
**Master Semester Project**

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# Pedestrian Destinations in Paléo Music Festival from Bluetooth Traces

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# Contents

# Introduction

Can we guess the destinations of attendees in a music festival from Bluetooth traces collected by 10 people with smartphones used as antennas? This project analyzes an existing dataset of Bluetooth traces from Paléo music festival in Nyon, Switzerland. The goal of the project is to follow Paléo festival attendees using collected Bluetooth traces and analyze specifications of the collected data in terms of precision and results, to predict attendees behaviour and crowd movement.
The data was collected on July 24th, 2010 by ten agents scanning for visible Bluetooth devices. The methodology for tracing Paléo festival attendees is a Bayesian approach derived by Danalet et al. [2012].

## Paléo Music Festival

Paléo festival is one of the major open-air music festivals in Europe, taking place each year for six days in July in Nyon, Switzerland. It has been growing since 1976, and attracts nowadays around fourty thousand spectators per day on an area of 120'000 square meters. The shows are performed by the artists on six stages. The festival gets its reputation from an excellent artists programming, great infrastructures and a nice environment.

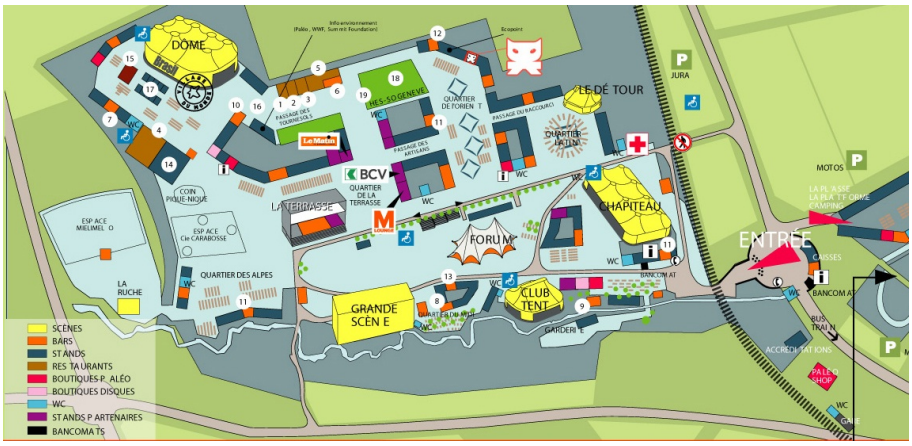



Figure 1: Paléo visitor map

# Chapter 1

# Literature

## 1.1 Bluetooth Data Collection

### Mobile Bluetooth Sensors

Naini et al. [2011] explain the Bluetooth data collection at the Paléo music festival, which is used in the present report. Ten attendees acted as Bluetooth probes and moved randomly in the festival. The population size has been estimated surprisingly well, given the relatively small number of agents compared to the area of the festival.
The smartphones sense Bluetooth devices in a range of 10-20 meters around the agents and capture the MAC adresses of the devices which Bluetooth visibility is turned on. To get an approximation of the number of attendees with visible Bluetooth devices, two mobile phones were installed at the main entrance of the festival, and one at the back entrance. Also the organizers provided an estimation of the total number of attendees. Bluetooth scanning was performed every 80 seconds, and the experiment lasted for a day.
A major part of the overall Bluetooth devices were detected by the agents and therefore the estimations could be computed.
The model is based on two assumptions:
- Poisson detection: the number of times an agent detects a Bluetooth device is Poisson distributed
- Independence of detection: the detection of any Bluetooth device by any agent is independent of all other individuals and agents.
The likelihood function, i.e., probability of observing the obtained measurements under the model described, is maximized to estimate the number of attendees with a visible Bluetooth device. The likelihoods of the unobserved individuals and of the observed pattern of detection are also computed to find, in the end, the maximum likelihood estimators and estimate the total number of attendees.
The results show that the choice of the function of arrival and departure time is primordial for the estimation of the total number of attendees, and the best population size estimation was given by taking into account the detected arrivals and departures measured at the entrance of the festival and computing the em-

pirical distribution of the function of departures and arrivals.
Further work can include applying the proposed model to specific parts of the collected data, to estimate, for example, the population size at different time intervals, or in different areas of the festival.
One important comment to make on the hypotheses taken in this report is that it is not realistic to assume independence of detection, as there is a timetable and the density of people is not distributed uniformly on the whole surface of the festival.

