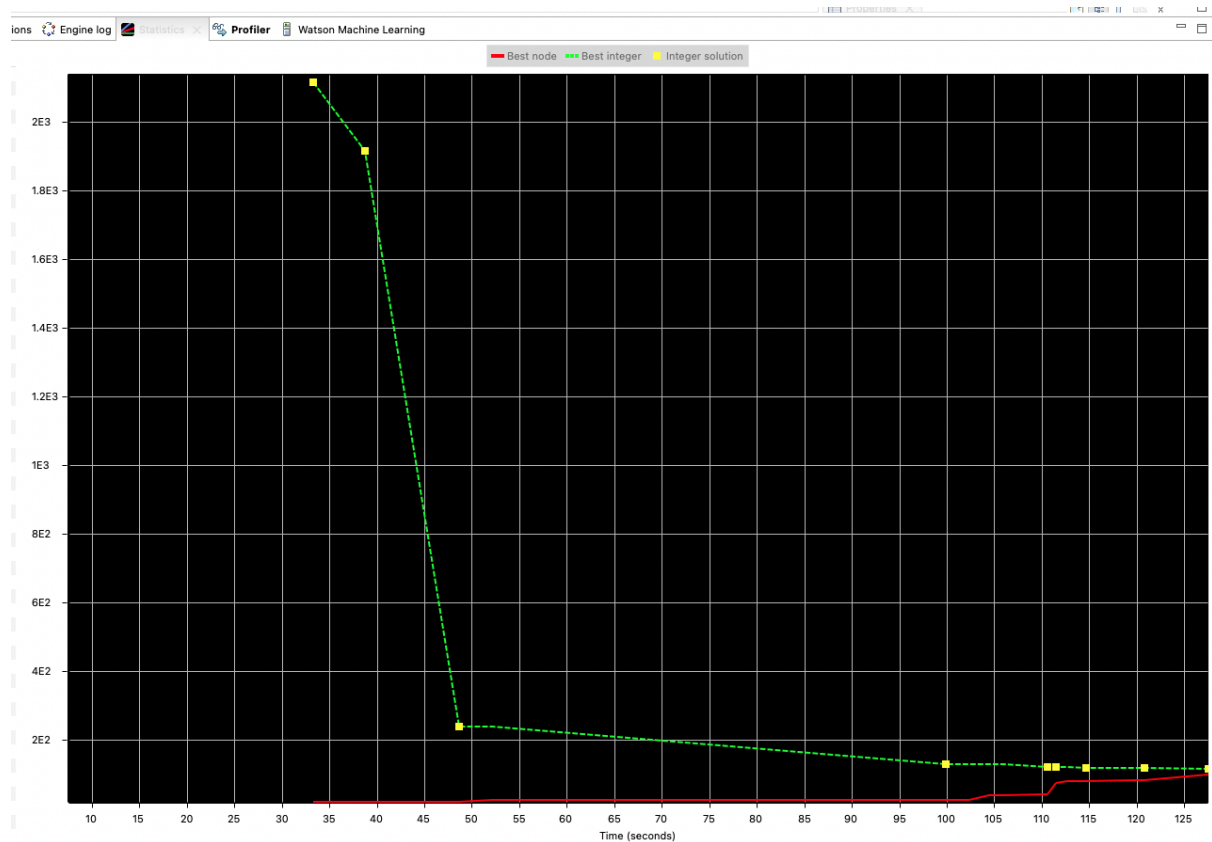
| Nodes |      | Cuts/     |                  | Best Bound | ItCnt     | Gap                 |
|-------|------|-----------|------------------|------------|-----------|---------------------|
| Node  | Left | Objective | Inf Best Integer |            |           |                     |
| *     | 0+   | 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         | 166.0000         | 20.0000    | 87.95%    |                     |
|       | 0    | 0         | 20.0000 1159     | 166.0000   | Cuts: 466 | 3357 87.95%         |
| *     | 0+   | 0         | 165.0000         | 20.0000    | 87.88%    |                     |
|       | 0    | 0         | 22.0141 1127     | 165.0000   | Cuts: 458 | 6293 86.66%         |
|       | 0    | 0         | 23.3838 985      | 165.0000   | Cuts: 953 | 8732 85.83%         |
| *     | 0+   | 0         | 162.0000         | 23.3838    | 85.57%    |                     |
| *     | 0+   | 0         | 159.0000         | 23.3838    | 85.29%    |                     |
|       | 0    | 0         | -1.000000e+75    | 0          | 159.0000  | 23.3838 8732 85.29% |
|       | 0    | 0         | 24.3540 985      | 159.0000   | Cuts: 721 | 12041 84.68%        |
| *     | 0+   | 0         | 154.0000         | 24.3540    | 84.19%    |                     |
|       | 0    | 0         | 24.6360 1024     | 154.0000   | Cuts: 665 | 14458 84.00%        |
| *     | 0+   | 0         | 142.0000         | 24.6360    | 82.65%    |                     |

