

# Maintenance Optimization of Wagons Mix

[MRS Logística S/A](#)

General Management of Digital Transformation

Innovation Management

Data Intelligence Cell

Authors:

[Carmo Crêdiney de Melo](#)

Data Science and Innovation Specialist at MRS

Specialist in Data Science at Mackenzie Presbyterian University

[Leonardo Mendes Vianna](#)

Senior Railway Specialist at MRS

Master in Transportation Engineering for Military Institute of Engineering

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## **Abstract**

Maintenance is a latent and important problem in the Brazilian railroad due to the high cost and dependencies on imported parts. The lack of planning can cause operational impacts on the railroad. For Brazilian exports, it can be emphasized that maintenance costs must be one of the main concerns of any company in order to contribute to the best planning. This work proposes to create a tool for support for cost reduction in wagon maintenance through the distribution of the annual plan in workshops. The distribution depends on the type of wagon, the scope of the maintenance service that each workshop serves, and the capacity that is supported by the workshops. Also of equal importance is to consider the cost of logistics from the wagon to the workshop. This plan is a mix of the sense of vision and awareness of the result before it is executed. This is essential for planning the workshop capacity, as it provides essential operational gains.

## 1. INTRODUCTION

In Brazil, the Imperial Government provided a concession for constructing a railway line to the entrepreneur Irineu Evangelista de Souza (future Baron of Mauá).

The Baron of Mauá Railway was inaugurated by the Emperor of Brazil, D. Pedro II, on April 30, 1854. The first section of the railway was 14.5 km long and had a narrow gauge of 1.68m, connecting the port from Mauá, in Guanabara Bay, to Fragoso Station, at the root of “Serra da Estrela” in “Petrópolis” (BRINA, 1983).

In 1854, after the inauguration of the first Brazilian railway line and with the implementation of the railroads in Brazil, it was observed that the railroads went through numerous difficulties due to the lack of money funds. Even so, there was a significant increase in the railroad network in the country, directly associated with the outflow of agricultural production. (BRINA, 1983).

With the industrialization in Brazil, there were great efforts try to articulate the expansion through the railroads. However, as many companies were still in deficit, the State had to take them over so that they were not deactivated with that, there was a strong movement of nationalization the railroads, culminating in the general takeover of the sector and the creation of the State-owned RFFSA, in 1957 (BRINA, 1983).

In 1996, with the privatization of RFFSA, the company MRS was created. When the Brazilian government transferred to the private sector the management of the national rail system for 30 years, a logistics operator was formed that manages an important part of the extinct RFFSA network. The network 1,643 km railway in the states of “Minas Gerais”, “Rio de Janeiro” and “São Paulo”, a region that concentrates about half of the Brazilian GDP. The MRS network connects regions that produce mineral and agricultural commodities and some of the main industrial parks in the country to the largest ports in the Southeast region, which gives the operation differentiated economic importance.

The production of MRS is diversified. Among the main cargo transport are containers, steel, cement, bauxite, agricultural, coke, coal, and iron ore. (MRS website, 2020).

In addition to cargo transportation such as ores, finished steel products, cement, bauxite, agricultural products, and containers, MRS offers broader logistical solutions. The planning and development of multimodal solutions (which use more than one medium transport) and customized rail services. The company currently has indicators comparable to those of the most efficient and safe North American and European railways, energy efficiency, transit time, availability and reliability of assets, safety, and productivity. It stands out for the intensive use of technology culture. of innovation. (MRS website, 2020).

## **2. DESIGN**

The objective of this work is to contribute to the planning of wagons conceptually and practically. In practice, we will create a support tool to reduce the maintenance costs of wagons.

The maintenance of wagons has a high impact on the demand for cargo transportation. Currently, it is a process under development, so this work is an excellent opportunity for innovation and contribution to the sector.

The reference tool to optimize the wagons maintenance demand uses linear programming (PL) to obtain the optimal solution. We will use the linear programming modeling (PL) framework in Python, the Pulp, the PL solver the open-source software CBC was chosen. It was created by IBM Research and donated to the open-source project COIN-OR. However, any market solver can be used.