### Stationnary Bluetooth Sensors

Versichele et al. [2012] present a case study of the Ghent Festival. It is a music and theatre festival in Ghent, Belgium, which attracts about 2 milion visitors over 10 days. Proximity-based Bluetooth tracking methodology was used for analyzing the spaciotemporal dynamics of visitor movement. The article mainly concentrates its attention on crowd movements during mass events.
Bluetooth tracking is anonymous, except for the detected devices MAC address. It does not provide any other information about the user, which guarantees there will be no privacy infringements.
As the covering of the whole study area with sensors was impossible due to their limited range, the scanner sites were chosen to cover the main movements between all the public squares, the main access points and the parking lots, tram and train stations in the area.
The number of observed attendees had to be extrapolated to estimate the total number of visitors using the detection ratio, which was observed by comparing visual counts of passing people with the number of Bluetooth devices detected during a time period.
This experiment used two types of stationnary Bluetooth sensors depending on the range of activity (100 or 300 meters). There were 22 located sensors with which around 153'000 trajectories were generated by approximately 81'000 visitors. The detection ratio taken is 11%, and the total number of unique visitors was estimated around 735'000 and the total number of visits around 1.4 milion, whereas the city department estimation lies at 1.5 milion visits.
The resulting estimation of visitors lied close to the city department estimation. The crowdedness in certain zones over time was also calculated by gathering the number of detected phones over regular time periods (one day or one hour), but it does not take into account the spatiotemporal dynamics of the crowd within the considered zone. Therefore, the distribution of the crowd at different squares was examined and taken into account. It was also possible to see if visitors came to the event more than one day, as the MAC adress is uniquely assigned to each device.
Data about visitors' transportation mode was also collected thanks to the sensors at parking lots, train and tram stations. The visit duration was also estimated, but varied a lot between different visitors.

A flow analysis can be made by generalyzing the data of device-carrying visitors to all visitors and integrating factors that can potentially influence visitors movement, such as time of shows.
The authors consider Bluetooth to be a suitable technology for studying spaciotemporal dynamics of crowds at mass events, as it can track a large number of devices and it has the ability to work as well indoor as outdoor. Its limited detection range (10-100 meters) makes the resulting trajectories more accurate than those received using other technologies, for example mobile positionning.
One issue to be considered is the possibility of oversampling certain parts of the population, as some population layers have more chances to carry a Bluetooth-enabled device. Another issue to take into account is the relatively small percentage of people carrying Bluetooth-enabled devices, which is between 7 and 11%, whereas if WiFi traces were used, this percentage would be much higher.
The proximity principle was used to generate trajectories from the detection data. These trajectories have shown the existence of multiple profiles, which would need more research to be conclusive and precise.

## 1.2 Existing Methodologies for Tracking Data

### WiFi Traces

Pedestrian modeling is becoming a useful tool for designing new infrastructures and optimizing the use of current ones. Danalet et al. [2012] present a way of generating pedestrian destinations using WiFi traces. A methodolody is developped to collect data about activities and a model of the observed behaviour is developped. Due to the poor quality of WiFi localization, a probabilistic method for the choice of visited destinations was proposed.
The same method will be used in this study to generate the pedestrian destinations at the Paléo festival from Bluetooth traces.
This method takes localization data and timestamps from the WiFi infrastructure as inputs, and outputs a list of possible candidate destinations and their probability of being the true one.
The concept of *domain of data relevance (DDR)* is used to generate the position of the destination. The *DDR* corresponds to the physical area where some defined data is relevant. Its definition depends on the precision of the measurement and on the type of data. Using it for each signal, a tree is generated with the possible future destinations as nodes. After the list of the potential destination locations is defined, the time of arrival and departure is generated using simple assumptions.
A Bayesian approach was used in this study to calculate the likelihood of the generated signals. A prior is developped, as the probability of being at some places depend on the time of the day (for example, the probability of being in a restaurant at lunch time is higher than at any other time). The probability that the visited places generated the observed traces is decomposed as a prod-