|  |      |      |              |          |          |           |        |        |
|--|------|------|--------------|----------|----------|-----------|--------|--------|
|  | 0    | 0    | 25.0032      | 945      | 142.0000 | Cuts: 638 | 16119  | 82.39% |
| *  | 0+   | 0    |              | 140.0000 | 25.0032  | 82.14%    |        |        |
| *  | 0+   | 0    |              | 137.0000 | 25.0032  | 81.75%    |        |        |
| *  | 0+   | 0    |              | 136.0000 | 25.0032  | 81.62%    |        |        |
|  | 0    | 0    | -1.00000e+75 | 0        | 136.0000 | 25.0032   | 16119  | 81.62% |
| *  | 0+   | 0    |              | 123.0000 | 25.0032  | 79.67%    |        |        |
|  | 0    | 0    | 25.3096      | 920      | 123.0000 | Cuts: 594 | 17258  | 79.42% |
| *  | 0+   | 0    |              | 121.0000 | 25.3096  | 79.08%    |        |        |
|  | 0    | 0    | 25.4147      | 920      | 121.0000 | Cuts: 564 | 17921  | 79.00% |
|  | 0    | 0    | 25.5056      | 1010     | 121.0000 | Cuts: 588 | 18627  | 78.92% |
|  | 0    | 0    | 25.7654      | 1020     | 121.0000 | Cuts: 509 | 19332  | 78.71% |
|  | 0    | 0    | 25.8203      | 994      | 121.0000 | Cuts: 511 | 19831  | 78.66% |
|  | 0    | 0    | 25.9107      | 1021     | 121.0000 | Cuts: 427 | 20481  | 78.59% |
|  | 0    | 0    | 26.0278      | 963      | 121.0000 | Cuts: 430 | 20995  | 78.49% |
|  | 0    | 0    | 26.0662      | 981      | 121.0000 | Cuts: 453 | 21393  | 78.46% |
|  | 0    | 0    | 26.1137      | 980      | 121.0000 | Cuts: 339 | 21736  | 78.42% |
|  | 0    | 0    | 26.1498      | 967      | 121.0000 | Cuts: 243 | 22026  | 78.39% |
|  | 0    | 0    | 26.1828      | 1082     | 121.0000 | Cuts: 229 | 22376  | 78.36% |
|  | 0    | 0    | 26.2048      | 964      | 121.0000 | Cuts: 414 | 22897  | 78.34% |
|  | 0    | 0    | 26.2160      | 983      | 121.0000 | Cuts: 395 | 23354  | 78.33% |
| *  | 0+   | 0    |              | 117.0000 | 26.2160  | 77.59%    |        |        |
|  | 0    | 0    | 26.2272      | 1073     | 117.0000 | Cuts: 295 | 23705  | 77.58% |
|  | 0    | 0    | 26.2650      | 1029     | 117.0000 | Cuts: 275 | 24035  | 77.55% |
|  | 0    | 0    | 26.2840      | 1016     | 117.0000 | Cuts: 369 | 24486  | 77.54% |
|  | 0    | 0    | 26.3035      | 1067     | 117.0000 | Cuts: 235 | 24787  | 77.52% |
|  | 0    | 0    | 26.3188      | 1019     | 117.0000 | Cuts: 304 | 25076  | 77.51% |
|  | 0    | 0    | 26.3481      | 933      | 117.0000 | Cuts: 312 | 25528  | 77.48% |
|  | 0    | 0    | 26.3549      | 1059     | 117.0000 | Cuts: 310 | 25807  | 77.47% |
|  | 0    | 2    | 26.3549      | 999      | 117.0000 | 26.9502   | 25807  | 76.97% |
| Elapsed time = 3.98 sec. (5603.28 ticks, tree = 0.02 MB, solutions = 14) |      |      |              |          |          |           |        |        |
|  | 3    | 4    | 27.2210      | 935      | 117.0000 | 26.9502   | 27372  | 76.97% |
|  | 26   | 19   | 64.0000      | 553      | 117.0000 | 27.2234   | 37550  | 76.73% |
|  | 61   | 39   | 77.0000      | 419      | 117.0000 | 39.0000   | 46163  | 66.67% |
|  | 116  | 104  | 88.0000      | 420      | 117.0000 | 39.0000   | 68709  | 66.67% |
|  | 195  | 142  | 89.4170      | 325      | 117.0000 | 39.0000   | 79030  | 66.67% |
|  | 311  | 243  | 88.7085      | 292      | 117.0000 | 39.0000   | 94488  | 66.67% |
|  | 483  | 363  | 101.0000     | 283      | 117.0000 | 39.0000   | 111583 | 66.67% |
|  | 605  | 446  | 54.5508      | 571      | 117.0000 | 39.0000   | 130578 | 66.67% |
|  | 634  | 324  | 42.2233      | 604      | 117.0000 | 39.0000   | 111655 | 66.67% |
|  | 792  | 620  | 45.7240      | 617      | 117.0000 | 39.0000   | 194568 | 66.67% |
| Elapsed time = 6.19 sec. (8875.45 ticks, tree = 8.77 MB, solutions = 14) |      |      |              |          |          |           |        |        |
|  | 1051 | 798  | 48.5765      | 698      | 117.0000 | 39.0000   | 252702 | 66.67% |
|  | 1257 | 1015 | 53.0446      | 701      | 117.0000 | 39.0000   | 308787 | 66.67% |
|  | 1509 | 1131 | 65.0000      | 672      | 117.0000 | 39.0000   | 358006 | 66.67% |
|  | 1825 | 1443 | 44.1097      | 700      | 117.0000 | 39.0000   | 443045 | 66.67% |
|  | 2016 | 1643 | 64.0000      | 479      | 117.0000 | 39.0000   | 533823 | 66.67% |
|  | 2354 | 1913 | 112.0000     | 123      | 117.0000 | 39.0000   | 605535 | 66.67% |
|  | 2812 | 2125 | 101.0000     | 314      | 117.0000 | 39.0000   | 652143 | 66.67% |
|  | 3330 | 2649 | 65.0000      | 509      | 117.0000 | 40.9792   | 733522 | 64.98% |
|  | 3636 | 2932 | 77.0000      | 403      | 117.0000 | 42.0000   | 789041 | 64.10% |