Linear Programming (PL) is considered to be one of the most widespread techniques of Operational Research. Although the name Operational Research can give the impression that it is research (in the sense of questionnaires), it is part of an area of knowledge treated as Management Science. PL is a technique that assumes the linear relationship between the characteristics of the problem, seeking the optimal solution to the studied problem using mathematics.

Linear Programming consists of representing the characteristics of a problem in the form of a set of linear equations. We call this step of modeling the problem. We can say that the modeling product, in this case, is nothing more than the translation of the characteristics of the problem to a mathematical language. Optimization problems generally make use of this technique that aims to minimize or maximize data in a situation. However, we must emphasize that the PL is not only used to minimize or maximize these items. We can find a problem, for example, of routing in which we want to minimize the travel time, thus allowing us to finish the route as soon as possible.

### **3. CHALLENGE**

The problem is to find the best cost and distribute demand among workshops in the simulated scenery, following a variety of operational restrictions.

The problem is latent and essential in the Brazilian railroad due to high maintenance costs and dependencies on imported parts. The lack of this planning can cause operational impacts on the railroad and Brazilian exports.

MRS restricts the data so that we will work with simulated scenery and data from other articles. However, it will be possible to understand how to improve the maintenance process by applying optimization to the wagon plan in workshops.

What motivated this subject was to study data science solutions for railcar maintenance in 2020, inspired by my colleague and maintenance specialist at MRS Leonardo Vianna. I am grateful for the support and use of references from his scientific. Some actions directed in this work can be used in MRS or any railway organization globally, thus contributing to the Brazilian and international railway sectors.

### **4. PROBLEM (PAIN)**

The distribution of the annual plan for the workshops is a non-linear relation to the demand. That is, an increase in demand has no relation to the increase in the determined workshop. This relationship depends on saturation information, efficiency, workshop costs asset availability. So optimization is a more appropriate technique for resource distribution. The tool will provide a forecast of demand for workshops, allowing for better planning of the workshops.

The applied technology must have a linear programming abstraction and use clear language with high potential for data analysis. It can use algorithms such as greedy algorithms, genetic algorithms, or combinatorial optimization to configure a viable initial solution and simplify the programming linear process solver processing.

## 5. SOLUTION

In this work, we will distribute resources (wagons) in workshops according to the infrastructure restrictions of each Workshop with a focus on minimizing the total maintenance costs mentioned by nature and contemplating the unavailability of the asset.

It was understood that the problem studied is to distribute the wagons by the Workshop and the variable that will model is linear, the cost of scope for each Workshop, and the capacity of wagons per fleet. We will apply linear optimization because it is a deterministic problem. We will have to model an objective function that minimizes scope costs and maximizes the capacity of the own workshops, as long as it meets planning restrictions.

Understood that the problem studied is to distribute the wagons by the Workshop and the variable that will provide:

- Linear model.
- The cost of scope for each Workshop.
- The capacity of wagons per fleet.

We will apply linear optimization because it is a deterministic problem.

We will have to model an objective function that minimizes scope costs and maximizes the capacity of the own workshops, as long as it meets planning restrictions.

## 5.1 SIMULATED SCENERY

We will present simulated scenery of wagon distribution in workshops to minimize costs over maintenance values by service scope between workshops.

Suppose that if you want to repair a set of wagons at minimum cost, as a scope possibility, we will have maintenance due annually (VR1), due every two years (VR2), due every four years (VR4), overhaul every eight years. (VRG), It is also necessary to consider a history of corrective measures that may arise in the short term (VMC). All of this scenery expires in the fictitious year of 2019, and we need to know the distribution by Workshops.

Components outside the scope of maintenance are a complicating factor in the problem. Here are some examples: wagon wheels that are like the car wheel, the hose connecting the wagon that would be like a winch cable, these components will in this example be added to the value of the maintenance of the wagon, however, can be done in practices in the second round of optimization, considering the quantities of wagons from the first optimization, if considered as a competing cost to that of the wagon, we would not have a linear problem, but a stochastic one, where we will have several variables competing with each other in the objective function, however, the expressive value is always of the wagon, and these components enter the scenery as a complement to the wagon, thus maintaining the deterministic and linear problem.

