

# Introducing to Industrial Engineering Students to Linear Programming with Pulp from Python: A Case Study in Peru

Carlos Sotomayor-Beltran, Alexi Delgado

**Abstract:** One core course in the curriculum of engineering industrial programs in Peruvian universities is operations research, which is regarding finding the optimal solution to real-life problems in a diverse range of industries (business, transport, agriculture, healthcare, etc.). In this paper the package PuLP from the programming language Python is presented as a computational tool that can help Peruvian industrial engineering students to solve optimization problems involving linear programming. An example about a fabric that produces beds and their accessories is presented. On the other hand, a function that needs to be maximized to obtain the best profit is defined along with its decision variables and some constraints. As a consequence of writing a program in Python using PuLP, the best values for the decision variables could be obtained. Furthermore, by algebraically solving the inequalities corresponding to the constraints and looking into the feasible region, the result obtained by this method was the same as using PuLP. Then, it could be suggested that the operation research courses can benefit the students by relying also in the use of this type of computational tools in view of the complexity that real-life linear optimization problems can have. In addition, the results of this work could contribute to improve the teaching-learning process in operations research courses within of engineering industrial programs in Peruvian universities.

**Index Terms:** linear programming, operations research, pulp, python

## I. INTRODUCTION

One of the main goals of industrial engineers is the optimal use of the resources at hand in order to maximize the profits of the industry where they are laboring and simultaneously to minimize the time and money expended in the related industrial processes [1]. One particular area of industrial engineering which concerns itself with these optimization problems is operations research. In some industrial engineering departments of different universities of Peru, operations research is a core course of the curriculum of this profession. For instance, two of the best universities (Universidad Nacional de Ingeniería and Pontificia Universidad Católica del Perú) to study industrial

engineering in Peru [2], offer an entire course of one semester on operations research. Operations research allows to take optimal decisions in a diversity of complex real-life situations through the use of analytical methods. In the area of management and business, for instance, operations research helps in taking the best decision in regards to sales and advertisements [3]–[8]. In transportation, operations research helps in finding the optimal routing as well as the appropriate transport requirements [9] – [12]. In the agricultural sector, operations research helps in allocating in the best possible way the supply for seeds and also finding the best mix of these so that they can produce an optimal yield [13]–[16]. In healthcare, operations research supports in better scheduling resources and better planning of treatments [17], [18]. One of the analytical methods to tackle this real-world problems in the search for optimization is linear programming. This technique consists basically in solving a series of linear inequalities derived from the industrial problem to optimize. In this paper, we present a computational tool that can be used in the classroom to introduce industrial engineering students to the world of linear programming. The aforementioned tool that can easily solve these types of problems is PuLP (<https://pythonhosted.org/PuLP/>) from the programming language Python. Python is an open source programming language at no cost, which can be also very motivating to the students because they can do their learning at home or somewhere off the classroom. Python is very popular worldwide and a case has been presented to start using this language in diverse Peruvian engineering departments [19]. In section II we present an optimization example about a company that produces and sells beds and is looking to make a certain profit. The implementation in PuLP is also shown. Section III presents the best solution for the foregoing problem and its implications. In section IV the conclusions are provided.

## II. MODELING AND SOFTWARE IMPLEMENTATION

The parts of a problem in linear programming are basically three: an objective function (which will be maximized), decision variables and constraints. In order to engage industrial engineering students in an operations research course, a basic but real-life problem can be proposed.

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For instance, in Lima, Peru a fabric that sells beds and its accessories is looking to maximize the profits made by the sale of beds and nightstands.

This fabric is expecting to gain S/. 110 per bed and S/. 60 per nightstand. However, there are some requirements that need to be taken into consideration before finding the maximum profit:

- A bed needs 4 hours of carpentry work and 2 hours of painting.
- A nightstand needs 2 hours of carpentry work and 2 hours of painting.
- The fabric can allocate only 140 hours to carpentry and 80 hours to painting per week.

Following the requirements above, the solution sought is the number needed of beds and nightstands to maximize the profit. To build the model, decision variables have to be introduced. First we define  $x_1$  as the number of beds produced each week and likewise  $x_2$  is defined as the number of nightstands produced each week. Considering the expected profits made by the sales of beds and nightstands, the objective function can be defined as follows:

$$y = 110x_1 + 60x_2 \quad (1)$$

A maximum value will be search for Eq. 1 considering the following two equations derived from the requirements or constraints:

$$4x_1 + 2x_2 \leq 140 \quad (2)$$

$$2x_1 + 2x_2 \leq 80 \quad (3)$$

Eq. 2 points to the working hours allocated to carpentry for beds and nightstands, whereas Eq. 3 makes reference to the hours dedicated to painting for beds and nightstands. Additionally, because there cannot be a negative number of beds or nightstands produced, two additional constraints have to be defined:

$$x_1 \geq 0 \quad (4)$$

$$x_2 \geq 0 \quad (5)$$

Solving Eq. 1 to 5 we will be provided with the maximum expected profit.