## 4. Resultado con simetrías

Como vemos, en este caso el resultado del mejor nodo y el mejor entero converge

rápidamente a 117, y solo le tomó 127 segundos, en ese momento el programa terminó de correr y no cambió el output generado.



## Scripting log

```
solution: 117 /size: 138 /time: 1669997271.607266903
Nodo 1: 2
Nodo 2: 1
Nodo 3: 1
Nodo 4: 2
Nodo 5: 1
Nodo 6: 1
Nodo 7: 4
Nodo 8: 1
Nodo 9: 1
Nodo 10: 2
Nodo 11: 2
Nodo 12: 2
Nodo 13: 1
Nodo 14: 1
Nodo 15: 1
Nodo 16: 1
Nodo 17: 1
```

Nodo 18: 3  
Nodo 19: 1  
Nodo 20: 9  
Nodo 21: 4  
Nodo 22: 3  
Nodo 23: 1  
Nodo 24: 4  
Nodo 25: 1  
Nodo 26: 5  
Nodo 27: 2  
Nodo 28: 2  
Nodo 29: 2  
Nodo 30: 1  
Nodo 31: 7  
Nodo 32: 5  
Nodo 33: 6  
Nodo 34: 1  
Nodo 35: 4  
Nodo 36: 8  
Nodo 37: 3  
Nodo 38: 3  
Nodo 39: 2  
Nodo 40: 4  
Nodo 41: 2  
Nodo 42: 2  
Nodo 43: 1  
Nodo 44: 1  
Nodo 45: 9  
Nodo 46: 2  
Nodo 47: 1  
Nodo 48: 2  
Nodo 49: 2  
Nodo 50: 2  
Nodo 51: 1  
Nodo 52: 1  
Nodo 53: 4  
Nodo 54: 8  
Nodo 55: 2  
Nodo 56: 3  
Nodo 57: 4  
Nodo 58: 3  
Nodo 59: 1  
Nodo 60: 4  
Nodo 61: 3  
Nodo 62: 2  
Nodo 63: 1  
Nodo 64: 1  
Nodo 65: 3  
Nodo 66: 2

Nodo 67: 2  
Nodo 68: 1  
Nodo 69: 2  
Nodo 70: 6  
Nodo 71: 1  
Nodo 72: 7  
Nodo 73: 2  
Nodo 74: 11  
Nodo 75: 1  
Nodo 76: 2  
Nodo 77: 1  
Nodo 78: 8  
Nodo 79: 1  
Nodo 80: 5  
Nodo 81: 10  
Nodo 82: 1  
Nodo 83: 6  
Nodo 84: 2  
Nodo 85: 1  
Nodo 86: 1  
Nodo 87: 1  
Nodo 88: 2  
Nodo 89: 4  
Nodo 90: 2  
Nodo 91: 1  
Nodo 92: 5  
Nodo 93: 1  
Nodo 94: 2  
Nodo 95: 4  
Nodo 96: 1  
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: 1  
Nodo 106: 2  
Nodo 107: 1  
Nodo 108: 6  
Nodo 109: 2  
Nodo 110: 2  
Nodo 111: 2  
Nodo 112: 1  
Nodo 113: 2  
Nodo 114: 1  
Nodo 115: 3

Nodo 116: 9  
Nodo 117: 1  
Nodo 118: 2  
Nodo 119: 1  
Nodo 120: 2  
Nodo 121: 2  
Nodo 122: 3  
Nodo 123: 10  
Nodo 124: 2  
Nodo 125: 1  
Nodo 126: 6  
Nodo 127: 1  
Nodo 128: 2  
Nodo 129: 1  
Nodo 130: 6  
Nodo 131: 4  
Nodo 132: 2  
Nodo 133: 3  
Nodo 134: 3  
Nodo 135: 7  
Nodo 136: 2  
Nodo 137: 1  
Nodo 138: 5