uct of individual location measurement probabilities, assuming the measurement events to be independent, and then calibrate with sensor precision.
A likelihood is associated with every list of destinations and considers the activity time at destination, the inacurracy of the WiFi traces and a travel model. Two processes compose the list of destinations: staying at a point, or moving to the next one.
State variables $(x_i, t_i, t_{i+1})$ are used where $x_i$ is the position, $t_i$ and $t_{i+1}$ are respectively the time of arrival and departure. The prior knowledge of the state variables is decomposed in a travel model and an activity model. The locations of two consecutive destinations are assumed to be independent. The travel model depends on the distance between the two destinations and a distribution of speed, and the activity model represents the prior knowledge of the time spent at destination, depending on the type of destination.
An experiment took place on the EPFL campus, which is attended by around thirteen thousand people every day. A pedestrian network was already existing and a database of points of interest was used to define the possible destinations. The errors in lattitude and longitude were assumed to be independently and normally distributed.
The domain of data relevance was set to a 20 meters radius. The travel model was analytically developped taking into account the distance and travel time between destinations, and the path was computed by taking the weighted shortest path, i.e. the smallest distance between two points by assigning a weight matrix to the residuals, in the pedestrian graph. Only the twenty most likely lists of destinations for each signal were considered to avoid having too many data, and the destinations where the time spent was less than two minutes were removed as it is not a destination, but more likely a signal generated while walking.
The presented methodology is flexible and tunable, so it can be reused with slight modifications for other experiments, for example with other types of sensors data than WiFi sensors.

# Chapter 2

# Choice of Pedestrian Destinations

## 2.1 Selection of Pedestrian Destinations

From the geographical data of Paléo festival, the pedestrian destinations have been chosen by analyzing the map of the festival and thinking about people behaviour at festivals. Only places where people's could stay for longer than 5 minutes were taken into account, as else they were not actual destinations, but only walking paths. Also there were lots of destinations where only Paléo staff can go which were encoded and had to be taken out. The sound studios, geographical data, electricity points, etc. had also not to be considered as pedestrian destination. A selection was made when two destinations were on the same spot, for example the tables under a tent, in which case only the tent was taken as destination, as the area was merely the same. Figure 1 shows the map of the festival as received by the visitors. The geographical data is encoded as seen in Figure 2.1, which helps to select the different areas. Unfortunately, the pedestrian paths are not encoded in the database, but one can quite easily see the boundaries of the festival. The camping area is also encoded, but will not be considered in this study as the experiment took place inside the festival area and therefore the destinations were taken within the limits of the Paléo festival. Figure 2.2 shows the pedestrian destinations which were selected in this project. The whole list of 216 selected destinations can be found in the Appendix 7.4

The destinations have been put in six different categories, namely :

- Stages
- Bars and Restaurants
- Stalls
- Kids activities
- WC
- First-Aid, Security

### Stages

This category depicts the places where people come to see concerts. There are six main stages in the festival (Grande-Scène, Chapiteau, Dôme, Club Tent, le Détour) as well as other places where shows are performed. These are the main pedestrian destinations, as people come to the festival to see the shows, listen to music and discover new artists.
In the database, the different stages are encoded as polygon areas.