We can have more than 10k items per year to analyze costs between several workshops in real scenery.

The case is real, and the data are simulated from the Brazilian maintenance railway industry.

Table 3 – Capacity in man hour Workshops

<b>Workshop</b>	<b>Minimum person-hour (HH)</b>	<b>Maximum person-hour (HH)</b>
OFA	1500	2040
OFB	2000	8000

Source: Melo, Carmo C.(2020).

Table 4 - Wagon maintenance demand

Type Scope	Class Scope	Demand Wagon	Description Scope
VR1P	A1	252	VR1P - 1P Scope Review
VR2P	A1	7	VR2P - 2P Scope Review
VR4P	A2	46	VR4P - 4P Scope Review
VRGP	A2	94	VR1P - General Scope Review P
VR1D	A1	109	VR1D - 1D Scope Review
VR2D	A1	14	VR2D - 2D Scope Review
VR4D	A2	31	VR4D - 4D Scope Review
VRGD	A2	8	VRGD - General Scope Review D
VMC	A1	443	Corrective Maintenance Review

Source: Melo, Carmo C.(2020).

We will consider 2 (two) workshops for the example to be more didactic, and the non-receipt restriction will be considered zero cost (0). We will also use the unit labor/person-hour (HH) standardized as 10 hours to simplify the understanding and not affect the optimization of the cost. The capacity of the workshop will be proportional to the number of wagons in this scenery. In this example, the “Workshop Cost” already has the aggregate component.

Table 5 - Scope parameters by Workshop (PEO)

Workshop	Type Scope	Scope Class	Cost per unit	HH by unit	Workshop	Type Scope	Scope Class	Cost per unit	HH by unit
OFA	VR1P	A1	95	10	OFB	VR1P	A1	75	10
OFA	VR2P	A1	120	10	OFB	VR2P	A1	125	10
OFA	VR4P	A2	100	10	OFB	VR4P	A2	105	10
OFA	VRGP	A2	105	10	OFB	VRGP	A2	110	0
OFA	VR1D	A1	70	10	OFB	VR1D	A1	60	10
OFA	VR2D	A1	110	10	OFB	VR2D	A1	115	10
OFA	VR4D	A2	115	10	OFB	VR4D	A2	110	10
OFA	VRGD	A2	140	10	OFB	VRGD	A2	141	10
OFA	VMC	A1	90	10	OFB	VMC	A1	70	10

Source: Melo, Carmo C.(2020).

## 5.2 MODELING THE PROBLEM

To build the optimization, we will use the model below for the problem we are simulating:

### INDEXES

ws – workshop

st, st2 - scope\_type

sc, sc2 - scope\_class

### PARAMETERS

SCOPE\_ID<sub>st</sub> – Scope identifier (1 = VR1; 2 = VR2; 3 = VR4; 4 = VRG)

SCOPE\_COST<sub>st,sc,ws</sub> – Scope unit cost per scope type and workshop

SCOPE\_HOUR<sub>st,sc,ws</sub> - Scope effort in person-hours per workshop

FLEET\_DEMAND<sub>st,sc</sub> – Total demand by scope type and scope class

CAPACITY\_MIN<sub>ws</sub> - Minimum person hour capacity per workshop

CAPACITY\_MAX<sub>ws</sub> - Maximum person hour capacity per workshop

### VARIABLES

PLAN\_WAGON<sub>ws,st,sc</sub> – Number of wagons in maintenance at the workshop

### OBJECTIVE FUNCTION

$$\text{MIN } \text{PLAN\_WAGON}_{ws,st,sc} * \text{SCOPE\_COST}_{st,sc,ws}$$

### RESTRICTIONS

$$\begin{aligned} & \text{FLEET\_DEMAND}_{st,sc} \\ &= \sum_{ws} \sum_{st2} \sum_{sc2} \text{PLAN\_WAGON}_{ws,st2,sc2} \quad \forall_{ws,st2,sc2} \mid \sum_{ws} \text{SCOPE\_HOUR}_{st2,sc2,ws} > 0 \end{aligned}$$

