

Optimization of the Waste Collection and Recycling Process

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## Optimización y Simulación

## 3º Grado en Ingeniería Matemática e Inteligencia Artificial

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# **Introduction**

The goal of this project is to provide an optimal solution for an everyday problem: waste collection. This is a crucial step towards building a sustainable and eco-friendly urban environment. Waste management refers to the activities and actions required to handle waste from its generation to its final disposal. This includes collection and transportation to the landfill site.

However, as global populations continue to grow and waste generation increases, the efficient management of garbage becomes more important than ever. By streamlining collection systems, improving sorting techniques, and enhancing recycling processes, communities can reduce their environmental impact, conserve natural resources, and contribute to a circular economy.

In the following pages we have described how to manage the routes a truck could use to collect as much litter as possible. We want to reduce how long it takes to empty all trash containers and the number of trucks needed for it. This approach not only benefits the planet but also creates economic opportunities and promotes healthier living conditions for residents. If we reduce the time, we are reducing carbon dioxide emissions; and by using less trucks the price goes down, making it more affordable.

With the solution proposed below, we want to transform waste management into a more effective and responsible practice by optimizing the truck routes. Such a small change can make a difference for the planet and our pockets.

# **Problem Statement and Visualization**

Waste collection companies must manage routes with varying distances in their daily operations, which presents a significant challenge in terms of efficiency and cost. To illustrate the real-world relevance of this issue, consider the example of managing an average of 19,600 daily routes to serve 20 million residential customers and 2 million commercial clients. The company operates a fleet of 26,000 collection trucks, with an approximate operational cost of $120,000 per vehicle. Given this high cost, it is crucial that each route is managed efficiently and cost-effectively.

In this context, route optimization must focus on reducing costs while ensuring the complete collection of waste within the estimated time. In our specific context, the goal is to optimize the number of recycling trucks within a network and their distribution, based on a system that measures the distance between network nodes using Manhattan distance, to allow coverage of the greatest number of containers. To simulate traffic and the conditions of a street, we have included the time it takes to pass through all containers considering that maybe the time spent on different streets varies.



# **Final Formulation**

Here we will present the step-by-step final formulation. The maximum is decided in each level of development, that is, at the basic level, number of rows and number of columns equals to three, and higher afterwards.

## 3.1 Sets

1. **Rows - i**

They represent the rows of the matrix that we will go down.

1. **Columns -j**

The columns of the matrix.

1. **Vehículos -k**

The number of trucks that will be operating.

1. **Step-s**

We introduced this set which is rows\*columns to make sure each vehicle moved once upon the matrix

## 3.2 Parameters

For the development of these parameters, we initialized an empty matrix of the desired width and height specified in the sets.

### Supposition on time of service – T(i,j)

As we said, at the basic level we considered the time a constant therefore there was no need to reduce the time in the objective function, because reducing the number of steps was reducing the time in the journey. But at the higher level we developed a matrix of random numbers that represented the time that would take a truck to use that cell, and therefore we added it to the objective function.

### Garbage in each stop – CP(i,j)

We used another matrix to represent the dirt quantity in each stop.

### Deposit-D(i,j)

This parameter represented the deposit form which all vehicles started their route, and due to the complexity of the problem we have only tried with one deposit through the whole matrix.

### Capacity of truck - 𝑪𝑲

This parameter symbolizes the amount of dirt that a vehicle can collect, and therefore it can vary to add more realism to the project.

## 3.3 Variables

The variable design has been through a lot of significant changes thought the implementation of this problem, but we came up with the final design that includes these:

1. **Truck route -** R𝒊𝒋𝒌s

It represents the steps between i and j for a vehicle k. It is a binary variable, so it will have a 1 if it uses that cell or 0 if not.

### Amount of garbage in the truck in a step - 𝑫𝒌s

Indicated the amount of dirt for each step that the vehicle makes in the matrix.

### Binary variable indicating if a vehicle can collect more garbage – can\_collect

We must model and make sure that each truck does not collect more garbage than its capacity constraint, for that, we need this binary variable.

1. **Binary variable indicating if all the garbage has been collected – all\_dirt\_collected**

To send all the vehicles into the deposit we need to have a “flag” to know when this is supposed to happen. This binary variable indicates when the trucks should stop collecting and head back to the deposit.

1. **Number of steps taken to return to deposit – return\_stepk**

This variable controls the number of steps each vehicle takes to return to the deposit which cannot surpass the number of cells of the matrix. This is what we will minimize, since it controls the number of cells that the vehicle goes trough since he leaves the depot until it returns.

1. **Mark if garbage has been collected at each step – is\_collectedi,j,s**

This variable controls if the truck collects garbage at each step it takes in the route of the matrix.

## 3.4 Objective Function

## The final objective function is:

## R\_{i,j,k,s}\*T\_{

## This function represents

## 3.5 Constraints

# **Methodology**

In this optimization problem, as explained before, we have considered minimizing both the number of trucks and the distance traveled by each of them. However, we have observed that reducing the distance does not always decrease the total cost, as some routes, although longer, may be completed in less time. Our goal is to optimize the waste management process.