## Engine log

Version identifier: 22.1.0.0 | 2022-03-09 | 1a383f8ce  
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 = 0.81 sec. (253.34 ticks)  
Found incumbent of value 2760.000000 after 1.07 sec. (465.00 ticks)  
Probing time = 0.07 sec. (13.12 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 = 0.27 sec. (144.06 ticks)  
Probing time = 0.07 sec. (12.15 ticks)  
Clique table members: 15717.  
MIP emphasis: balance optimality and feasibility.  
MIP search method: dynamic search.  
Parallel mode: deterministic, using up to 10 threads.  
Root relaxation solution time = 30.68 sec. (1091.18 ticks)



| Nodes   |      | Cuts/     |              |              |            |            |              |
|---|------|-----------|--------------|--------------|------------|------------|--------------|
| Node  | Left | Objective | Inf          | 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         | 20.9262      | 10063        | 1917.0000  | Cuts: 1839 | 2335 98.91%  |
| *   | 0+   | 0         |              | 240.0000     | 20.9262    | 91.28%     |              |
|   | 0    | 0         | 25.0994      | 8732         | 240.0000   | Cuts: 1328 | 24746 89.54% |
| *   | 0+   | 0         |              | 196.0000     | 25.0994    | 87.19%     |              |
| *   | 0+   | 0         |              | 192.0000     | 25.0994    | 86.93%     |              |
| *   | 0+   | 0         |              | 159.0000     | 25.0994    | 84.21%     |              |
| *   | 0+   | 0         |              | 147.0000     | 25.0994    | 82.93%     |              |
| *   | 0+   | 0         |              | 138.0000     | 25.0994    | 81.81%     |              |
| *   | 0+   | 0         |              | 135.0000     | 25.0994    | 81.41%     |              |
| *   | 0+   | 0         |              | 129.0000     | 25.0994    | 80.54%     |              |
|   | 0    | 0         | -1.00000e+75 | 0            | 129.0000   | 25.0994    | 34079 80.54% |
| Repeating presolve.   |      |           |              |              |            |            |              |
| Tried aggregator 1 time.  |      |           |              |              |            |            |              |
| MIP Presolve eliminated 11998 rows and 6638 columns.                    |      |           |              |              |            |            |              |
| MIP Presolve modified 1907 coefficients.                                |      |           |              |              |            |            |              |
| Reduced MIP has 22900 rows, 12544 columns, and 76153 nonzeros.          |      |           |              |              |            |            |              |
| Reduced MIP has 12406 binaries, 138 generals, 0 SOSs, and 0 indicators. |      |           |              |              |            |            |              |
| Presolve time = 0.19 sec. (89.08 ticks)                                 |      |           |              |              |            |            |              |
| Probing time = 0.07 sec. (21.67 ticks)                                  |      |           |              |              |            |            |              |
| Tried aggregator 1 time.  |      |           |              |              |            |            |              |
| Detecting symmetries...   |      |           |              |              |            |            |              |
| Reduced MIP has 22900 rows, 12544 columns, and 76153 nonzeros.          |      |           |              |              |            |            |              |
| Reduced MIP has 12406 binaries, 138 generals, 0 SOSs, and 0 indicators. |      |           |              |              |            |            |              |
| Presolve time = 0.18 sec. (82.21 ticks)                                 |      |           |              |              |            |            |              |
| Represolve time = 0.73 sec. (393.99 ticks)                              |      |           |              |              |            |            |              |
| Probing time = 0.07 sec. (21.64 ticks)                                  |      |           |              |              |            |            |              |
| Clique table members: 10360.  |      |           |              |              |            |            |              |
| MIP emphasis: balance optimality and feasibility.                       |      |           |              |              |            |            |              |
| MIP search method: dynamic search.                                      |      |           |              |              |            |            |              |
| Parallel mode: deterministic, using up to 10 threads.                   |      |           |              |              |            |            |              |
| Root relaxation solution time = 41.10 sec. (875.07 ticks)               |      |           |              |              |            |            |              |
| Nodes   |      | Cuts/     |              |              |            |            |              |
| Node  | Left | Objective | Inf          | Best Integer | Best Bound | ItCnt      | Gap          |
| *   | 0+   | 0         |              | 129.0000     | 25.0994    | 80.54%     |              |
|   | 0    | 0         | 25.6928      | 700          | 129.0000   | 25.6928    | 34120 80.08% |
|   | 0    | 0         | 34.5847      | 1353         | 129.0000   | Cuts: 522  | 43477 73.19% |
|   | 0    | 0         | 40.5952      | 2152         | 129.0000   | Cuts: 267  | 50725 68.53% |
|   | 0    | 0         | 40.9558      | 860          | 129.0000   | Cuts: 300  | 55057 68.25% |
| *   | 0+   | 0         |              | 126.0000     | 40.9558    | 67.50%     |              |
| *   | 0+   | 0         |              | 125.0000     | 40.9558    | 67.24%     |              |
| *   | 0+   | 0         |              | 123.0000     | 40.9558    | 66.70%     |              |
| *   | 0+   | 0         |              | 122.0000     | 40.9558    | 66.43%     |              |
|   | 0    | 0         | -1.00000e+75 | 0            | 122.0000   | 40.9558    | 55057 66.43% |

|   |    |   |         |          |          |           |       |        |
|---|----|---|---------|----------|----------|-----------|-------|--------|
|   | 0  | 0 | 43.0873 | 830      | 122.0000 | Cuts: 289 | 57049 | 41.16% |
| * | 0+ | 0 |         | 121.0000 | 71.7885  | 40.67%    |       |        |
|   | 0  | 0 | 43.3289 | 851      | 121.0000 | Cuts: 202 | 59296 | 37.57% |
|   | 0  | 0 | 43.3400 | 704      | 121.0000 | Cuts: 75  | 59700 | 37.57% |
|   | 0  | 0 | 43.3400 | 721      | 121.0000 | Cuts: 137 | 60068 | 37.57% |