### Bars and Restaurants

Another subdivision of places is bars and restaurants. There are many places for attendees to have a drink or eat, and tables and tents associated to them. For example the Forum is a huge bar under a tent, some traditional fondue can be eaten at the Terroir restaurant stall, and you can enjoy a cocktail at the Cocktail Bar.
The restaurants will mainly be pedestrian destinations at lunch and dinner time, whereas the bars are more attended in the evening, and inbetween concerts.
There were cases where a single point was encoded three times in the database, for example in the same area as a bar, a tent and a table. In such cases only the widest area, i.e. the tent was kept to ensure less confusion. Also the bars and restaurants, as the stalls, are encoded in small surfaces which do not take into account where the visitors wait in line.

### Stalls

Many stalls are spread throughout the festival, with shops and games, for example Paléo shops and disc shops. Also many companies have their stall, like Swisscom, Philip Morris or Rouge FM, where you can get information about the different companies and participate to mini-games.
This category contains pedestrian destinations for the time inbetween concerts.
In the database, stalls are encoded as small areas which only take into account the surface of the stall itself, not the larger surface where visitors can stand.


Figure 2.1: Geographically coded map

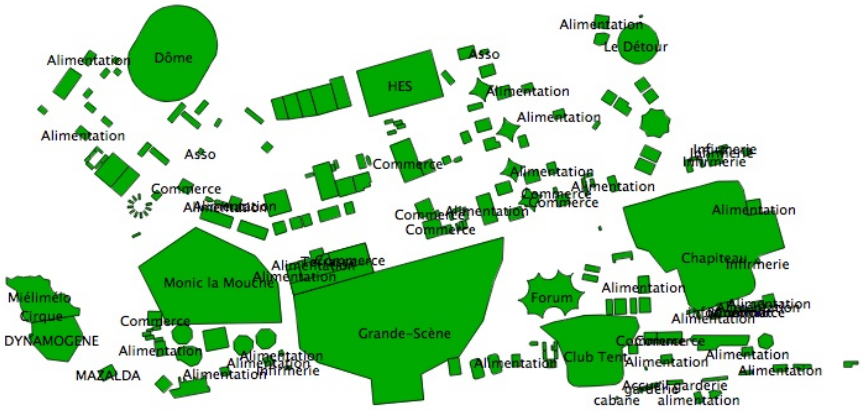



Figure 2.2: Chosen pedestrian destinations

### Kids Activities

There is a whole playground for kids and a nursery in the festival, so that the parents play with their children in a friendly atmosphere and at the same time they can enjoy their favorite concerts without having to worry about their children's safety.
These are pedestrian destinations mainly in the afternoon.

### First-Aid and Security

In case of problems, there are areas where attendees can get first-aid. It is not a main pedestrian destination, but can be taken into account. There are around four hundred medical interventions per day.

| | |
|---|---|
| **During concerts** | |
| Grande Scène | 30'000 |
| Chapiteau | 8'000 |
| Club Tent | 2'000 |
| Dôme | 2'000 |
| Le Détour | 500 |
| La Ruche | 600 |
| **No concerts** | |
| Grande Scène | 100 |
| Chapiteau | 100 |
| Club Tent | 100 |
| Dôme | 100 |
| Le Détour | 50 |
| La Ruche | 50 |
| **At all times** | |
| Tents | 50 |
| Bars and Restaurants | 20 |
| Stalls | 20 |
| Tables | 16 |
| WC | 3 |

Table 2.1: Potential affluence of the different pedestrian destinations

## 2.2 Potential Affluence of the Destinations

Potential affluence of destinations had to be defined in order to compute the prior. Table 2.1 shows the different affluences taken for the pedestrian destinations. The maximal capacity of Paléo stages is well-known and given by the organizers, so it was selected as potential during concerts, whereas it was reduced when there are no concerts, as there are less people near the stages. For the other categories there is no information about the capacity, so it has been estimated and stays constant during the whole festival. For example, the capacity of a table is set to be 16 people, and the capacity of the WC is 3 people per cabin, because of the waiting lines. Indeed, there are 42 encoded WC cabins, which makes the total WC capacity 126 people at all times.