Minimizing the number of trucks also presents limitations. Although fewer trucks could be used, this might result in less efficiency than before. In the long run, it could be more cost-effective to employ a larger number of trucks, which would significantly reduce the total time of the process. In this sense, it is a trade-off between labor costs and the additional use of trucks, which could ultimately be more beneficial.

Therefore, we have determined that time is the key variable to minimize, as it directly impacts costs such as wages, fuel, and other expenses related to the actual duration of the process, which are not directly addressed in our optimization problem. For this reason, we have decided that the best strategy to optimize this problem is to minimize the route time for each truck, so that is our goal.

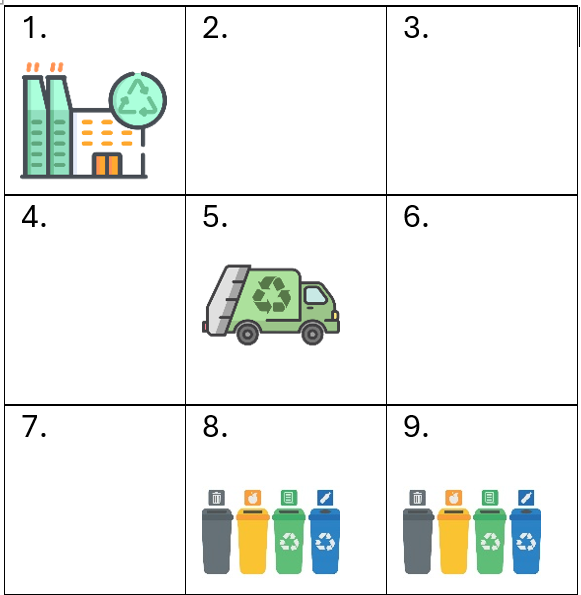


The difficulty of the problem makes us divide the project into two phases: functionality and realism. We want for sure a real solution, but we are giving priority to finding an optimal one first. We will first find the shortest route for one truck, if minimizing distance and time is equivalent, although we have discussed before that it is not always true.

After achieving an optimal solution, we will start increasing the difficulties of the problem step by step, only moving forward once we have reached an optimal solution for each new upgrade. We want the final version of the problem to address the time it takes to travel from one node to another in the grid, simulating the streets, with some taking longer to travel. This time is predetermined. Initially, it will be constant, but in an expanded version of the problem, it will vary, allowing for optimization of the different possible routes.

## 4.2 First Phase – Functional solution

To start with, the problem will consist of a 3x3 grid with only one truck, one deposit, and three litter dumps. We included initially a constant representing the time it takes to move from one cell to another. However, we noticed soon that this was useless, because minimizing the time of the route is the same as minimizing the number of cells the truck passes, so we formulated the solution of the simplified version. The initial grid is presented below.



Modifications: objective function,

Results:

After obtaining an optimal solution, we tried with a 5x5 grid and three litter dumps.



Results:

## 4.2 Second Phase – Realistic solution

Now we modified the code and finally came up with the formulation in the point 3 that makes the problem work efficiently.

Add image:

Add results:

Sets:

#set más secuenciación de máquinas…? O igual recolectar el orden de casillas que hace, el último n debe ser el depósito.

En qué orden van recorriendo las casillas…

Hacer xijk sea no binaria y marque el orden

#como recorro la matriz, que recorro uno más en i y en j.





Parámetros:

Un **parámetro** es un valor numérico fijo que representa datos conocidos o constantes en el modelo. A diferencia de las variables de decisión, los parámetros no están sujetos a optimización; en su lugar, proporcionan las entradas esenciales y la estructura necesaria para definir la función objetivo y las restricciones del problema.

En nuestro problema, incluiremos los siguientes parámetros:

### Suposición sobre el Tiempo de Servicio

Aunque inicialmente consideramos incluir el tiempo de servicio en cada parada como un parámetro, asumimos que, para nuestro caso, el tiempo por parada será uniforme. Esta suposición se basa en el uso de contenedores y procesos idénticos en cada parada regular. En consecuencia, no es necesario incluir el tiempo de servicio como un parámetro, ya que no contribuiría a optimizar el problema.

1. **Paradas regulares P (i, j):**

Esta matriz binaria nos indica en que celdas de nuestra malla se encuentran las paradas en las que los camiones deben recoger basura. (Seleccionamos las posiciones de las paradas previamente a solucionar el problema).

1. **Depósito D (i, j):**

Esta matriz binaria nos indica en que celdas de nuestra malla se encuentran los depósitos desde los que parten los camiones. Seleccionamos las posiciones de las paradas previamente a solucionar el problema).

1. **Número de camiones - NC**
2. **Número de filas - N\_FIL**
3. **Número de columnas - N\_COL**
4. **Número de depósitos totales - ND (¿hace falta?)**
5. **Tiempo entre nodos – T:**

El tiempo que se tarda en ir de un nodo a otro en la malla viene determinado. En un principio será constante y en la ampliación del problema variará, de forma que se puedan optimizar las distintas rutas posibles.