$$\begin{aligned} & \text{CAPACITY\_MIN}_{st,sc} \\ &\geq \sum_{ws} \sum_{st2} \sum_{sc2} \text{PLAN\_WAGON}_{ws,ct2,sc2} \\ &* \text{SCOPE\_HOUR}_{st2,sc2,ws} \quad \forall_{st2,sc2} \mid \sum_{st2} \text{CAPACITY\_MIN}_{st2,sc2} > 0 \end{aligned}$$

$$\begin{aligned} & \text{CAPACITY\_MAX}_{st,sc} \\ &\leq \sum_{ws} \sum_{st2} \sum_{sc2} \text{PLAN\_WAGON}_{ws,ct2,sc2} \\ &* \text{SCOPE\_HOUR}_{st2,sc2,ws} \quad \forall_{st2,sc2} \mid \sum_{st2} \text{CAPACITY\_MAX}_{st2,sc2} > 0 \end{aligned}$$



### 5.3 RESULT OF OPTIMIZATION FOR THE SCENERY:

Figure 15 - Result of the attached Solver Python

Workshop Scope Type	The amount of wagons	Optimal cost	Capacity of person-hour (HH)
<b>OFA</b>	<b>204</b>	<b>21815</b>	<b>2040</b>
VMC	0	0	0
VR1D	4	280	40
VR1P	0	0	0
VR2D	14	1540	140
VR2P	7	840	70
VR4D	31	3565	310
VR4P	46	4600	460
VRGD	8	1120	80
VRGP	94	9870	940
<b>OFB</b>	<b>800</b>	<b>56210</b>	<b>8000</b>
VMC	443	31010	4430
VR1D	105	6300	1050
VR1P	252	18900	2520
VR2D	0	0	0
VR2P	0	0	0
VR4D	0	0	0
VR4P	0	0	0
VRGD	0	0	0
VRGP	0	0	0
<b>Grand total</b>	<b>1004</b>	<b>78025</b>	<b>10040</b>

The result delivered the best solution given the maximum capacity of the workshops. To improve even more, it is necessary to put zero (0) in the capacities and analyze the result without the capacity restriction. This approach can be made for a project of expansion of the workshop. This tool will also be able to attend a saturation study of the workshop.

## 6. CONCLUSION

The work was elaborated presents an important one to support decision-making in the distribution of wagons in the workshop.

We can conclude that the work has the objective of providing the reference tool for planning and support to reduce maintenance. It can be better adapted to the organization's reality.

With the use of these optimization tools, it is hoped that it will be possible to obtain a more adherent plan and reduce cost in the maintenance of wagons or qualitative improvement in the elaboration of the wagon maintenance plan.

With the work done, it is expected that there will be more motivation to apply data science techniques on the railroad that this material can collaborate to carry out future work in similar ways. Concerning maintenance management, it is believed that the optimization suggestion developed is applicable immediately and has positive results.

## 7. REFERENCES

BRINA, H. L. **Railways vol. 1 and 2 - Technical and Scientific Books Editora S / A** - Rio de Janeiro / R.J., 1983;

Vianna, L.M., **Methodology for cost reduction in Machining of Locomotive Wheels**, Institute Military Engineering, 2013.

Melo, Carmo C., **Machine Learning in Prediction and Optimization of Wagons Mix Maintenance**, Coordination of Continuing Education in Computing and Information, Mackenzie Presbyterian University, 2020.

MRS LOGÍSTICA S.A. , <https://www.mrs.com.br/empresa/ferrovia-frota/> , accessed April 20, 2021.