# Chapter 3

# GPS and Bluetooth Data

## 3.1 Data Collection

The data collection was made on July 24th, 2010 using mobile phones (Nokia N95) with Texas Instruments' NaviLink 4.0 GPS5300 chip, that was programmed to scan for Bluetooth devices every 80 seconds within a 10-20 meters range. The MAC addresses of detected mobile devices are then collected, and are used as identifiers of visitors. This is possible because the MAC addresses are unique to each device. A regular scanning is done at the entrance of the festival to have an approximation of the total number of visible Bluetooth devices.
At the entrance, 3326 different Bluetooth devices were detected, and the total number of attendees estimated by the organizers of the festival was 40'536, which gives a percentage of attendees that have visible Bluetooth devices of 8.2%.
The 10 agents detected 2637 different Bluetooth devices of the total 3326 detected at the entrance, which corresponds to 79.3% of the devices. This ratio is less than 100% because of the short range of mobile devices Bluetooth detection and because of the relatively low number of agents.

## 3.2 Data Files

The collected data is in three files:

- GPS coordinates and timestamps of agents
- List of MAC addresses of detected Bluetooth-enabled devices
- Number of times each device was detected

The GPS coordinates were recorded as the Bluetooth devices were moving. As GPS becomes inactive if the device is stationnary, an interpolation was made to set the last visited destination as device destination every minute it is inactive. The accuracy of GPS coordinates is given by the Horizontal Dilution Of Precision (HDOP) multiplied by the sensors accuracy (which is 8 in our case). The HDOP

depends on the position of the GPS satellites and increases if they are close together, as the uncertainties of the sensors collapse into a larger area.

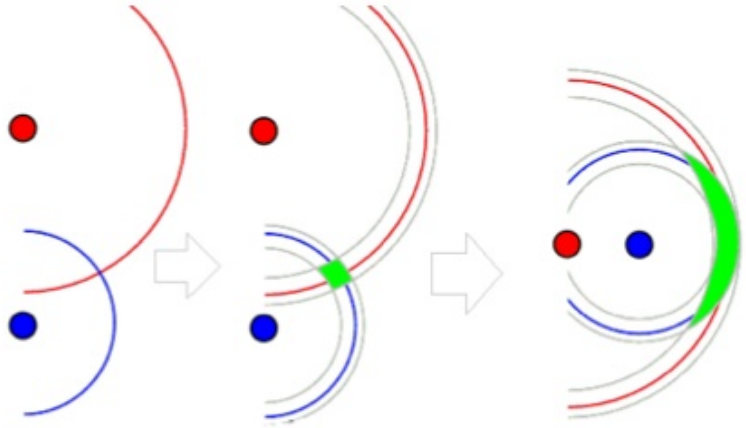


Figure 3.1: HDOP illustration

The number of times each device was detected is very important, as if a device was seen by the agents a large number of times, it is possible to compute its trajectory during a relatively long time period, whereas if it has been seen only twice, we can not assume those are the only two destinations which were visited.

Figure 3.2 shows the traces of the agents during the festival. We can notice that none of them visited the Détour stage, which is nonetheless a pedestrian destination where people go. So it should be kept in mind that the small number of agents does not completely reflect the attendees' behaviour. Figure 3.3 shows the points which were considered in the project, others being out of range. Around 68% of the GPS points (15'000 points) are usable, and almost 25'000 Bluetooth traces were collected.
Figures 3.6 and 3.7 show the number of times the different destinations appear as potential destinations during a one-hour period from only prior data, i.e. the concerts schedules. Comparing with the concerts timetable, it can be seen that the stages where concerts are ongoing appear more as potential destinations than where there are no concerts. In Figure 3.6, the big red spot is the Grande Scène, where Paolo Nutini's concert started at 9 p.m. The wide orange spot is the Chapiteau stage where Da Silva finished his concert after 9 p.m. The Dôme stage, on the top left, had no concerts running and was almost not attended by the agents.