### Capacidad de un camión - Ck:

### La cantidad de basura que puede cargar un camión vendrá determinada y puede variar, medida en kilos.

### Cantidad de basura en una parada regular- CP (i, j):

### Necesitamos de una matriz que nos indique cuanta basura hay en cada parada (en kilos).

Variables:

Las variables de decisión son los valores desconocidos que el modelo de optimización debe determinar. Representan las decisiones a tomar para alcanzar el objetivo, como qué rutas tomar, qué vehículos utilizar o cuánto recoger en cada parada.

En nuestro problema, utilizaremos las siguientes variables de decisión:

1. **Recorrido de un camión - x𝒊𝒋𝒌:**

Como lo que queremos es optimizar el tiempo, debemos obtener una matriz que nos indique que nodos atraviesa un camión. Para ello generaremos una matriz binaria que nos indique porqué nodos atraviesa. Esto es 0 si no pasa por ahí o 1 si pasa.

### Cantidad de nodos que atraviesa un camión - y𝒌:

### Como la función objetivo que minimizamos es el tiempo (en principio constante) pro los nodos que recorre un camión necesitamos esta información, ya que con la anterior variable no se define toda la información.

### Cantidad de basura de un camión - b𝒌:

Para ir asegurándonos de que el camión se va llenando y no de más, necesitamos esta variable, que se verá modificada cada vez que el camión pase por una parada regular y en el futuro al descargar en un vertedero.

Que no pueda pasar dos veces por la parada, aunque esté de vuelta hacia el depósito.

Variable que deje pasar si se ha recogido. Lo que he recogido. Modificar la D🡪variable

Tengo que contabilizar cuantos camiones pasan por una parada

Función Objetivo

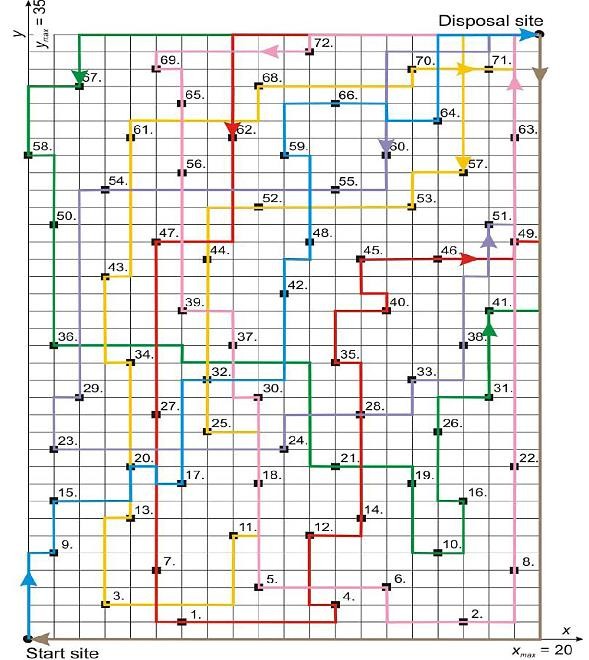
La función objetivo es una expresión matemática que describe el objetivo principal del problema de optimización. En nuestro caso, el objetivo es minimizar el tiempo total de recorrido de todos los camiones en el conjunto KKK. Este tiempo total se calcula como la suma del tiempo asociado a todos los arcos utilizados en las rutas de los camiones.

La función objetivo se define como:

min ∑ T ∙ y𝑘

k

Minimizar el tiempo total permite optimizar factores como salarios, combustible y costos operativos, que están directamente relacionados con la duración del proceso. Por ello, esta formulación asegura que el modelo sea tanto eficiente como económicamente viable.



Restricciones:

Las restricciones son las condiciones necesarias que debe cumplir cualquier solución del modelo para ser válida. Estas limitan las posibles soluciones del problema y garantizan que las operaciones de recolección de basura respeten las condiciones del sistema.

1. Cada parada debe ser atendida por exactamente un vehículo:

Esta restricción asegura que cada parada de recolección sea visitada por un solo vehículo, evitando duplicidades o paradas desatendidas.

1. Cada ruta debe comenzar desde el depósito: (¿?)🡪 convertir a parámetro, decirle donde está
2. La basura recolectada debe caber en el camión
3. Restricción para actualizar la carga del camión si visita una parada

* Si 𝑥𝑖,𝑗,𝑘\*Pi,j = 1: El camión recoge basura, y la carga en el nodo i,j que es la parada. Se actualiza sumando la carga de los nodos anteriores (bk) y la basura recolectada.
* Si 𝑥𝑖,𝑗,𝑘\*Pi,j = 0: El camión no recoge basura en i,j, por lo que la carga no cambia.
* M grande??

1. Ultimo nodo de cada ruta debe ser el depósito (¿¿del que proviene entiendo??, dudas es como la segunda)
2. Se recoge toda la basura (¿aunque ya es implícito en el problema?)🡪 sobra

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