The construction of the problem above using the programming language Python is as follows:

```
import pulp
```

The package PuLP needs to be imported into the Python environment to be used. Then we use the class LpProblem to initiate the model for which a maximum will be looked for:

```
linear_prob = pulp.LpProblem ("Bed problem",
pulp.LpMaximize)
```

The decision variables  $x_1$  and  $x_2$  are defined as follows:

```
x1 = pulp.LpVariable("x1", lowBound=0)
```

```
x2 = pulp.LpVariable("x2", lowBound=0)
```

The lowBound option from the LpVariable defines the constraints that cannot be negative numbers of beds and

nightstands (Eq. 4 and 5). Afterwards, we proceed to add the objective function (Eq. 1) to the model:

```
linear_prob += 110*x1 + 60*x2
```

The constraints defined by Eq. 2 and 3, about the hours dedicated to carpentry and painting to beds and nightstands are also added to the model as follows:

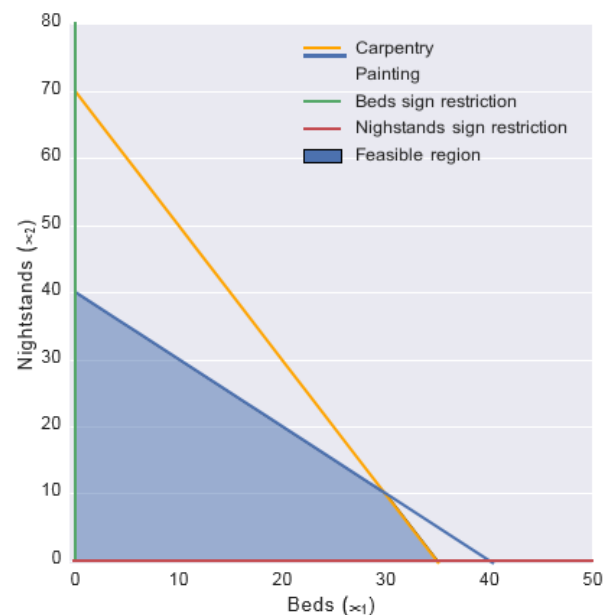
```
prob += 4*x1 + 2*x2 <= 140 prob += 2*x1 + 2*x2 <= 80
```

## III. RESULTS AND DISCUSSION

In order to find the optimal solution for Eq. 1 to 5, we used the class solve from PuLP as follows:

```
prob.solve()
```

This provided us with values for the two decision variables; for  $x_1$  it gave us a total of 30 beds and for  $x_2$  it gave us a total of 10 nightstands. Hence, the optimal profit expected with these number of beds and nightstands is of S/. 3900. However, it has to be mentioned that there are many solutions for the constraints defined by Eq. 2 to 5. These many values that  $x_1$  and  $x_2$  can take define an area in the  $x_1x_2$  -plane known as the feasible region.



**Fig. 1: Constraints of the “Bed problem” along with the feasible region**

In Fig. 1 we have plotted the four inequalities defined by Eq. 2 to 5. The red and green lines define the constraints that cannot be negative beds or nightstands (Eq. 4 and 5, respectively). The orange line in Fig. 1 represents the carpentry hours dedicated to beds and nightstands (Eq. 2), whereas the blue line indicates the hours dedicated to painting (Eq. 3). Additionally, in Fig. 1 we also observe a light blue-shaded area, which is none other than the feasible region. The optimal solution to the given constraints lies in one of the four corners of this region. Thus, we can evaluate the objective function (Eq. 1) for each of the four points.

**TABLE I: Evaluation of objective function for the corners of the feasible region (Fig. 1).**

$x_1$	$x_2$	$y = 110x_1 + 60x_2$
0	40	2400
30	10	3900
35	0	3850
0	0	0

By evaluating these four points (Table I) we can see that the optimal profit is given when  $x_1 = 30$  and  $x_2 = 10$ . This solution has been provided already by our software implementation with PuLP, which means that solutions to this type of linear problems can be done algebraically with the help of graphics, otherwise can also be solved with the help of computational tools. However, because the bed problem demonstrated was a basic one, the faster and effective way to solve a complex real-world optimization problem, made up of many constraints and decision variables, would be with the help of a computational package like PuLP. The method used in this work could be applied to resolve problems in topics such as social issues[20], educational topics [21] or environmental problems[22].

#### IV. CONCLUSIONS

Use Using the package PuLP from the programming language Python, it has been shown that problems of optimization involving linear programming can be solved using this tool. In this paper, a situation regarding the production of beds and the profit expected of this, was proposed to show how PuLP can be taught in the classroom to industrial engineering students. The optimal solution provided by PuLP to this problem was further confirmed by graphically looking into the feasible region defined by the constraints of the problem. A course in operations research teaching linear programming will involve a higher complexity of examples with the pass of time over the duration of this. Hence, providing engineering industrial with computational tools, such as PuLP, can help them in solving this complex situations and can be very beneficial to them.

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