## APPENDIX

### Source: OptimizerMixWagons.py:

```
#!/usr/bin/python
# coding: utf-8
# -----
# Title: Wagon mix optimization by scope and workshop
# Author: Carmo Crediney de Melo - https://www.linkedin.com/in/carmo-melo - 5/2/2020
# Assortment Optimization
# -----
# TO SET UP:
# Framework Modeler: pip install PuLP==2.0
# DataFrame: pip install Pandas==1.0
# MiniConda's Windows CBC Solver: or https://ampl.com/dl/open/cbc/
# -----
import pandas as pd
import numpy as np
import pulp
import time
import math
import csv
import os
import warnings
# warnings.simplefilter ('default')
warnings.simplefilter ('ignore')
pd.set_option ('display.max_rows', 999)
pd.set_option ('display.max_columns', 500)
pd.set_option ('display.width', 1000)
print ('Current folder Python:', os.getcwd ())
print ('Running Python:', __file__)
path_data = os.getcwd ();
# -----
# Reading of CSV format data file
# -----
start = time.time ()
quotechar = "",
print ("Pulp version:", pulp.__version__)

def isNaNStr (x): # Nan data processing (null / missing)
    return str (x) == str (1e400 * 0)

pd_workshop_scope = pd.read_csv (path_data + "/workshop_scope.csv", encoding = "ISO-8859-1", sep = ",", quotechar = "'",
                                index_col = ['workshop', 'scope_type', 'scope_class'],
                                names = ['workshop', 'scope_type', 'scope_class',
                                'unit_cost', 'HH_unit_standard'], header = 0)

pd_scope_demand = pd.read_csv (path_data + "/scope_demand.csv", encoding = "ISO-8859-1", sep = ",", quotechar = "'",
                                index_col = ['scope_type', 'scope_class'],
                                names = ['scope_type', 'scope_class', 'wagon_demand',
                                'scope_description'], header = 0)

pd_workshop_capacity = pd.read_csv (path_data + "/workshop_capacity.csv", encoding =
"ISO-8859-1", sep = ",", quotechar = "'",
                                index_col = ['workshop'],
                                names = ['workshop', 'minimum_HH', 'maximum_HH'],
header = 0)

# Sets the optimization variable
Lp_plan_wagons = pulp.LpVariable.dicts ("Vo", ((workshop, scope_type, scope_class)
for workshop, scope_type, scope_class in pd_workshop_scope.index),
lowBound = 0, cat = 'Integer')

# Defines the problem of the dynamic model in PL
```

```

model = pulp.LpProblem ("Cost minimizing scheduling problem", pulp.LpMinimize)

# Defines the objective function
model += pulp.lpSum([Lp_plan_wagons [workshop, scope_type, scope_class] *
                        pd_workshop_scope.loc [(workshop, scope_type, scope_class),
                        'unit_cost']
                        for workshop, scope_type, scope_class in
pd_workshop_scope.index])

# Defines restriction to meet demand
for d_type_scope, d_class_scope in pd_scope_demand.index:
    demand_restriction = ""
    demand = pd_scope_demand.loc [(d_type_scope, d_class_scope), 'wagon_demand']
    for o_workshop, o_type_scope, o_class_scope in pd_workshop_scope.index:
        if o_type_scope == d_type_scope and o_class_scope == d_class_scope:
            if pd_workshop_scope.loc [(o_workshop, o_type_scope, o_class_scope),
            'unit_cost'] == 0: continue
            demand_restriction += Lp_plan_wagons [(o_workshop, o_type_scope,
o_class_scope)]

        if demand_restriction != '':
            model += demand_restriction == demand

# Defines capacity restriction of workshops (Maximum and minimum in HH)
for workshop in pd_workshop_capacity.index:
    capacity_constraints = ""
    for o_workshop, o_type_scope, o_class_scope in pd_workshop_scope.index:
        if not (o_workshop == workshop): continue
        if pd_workshop_scope.loc [(o_workshop, o_type_scope, o_class_scope),
'unit_cost'] == 0: continue
        o_HH_unit_standard = int (float (pd_workshop_scope.loc [(o_workshop,
o_type_scope, o_class_scope), 'HH_unit_standard']))
        capacity_constraints += Lp_plan_wagons [(o_workshop, o_type_scope,
o_class_scope)] * o_HH_unit_standard
        minimum_HH = int (float (pd_workshop_capacity.loc [(workshop), 'minimum_HH']))
        maximum_HH = int (float (pd_workshop_capacity.loc [(workshop), 'maximum_HH']))
        if capacity_constraints != "":
            if maximum_HH > 0:
                model += capacity_constraints >= minimum_HH
            if maximum_HH > 0:
                model += capacity_constraints <= maximum_HH

# Run the PL Solver
fileLP = path_data + '/Model_MixWagons.LP'
model.writeLP (fileLP)
pulp.LpSolverDefault.msg = 1
verbose = False # Print message verbose True or False
solver_set = pulp.solvers.PULP_CBC_CMD (msg = verbose, maxSeconds =
120, threads=2, fracGap = 0.01)
print ("Running Solver: ...")
result = model.solve (solver_set)
pulp.LpStatus [model.status]

# Solver result
ResultSolver = {1: "Great", 0: "Not resolved", -1: "Not viable", -2: "Not linked", -
3: "Undefined"}
descResult = ResultSolver.get (result, "Error")
print ("Result of Solver Wagons:", descResult, "status", result)
quant_variables = 0
for v in model.variables ():
    quant_variables += 1
    # print (v.name, "=", v.varValue)
print ("Number of Model Variables:", quant_variables)

# Export Result from Solver
pd_workshop_scope ['optimized_amount'] = 0
pd_workshop_scope ['optimized_cost'] = 0
pd_workshop_scope ['HH_capacity'] = 0