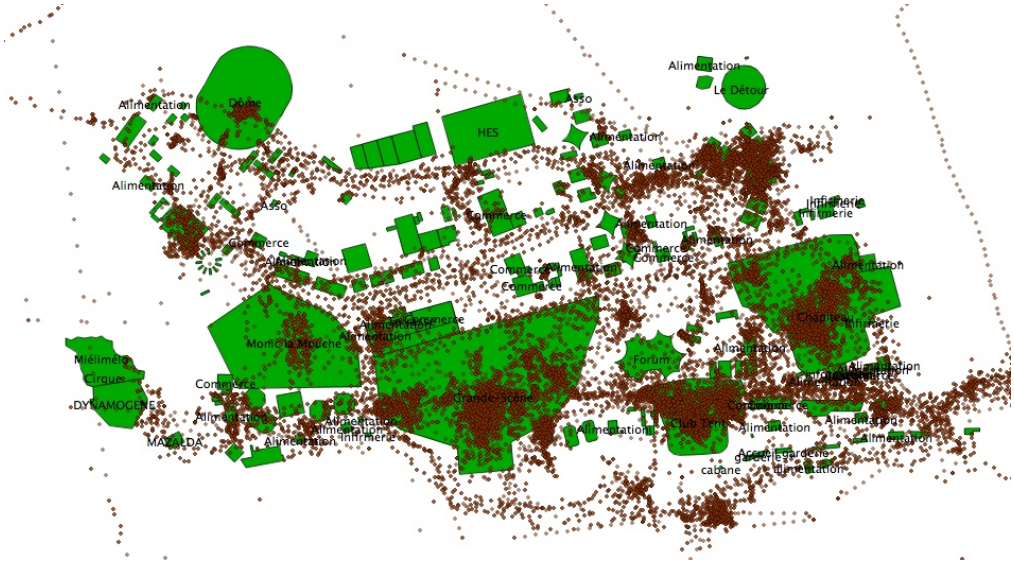



Figure 3.2: Traces of the 10 agents during the festival

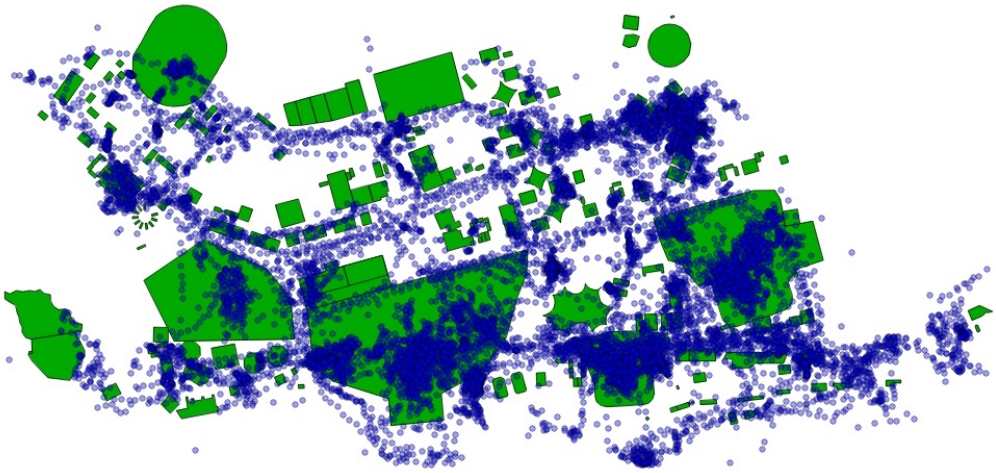


Figure 3.3: Selected traces of the 10 agents during the festival

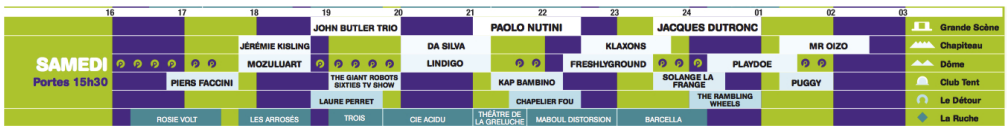