Detecting symmetries...

|  |   |   |         |     |          |         |       |        |
|--|---|---|---------|-----|----------|---------|-------|--------|
|  | 0 | 2 | 43.3789 | 597 | 121.0000 | 80.2480 | 60128 | 33.68% |
|--|---|---|---------|-----|----------|---------|-------|--------|

Elapsed time = 111.95 sec. (58937.14 ticks, tree = 0.02 MB, solutions = 22)

|  |     |     |          |     |          |         |        |        |
|--|-----|-----|----------|-----|----------|---------|--------|--------|
|  | 3   | 4   | 116.8333 | 164 | 121.0000 | 80.2480 | 61746  | 33.68% |
|  | 46  | 12  | 117.4705 | 155 | 121.0000 | 80.2480 | 67823  | 33.68% |
|  | 100 | 43  | 83.5501  | 316 | 121.0000 | 80.2480 | 79964  | 33.68% |
|  | 230 | 107 | 110.3955 | 308 | 121.0000 | 80.2480 | 94503  | 33.68% |
|  | 365 | 162 | 92.0261  | 266 | 121.0000 | 80.2480 | 106492 | 33.68% |
|  | 488 | 253 | 116.5026 | 136 | 121.0000 | 80.2480 | 125533 | 33.68% |
|  | 559 | 325 | 110.0862 | 320 | 121.0000 | 80.2480 | 137968 | 33.68% |
|  | 727 | 369 | 115.6044 | 114 | 121.0000 | 80.2480 | 144426 | 33.68% |

|   |      |      |          |          |          |         |        |        |
|---|------|------|----------|----------|----------|---------|--------|--------|
| * | 896+ | 501  |          | 119.0000 | 80.2480  | 32.56%  |        |        |
|   | 907  | 519  | 104.7734 | 245      | 119.0000 | 80.2480 | 161253 | 32.56% |
|   | 1707 | 1105 | 95.0021  | 210      | 119.0000 | 80.2480 | 204188 | 32.56% |

Elapsed time = 114.37 sec. (62095.79 ticks, tree = 7.28 MB, solutions = 23)

|  |      |      |         |     |          |         |        |        |
|--|------|------|---------|-----|----------|---------|--------|--------|
|  | 2172 | 1372 | 99.1231 | 237 | 119.0000 | 80.2480 | 251788 | 32.56% |
|  | 2898 | 1821 | 99.2143 | 199 | 119.0000 | 81.0490 | 305782 | 31.89% |
|  | 3612 | 2233 | 91.2438 | 216 | 119.0000 | 83.7754 | 342395 | 29.60% |

Performing restart 1

Repeating presolve.

Tried aggregator 4 times.

MIP Presolve eliminated 18497 rows and 9873 columns.

MIP Presolve modified 206 coefficients.

Aggregator did 12 substitutions.

Reduced MIP has 4391 rows, 2659 columns, and 13753 nonzeros.

Reduced MIP has 2540 binaries, 119 generals, 0 SOSs, and 0 indicators.

Presolve time = 0.04 sec. (33.37 ticks)

Tried aggregator 1 time.

Reduced MIP has 4391 rows, 2659 columns, and 13753 nonzeros.

Reduced MIP has 2541 binaries, 118 generals, 0 SOSs, and 0 indicators.

Presolve time = 0.03 sec. (12.83 ticks)

Represolve time = 0.20 sec. (318.50 ticks)

|  |      |   |         |     |          |           |        |        |
|--|------|---|---------|-----|----------|-----------|--------|--------|
|  | 3614 | 0 | 47.8157 | 754 | 119.0000 | Cuts: 519 | 359217 | 29.60% |
|  | 3614 | 0 | 48.1922 | 697 | 119.0000 | Cuts: 571 | 359869 | 29.60% |
|  | 3614 | 0 | 50.3506 | 544 | 119.0000 | Cuts: 617 | 360709 | 29.60% |
|  | 3614 | 0 | 50.5791 | 568 | 119.0000 | Cuts: 598 | 361194 | 29.60% |
|  | 3614 | 0 | 50.7980 | 512 | 119.0000 | Cuts: 320 | 361623 | 29.60% |
|  | 3614 | 0 | 50.9215 | 556 | 119.0000 | Cuts: 487 | 362160 | 29.60% |
|  | 3614 | 0 | 50.9984 | 508 | 119.0000 | Cuts: 207 | 362525 | 29.60% |
|  | 3614 | 0 | 51.0961 | 519 | 119.0000 | Cuts: 499 | 362879 | 29.60% |
|  | 3614 | 2 | 51.0961 | 506 | 119.0000 | 83.7754   | 362879 | 29.60% |
|  | 3618 | 4 | 51.2385 | 495 | 119.0000 | 83.7754   | 363236 | 29.60% |

|   |       |    |          |          |          |         |        |        |
|---|-------|----|----------|----------|----------|---------|--------|--------|
| * | 3619+ | 1  |          | 118.0000 | 83.7754  | 29.00%  |        |        |
|   | 3631  | 3  | 101.6732 | 396      | 118.0000 | 83.7754 | 365446 | 29.00% |
|   | 3659  | 7  | 51.3142  | 486      | 118.0000 | 83.7754 | 370487 | 29.00% |
|   | 3738  | 20 | 99.0154  | 224      | 118.0000 | 83.7754 | 387744 | 29.00% |
|   | 4168  | 23 | 89.9042  | 336      | 118.0000 | 83.7754 | 421078 | 29.00% |
|   | 4778  | 51 | 113.7188 | 169      | 118.0000 | 83.7754 | 454126 | 29.00% |

