Optimizing waste recycling points in Eindhoven

Currently, in 2023, Eindhoven has two waste recycling points (WRPs / “milieustraten”): Acht and Lodewijkstraat. In 2012, however, there were three waste recycling points in Eindhoven: Esperheide, Lodewijkstraat, and Gabriël Metsulaan. In this assignment we focus on the third. The municipality has decided to close this waste recycling point a few years ago and open a new one in Acht with higher capacity. Still, we are interested in whether it would have been possible to make the waste recycling point at the Gabriël Metsulaan more efficient. In this assignment we go back in time to 2012, when a team of students collected very detailed customer data in this WRP. Your task is to model the waste recycling point using a queueing model and to write a discrete event simulation to get more insight in the most relevant performance characteristics and identify the bottlenecks.

Waste recycling is free for residents of Eindhoven, but they have to identify themselves by showing their city pass to the operator at the entrance. Most residents arrive by car or a small van, which form a queue in front of the entrance. The design of the Gabriël Metsulaan WRP is not optimal: if the queue is longer than three cars, the remaining vehicles have to wait on the road (see Figure 1). Obviously, this is an undesirable situation and the municipality of Eindhoven would like to improve this situation. The situation will become even more worrisome in the near future (2013), when the Esperheide WRP will be closed permanently. For this reason, the municipality of Eindhoven hires experts (you) to advise them on how to improve the situation at the Gabriël Metsulaan WRP.

Figure 1: Current layout of the garbage dump at the Gabriël Metsulaan. The entrance is located at the red arrow.

Students of TU/e have collected data at the WRP on three different days, September 4, 6, and 7, 2012. On these days, the garbage dump opened at 1pm and closed at 5pm. The data is stored in three Excel files which will be discussed in more detail later. First we will give a detailed description of the layout of the WRP and the waste disposal processes.

Layout of the WRP

For simplicity we will focus on the vast majority of customers arriving by car or van. Most of them bring more than one type of waste, meaning that they will park their vehicle at multiple different locations inside the WRP and dump their waste by foot, before exiting the WRP. In general, big vehicles (vans or cars with a small trailer) occupy two parking spots, whereas regular cars occupy one spot. The Gabriël Metsulaan WRP can be divided into five areas (see Figure 2):

- The entrance (or gate). This is where customers show their city pass, which is checked by the WRP employee before granting access. Only one customer can be checked at a time.
- Flammable/Wood/Paper/Metal (FWPM). Flammable is by far the most popular type of waste. In this area, there is enough room to park four small cars (or two vans).
- Debris (clean or dirty)/Gypsum/Chemicals (DcDdGpCh). There are four parking spots in this area.
- Green/Wood/Tires/Electrical devices/Gas canisters (GrWcTEGs). There is only space to park three small cars, or one big vehicle.
- Rest of the WRP (including Carpet/Matrasses/Soil/Asbestos/Roofing), with two parking spots.

Inside each of these areas, customers will park their vehicle only once and dump their waste by foot. Customers who need to visit multiple areas, will park exactly once in each area.

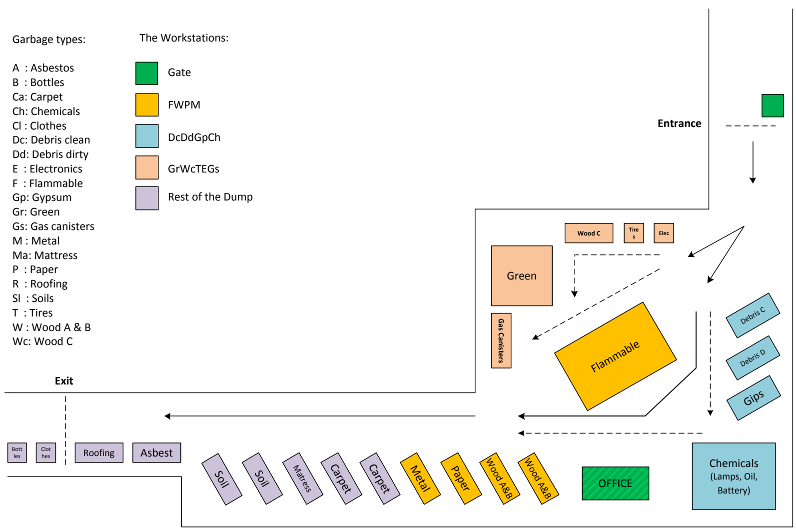

Figure 2: A schematic representation of the garbage dump at the Gabriël Metsulaan.

Blocking

In order to prevent blocking inside the WRP, there are strict rules regarding the routing of customers. Stations can only be visited in this order:

$$\text{Entrance} \longrightarrow \text{FWPM} \longrightarrow \text{DcDdGpCh} \longrightarrow \text{GrWcTEGs} \longrightarrow \text{Rest.}$$

The operator at the entrance checks the garbage types of the customer. If *any* of the areas the customer needs to visit is full (meaning that all parking spots in that area are occupied), the customer is not allowed to enter the WRP until all of the areas he/she needs to visit have sufficiently many free parking spots (depending on the size of the vehicle).

Note that blocking *inside* the WRP area can still take place. We will illustrate this by a simple example: suppose that every station inside the WRP has exactly one free parking spot. Assume that there are two cars waiting to enter the WRP: one that needs to visit FWPM and Rest, and one that wants to visit DcDdGpCh and Rest. Both of them are allowed to enter the dump, because there is at least one available spot in each of these stations. However, by the time that the second vehicle wants to travel from DcDdGpCh to Rest, the parking spot at Rest may be occupied by the first vehicle (that visited FWPM first). In that case, the second vehicle will be blocked inside the DcDdGpCh station until the first vehicle leaves the rest station.