```

```

for o_workshop, o_tipo_escopo, o_classe_escopo in pd_workshop_scope.index:
    unit_cost = int (float (pd_workshop_scope.loc [(o_workshop, o_type_scope,
o_class_scope), 'unit_cost']))
    HH_unit_standard = int (float (pd_workshop_scope.loc [(o_workshop, o_tipo_escopo,
o_classe_escopo), 'HH_unit_standard']))
    if unit_cost == 0 or HH_unit_standard == 0: continue
    quantity_solver = int (float (Lp_plan_wagons [(o_workshop, o_type_scope,
o_class_scope)].varValue))
    if quantity_solver is not None and not isNaNStr (quantity_solver) and
quantity_solver> 0:
        pd_workshop_scope.loc [(o_workshop, o_type_scope, o_class_scope),
'optimized_amount'] = quantity_solver
        pd_workshop_scope.loc [(o_workshop, o_type_scope, o_class_scope),
'optimized_cost'] = quantity_solver * unit_cost
        pd_workshop_scope.loc [(o_workshop, o_type_scope, o_class_scope),
'HH_capacity'] = quantity_solver * HH_unit_standard
pd_workshop_scope.to_csv (path_data + "/result_solver.csv")

stop = time.time ()
print ("Processing completed. Time in seconds:", '{: .2f}'. format (stop - start))

```

#### File format scope demand “scope\_demand.csv”:

```

scope_type,scope_class,wagon_demand,scope_description
VR1P,A1,252,VR1P Scope Review 1P
VR2P,A1,7,VR2P Scope Review 2P
VR4P,A2,46,VR4P Scope Review 4P
VRGP,A2,94,VRGP Review General Scope P
VR1D,A1,109,VR1D Scope Review 1D
VR2D,A1,14,VR2D Scope Review 2D
VR4D,A2,31,VR4D Scope Review 4D
VRGD,A2,8,VRGD Review General Scope D
VMC,A1,443,Corrective Maintenance Review

```

#### File format workshop capacity “workshop\_capacity.csv”:

```

workshop,minimum_HH,maximum_HH
OFA,1500,2040
OFB,2000,8000

```

#### File format scope workshop “workshop\_scope.csv”:

```

workshop,scope_type,scope_class,unit_cost,HH_unit_standard
OFA,VR1P,A1,95,10
OFA,VR2P,A1,120,10
OFA,VR4P,A2,100,10
OFA,VRGP,A2,105,10
OFA,VR1D,A1,70,10
OFA,VR2D,A1,110,10
OFA,VR4D,A2,115,10
OFA,VRGD,A2,140,10
OFA,VMC,A1,90,10
OFB,VR1P,A1,75,10
OFB,VR2P,A1,125,10
OFB,VR4P,A2,105,10
OFB,VRGP,A2,110,10
OFB,VR1D,A1,60,10
OFB,VR2D,A1,115,10
OFB,VR4D,A2,110,10
OFB,VRGD,A2,141,10
OFB,VMC,A1,70,10

```