Elapsed time = 123.07 sec. (74935.85 ticks, tree = 0.08 MB, solutions = 24)

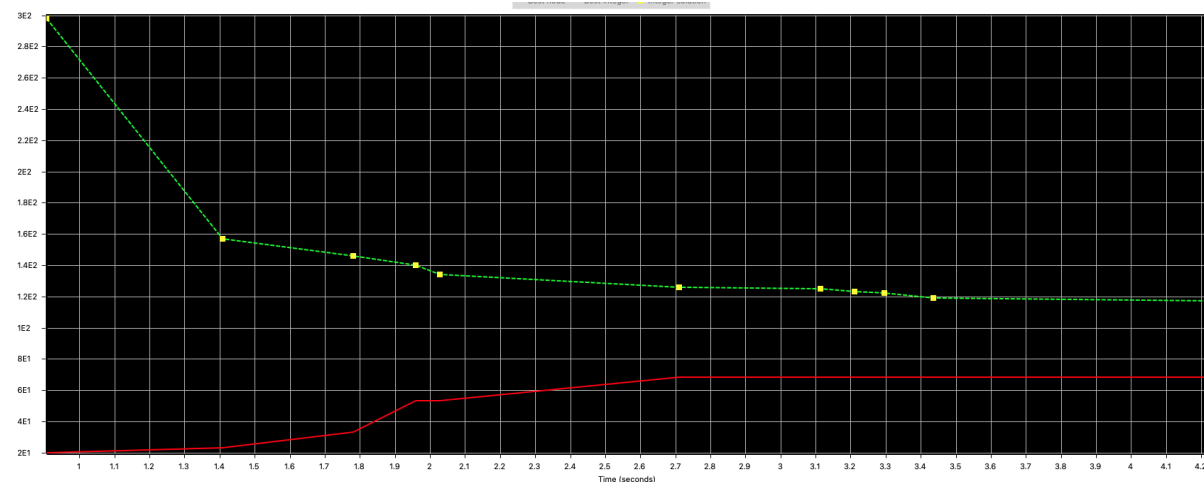
|  |      |     |         |     |          |         |        |        |
|--|------|-----|---------|-----|----------|---------|--------|--------|
|  | 5933 | 55  | 84.6319 | 307 | 118.0000 | 83.7754 | 515646 | 29.00% |
|  | 6771 | 558 | cutoff  |     | 118.0000 | 83.7754 | 566350 | 29.00% |
|  | 7318 | 854 | 92.2141 | 284 | 118.0000 | 83.7754 | 635757 | 29.00% |

|  |      |            |     |          |          |        |        |
|--|------|------------|-----|----------|----------|--------|--------|
| 8666   | 1350 | 110.7131   | 196 | 118.0000 | 92.0817  | 748159 | 21.96% |
| * 9111+  | 1353 |            |     | 117.0000 | 97.5038  |        | 16.66% |
| 10669  | 1383 | infeasible |     | 117.0000 | 106.0435 | 838124 | 9.36%  |
| Clique cuts applied: 10<br>Implied bound cuts applied: 49<br>Flow cuts applied: 70<br>Mixed integer rounding cuts applied: 91<br>Zero-half cuts applied: 49<br>Lift and project cuts applied: 5<br>Gomory fractional cuts applied: 41<br><br>Root node processing (before b&c):<br>Real time = 111.82 sec. (58602.78 ticks)<br>Parallel b&c, 10 threads:<br>Real time = 15.59 sec. (21735.54 ticks)<br>Sync time (average) = 4.39 sec.<br>Wait time (average) = 0.01 sec.<br>-----<br>Total (root+branch&cut) = 127.41 sec. (80338.32 ticks) |      |            |     |          |          |        |        |

5. Resultado con simetrías y cota de 15 lavados

En solo 9 segundos llegó al óptimo de 117 para el caso del mejor entero, y para el mejor nodo da 108, hasta ahora parece el resultado.

El algoritmo terminó de ejecutarse, mostrando en consola la ejecución de cada nodo.



Engine log

| Nodes |      | Cuts/     |     |              | ItCnt | Gap |
|-------|------|-----------|-----|--------------|-------|-----|
| Node  | Left | Objective | Inf | Best Integer |       |     |