Queueing in front of the gate

There is one queue at the entrance, where customers are served in order of their arrival except for customers arriving by foot or by bike. These customers get priority and may go to the front of the queue, but their city pass still needs to be checked. Some customers get impatient and abandon the queue. Customers who forgot to bring their city pass (and only notice this when they arrive at the gate) drive through the WRP without being allowed to dispose of any of their garbage. Since there are only three parking spots on the WRP ground, a particular important performance measure is the fraction of time that the queue is longer than three vehicles. Finally, note that you can conclude from the data that there are quite a few customers arriving *before* the WRP opens.

Available data

There are two sets of data that you can use for this assignment. The first data set has been cleaned and is immediately ready to use in your simulation. The second collection of data sets is the raw data collected by the TU/e students on three different days. This data is more realistic and contains more information (for example, the cleaned data set does not contain any impatient customers). If you decide to use the raw data, you will have more work cleaning the data and extracting the relevant information from it, for which you will be rewarded with a maximum of 1 extra bonus point (on a scale of 10).

Cleaned data. Note that this data has *not* been collected in the afternoon, but on days when the WRP was open from 10am until 2pm. It contains the numbers of arriving cars throughout the day, the percentage of big/small cars and the means and standard deviations of the different service times. The second sheet contains information about the types of waste that the customers brought and the routing.

Raw data. The raw data are three Excel files filled with details of each vehicle from which you should extract all the relevant information regarding arrival rates, service times, routing, and customer types. Each file contains the following sheets:

- Main Data Sheet: information on car id, car size (B = big, S = small), arrival time inside the WRP, departure time from the WRP, sojourn time inside the WRP, types of waste. Please note: the time waiting in the queue and being checked by the operator at the gate is *not* included in this sheet!
- Queue outside: car id, car size, arrival time *at the queue*, possible comments indicating whether something special or strange happened.
- Entrance: car id, entrance time (= arrival time inside the WRP), information about whether the gate was blocked (and why), and comments.
- GrWcTEGs, DcDdGpCh, FWPM 1, FWPM 2, rest and exit: car id, arrival time at this station, departure time from this station, types of waste that was dumped. Note that the area FWPM had two observers: usually one person recorded times for flammable (F) only and the other for Wood/Paper/Metal (WPM).

Hint: in the raw data there is no direct information about service times at the gate. You have to extract that information by comparing successive entrance times (arrival time inside the WRP), but be sure to also include the arrival times at the queue to find out whether vehicles were waiting in the queue, or could immediately pass without delay.

Main questions

The municipality of Eindhoven expects that after the closure of the Esperheide WRP, up to 20% more people are going to use the Gabriël Metsulaan WRP. They have two main questions:

- Can you simulate the waiting times and queue lengths of the WRP in its current state?
- Can you quantify how the WRP will perform with 20% more people than currently visit the WRP (according to the data)?
- Can you suggest improvements that significantly improve this performance? You can think of: shortening service times, adding parking spots, creating different stations. In principle you are allowed to claim a larger territory for the WRP, because the whole rectangular area south of Kanaaldijk and east of Gabriël Metsulaan can be used.

Your task is to develop a discrete-event simulation that simulates the WRP based on the data that has been provided. You should probably take the following steps: first simulate the current situation and validate the correctness of your simulation by comparing the simulated sojourn times with the observed sojourn times. Next, simulate scenarios where 10% and 20% more customers arrive and identify the bottlenecks (if there are any). Finally, try to come up with the most cost-effective way to increase the capacity of the WRP. You should deliver a well-written report with clear, understandable graphs and tables that support your advice to the municipality of Eindhoven. Each group should hand in a separate PDF file of the report and a zip file containing the source code of their simulation programs. In general, a more realistic model will also result in a higher grade (as long as the results are correct obviously). More detailed guidelines (the rubric) and the deadline can be found in Canvas.

Programming tips

- Usually, a `deque` is the best data structure for queues. However, for the entrance gate, you should probably use a `heapq` because of the priority customers who arrive by bike or by foot. It might be useful (but not necessary) to write a `PriorityQueue` class that sorts the customers (1) by their priority level and (2) by their arrival time. You can use the source code of the FES class as inspiration. However, due to the customer impatience, you will need to remove specific elements. In the FES class, this could be achieved with the following code:

  ```
  def remove(self, event):
      self.events.remove(event)
      heapq.heapify(self.events)
  ```

  The `heapify` function makes sure that the heap gets restructured correctly after the element 'event' is removed.

- You don't have to implement the exact routing matrices from the (cleaned) Excel file. If you want, you can ignore the customer classes that with less than 10% of the total number of customers.

- It's probably a good idea to use an array of queues, just like in the example discussed in Week 4.

- One way to keep track of all the customers that are blocked, is to put them in a separate queue (which should be a `deque`). This means that each customer is simultaneously in their own queue in the WRP *and* in a deque that keeps track of all blocked customers. This makes it easy to check which vehicle is blocked the longest.

- Don't create a for-loop to move all the unblocked customers. A parking spot becomes available upon a DEPARTURE event. When this happens, check the aforementioned deque of blocked customers to see if there is a customer that wants to move to the empty parking space. If so, you can schedule a DEPARTURE event for this customer at the same time t. Then, when handling that DEPARTURE event, the same code will check if there is another blocked customer that wants to occupy that specific spot. Etc..