|   |          |      |              |          |          |            |        |        |
|---|----------|------|--------------|----------|----------|------------|--------|--------|
| *   | 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      | 1157     | 157.0000 | Cuts: 1090 | 5698   | 85.30% |
| *   | 0+       | 0    |              | 146.0000 | 23.0769  | 84.19%     |        |        |
|   | 0        | 0    | 25.7027      | 903      | 146.0000 | Cuts: 705  | 9668   | 77.17% |
| *   | 0+       | 0    |              | 140.0000 | 33.3333  | 76.19%     |        |        |
|   | 0        | 0    | 26.4823      | 830      | 140.0000 | Cuts: 640  | 11420  | 61.89% |
| *   | 0+       | 0    |              | 134.0000 | 53.3534  | 60.18%     |        |        |
|   | 0        | 0    | -1.00000e+75 | 0        | 134.0000 | 53.3534    | 11420  | 60.18% |
|   | 0        | 0    | 27.8635      | 932      | 134.0000 | Cuts: 513  | 12607  | 60.18% |
|   | 0        | 0    | 28.3583      | 699      | 134.0000 | Cuts: 367  | 13373  | 51.49% |
|   | 0        | 0    | 28.9929      | 734      | 134.0000 | Cuts: 517  | 14115  | 51.49% |
| *   | 0+       | 0    |              | 129.0000 | 65.0000  | 49.61%     |        |        |
| *   | 0+       | 0    |              | 127.0000 | 68.1439  | 46.34%     |        |        |
| *   | 0+       | 0    |              | 126.0000 | 68.1439  | 45.92%     |        |        |
|   | 0        | 0    | -1.00000e+75 | 0        | 126.0000 | 68.1439    | 14115  | 45.92% |
|   | 0        | 2    | 30.2094      | 604      | 126.0000 | 68.1439    | 14404  | 45.92% |
| Elapsed time = 2.52 sec. (2999.21 ticks, tree = 0.02 MB, solutions = 9) |          |      |              |          |          |            |        |        |
|   | 25       | 19   | 108.8392     | 187      | 126.0000 | 68.1439    | 17779  | 45.92% |
| *   | 108      | 61   | integral 0   | 125.0000 | 68.1439  | 24017      | 45.48% |        |
|   | 201      | 99   | 113.2969     | 200      | 125.0000 | 68.1439    | 28553  | 45.48% |
| *   | 205+7    |      | 123.0000     |          | 68.1439  | 44.60%     |        |        |
| *   | 264+3    |      | 122.0000     |          | 68.1439  | 44.14%     |        |        |
|   | 499      | 245  | 107.3333     | 154      | 122.0000 | 68.1439    | 40930  | 44.14% |
| *   | 553+ 263 |      |              | 120.0000 | 68.1439  | 43.21%     |        |        |
| *   | 624+ 271 |      |              | 119.0000 | 68.1439  | 42.74%     |        |        |
|   | 1117     | 480  | 97.8261      | 241      | 119.0000 | 68.1439    | 53496  | 42.74% |
|   | 1760     | 851  | 108.5341     | 266      | 119.0000 | 68.1439    | 77090  | 42.74% |
|   | 2381     | 1117 | 110.4618     | 233      | 119.0000 | 68.1439    | 92067  | 42.74% |
|   | 3427     | 1621 | 118.0000     | 78       | 119.0000 | 68.1439    | 109194 | 42.74% |
| *   | 3875     | 1783 | integral 0   | 118.0000 | 68.1439  | 120168     | 42.25% |        |
| *   | 3881     | 1544 | integral 0   | 117.0000 | 68.1439  | 123362     | 41.76% |        |
|   | 4024     | 1287 | cutoff       | 117.0000 | 68.1439  | 124504     | 41.76% |        |
|   | 4459     | 1339 | 109.7719     | 254      | 117.0000 | 68.1439    | 139930 | 41.76% |

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. (9.39 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 = 0.02 sec. (8.67 ticks)

Represolve time = 0.11 sec. (66.72 ticks)

|      |   |         |     |          |           |        |        |
|------|---|---------|-----|----------|-----------|--------|--------|
| 5502 | 0 | 83.3488 | 381 | 117.0000 | Cuts: 334 | 200933 | 28.76% |
| 5502 | 0 | 83.5303 | 382 | 117.0000 | Cuts: 415 | 201756 | 28.61% |
| 5502 | 0 | 84.0923 | 401 | 117.0000 | Cuts: 350 | 202471 | 28.13% |
| 5502 | 0 | 84.4374 | 398 | 117.0000 | Cuts: 293 | 202927 | 27.83% |
| 5502 | 0 | 84.9684 | 362 | 117.0000 | Cuts: 300 | 203516 | 27.38% |

|   |      |          |                            |          |           |        |        |
|---|------|----------|----------------------------|----------|-----------|--------|--------|
| 5502  | 0    | 85.1453  | 374                        | 117.0000 | Cuts: 317 | 204029 | 27.23% |
| 5502  | 0    | 85.6873  | 387                        | 117.0000 | Cuts: 300 | 204612 | 26.76% |
| 5502  | 0    | 87.4710  | 383                        | 117.0000 | Cuts: 289 | 205760 | 25.24% |
| 5502  | 0    | 87.7556  | 386                        | 117.0000 | Cuts: 283 | 206311 | 25.00% |
| 5502  | 0    | 88.0655  | 389                        | 117.0000 | Cuts: 295 | 206715 | 23.74% |
| 5502  | 0    | 88.5011  | 384                        | 117.0000 | Cuts: 230 | 207119 | 23.74% |
| 5502  | 0    | 90.5844  | 381                        | 117.0000 | Cuts: 236 | 208012 | 22.58% |
| 5502  | 0    | 90.6762  | 375                        | 117.0000 | Cuts: 311 | 208352 | 22.50% |
| 5502  | 0    | 90.7708  | 399                        | 117.0000 | Cuts: 251 | 208756 | 22.42% |
| 5502  | 0    | 91.1075  | 406                        | 117.0000 | Cuts: 274 | 209363 | 22.13% |
| 5502  | 0    | 91.7300  | 372                        | 117.0000 | Cuts: 257 | 210059 | 21.60% |
| 5502  | 0    | 91.8071  | 392                        | 117.0000 | Cuts: 219 | 210341 | 21.53% |
| 5502  | 0    | 92.0416  | 349                        | 117.0000 | Cuts: 238 | 210590 | 21.33% |
| 5502  | 0    | 92.2069  | 350                        | 117.0000 | Cuts: 232 | 210938 | 21.19% |
| 5502  | 0    | 92.2075  | 362                        | 117.0000 | Cuts: 257 | 211048 | 21.19% |
| 5502  | 0    | 92.2553  | 379                        | 117.0000 | Cuts: 99  | 211221 | 21.15% |
| 5502  | 0    | 92.2565  | 387                        | 117.0000 | Cuts: 275 | 211421 | 21.15% |
| 5502  | 0    | 92.2595  | 352                        | 117.0000 | Cuts: 144 | 211581 | 21.15% |
| 5502  | 0    | 92.2823  | 357                        | 117.0000 | Cuts: 224 | 211870 | 21.13% |
| 5502  | 0    | 92.3026  | 330                        | 117.0000 | Cuts: 174 | 212151 | 21.11% |
| 5502  | 0    | 92.3485  | 301                        | 117.0000 | Cuts: 167 | 212553 | 21.07% |
| 5502  | 0    | 92.3773  | 381                        | 117.0000 | Cuts: 197 | 212830 | 21.05% |
| 5502  | 0    | 92.4148  | 388                        | 117.0000 | Cuts: 182 | 213034 | 21.01% |
| 5502  | 0    | 92.4315  | 379                        | 117.0000 | Cuts: 178 | 213268 | 21.00% |
| 5502  | 0    | 92.4318  | 375                        | 117.0000 | Cuts: 92  | 213386 | 21.00% |
| 5502  | 2    | 92.4318  | 368                        | 117.0000 | 92.4318   | 213388 | 21.00% |
| Elapsed time = 8.72 sec. (11010.17 ticks, tree = 0.02 MB, solutions = 22) |      |          |                            |          |           |        |        |
| 5585  | 22   | 113.6791 | 169                        | 117.0000 | 93.6040   | 229630 | 20.00% |
| 6573  | 484  | 106.6072 | 217                        | 117.0000 | 98.7604   | 317385 | 15.59% |
| 7544  | 963  | 107.6375 | 174                        | 117.0000 | 104.5733  | 433714 | 10.62% |
| 8653  | 1194 | 114.8000 | 140                        | 117.0000 | 108.5907  | 530631 | 7.19%  |
| Clique cuts applied: 9  |      |          |                            |          |           |        |        |
| Implied bound cuts applied: 11  |      |          |                            |          |           |        |        |
| Flow cuts applied: 68   |      |          |                            |          |           |        |        |
| Mixed integer rounding cuts applied: 230                                  |      |          |                            |          |           |        |        |
| Zero-half cuts applied: 32  |      |          |                            |          |           |        |        |
| Lift and project cuts applied: 18   |      |          |                            |          |           |        |        |
| Gomory fractional cuts applied: 6   |      |          |                            |          |           |        |        |
| Root node processing (before b&c):  |      |          |                            |          |           |        |        |
| Real time   |      | =        | 2.49 sec. (2942.61 ticks)  |          |           |        |        |
| Parallel b&c, 10 threads:   |      |          |                            |          |           |        |        |
| Real time   |      | =        | 9.40 sec. (12816.58 ticks) |          |           |        |        |
| Sync time (average)   |      | =        | 1.51 sec.                  |          |           |        |        |
| Wait time (average)   |      | =        | 0.01 sec.                  |          |           |        |        |

## 6.Comparación de paso 3 y 5

En el caso 3 (resultado con cota de 15 lavados), vemos que pese a haber llegado a un buen resultado a los 3.98 segundos, tarda 127 segundos en obtener el máximo.

Luego en el caso que tiene cota de 15 lavados y además simetría, sólo tarda 3 segundos en llegar a un buen resultado, pero continúa buscándolo hasta los 9

segundos.

Podríamos decir que ambos llegaron a un óptimo, pero el segundo caso, que se trataba de un modelo más restrictivo y no estaba obligado a probar tantas combinaciones pudo converger más rápidamente.

Esto sucede con un problema de tan solo 138 prendas, y sus posibles combinaciones, nos damos cuenta que en caso de no contar con el suficiente tiempo, a futuro en problemas de encontrar óptimos, si tenemos información del problema, conviene fijar las restricciones que conozcamos.

## **7.Comparación heurística y modelo de programación lineal.**

La heurística propuesta dio un peor resultado, pero en un tiempo mucho mejor, y no estaba tan alejado del óptimo. Recordemos que la heurística se obtuvo en 16 milisegundos, mientras que el problema de programación lineal continua en el mejor de los casos tardó 9 segundos (si miramos el orden de magnitud del tiempo consumido, no es para nada despreciable).

El resultado de la heurística fue de 123, mientras que el del modelo de programación lineal dió 117, es menos del 5%.