Figure 3.4: Concerts Timetable

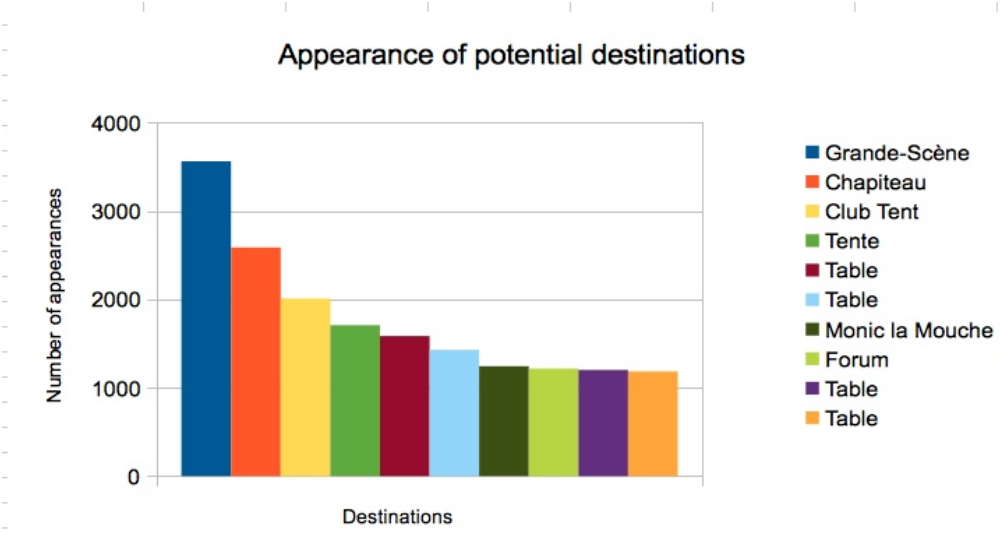



Figure 3.5: Top 10 potential destinations

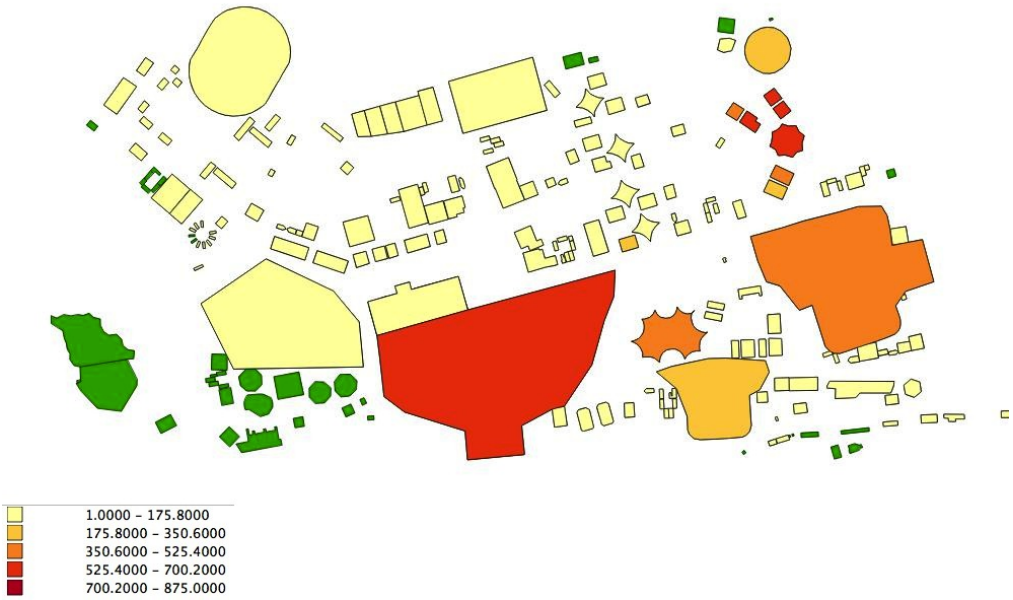



Figure 3.6: Appearance of potential destinations from 9 p.m. to 10 p.m.

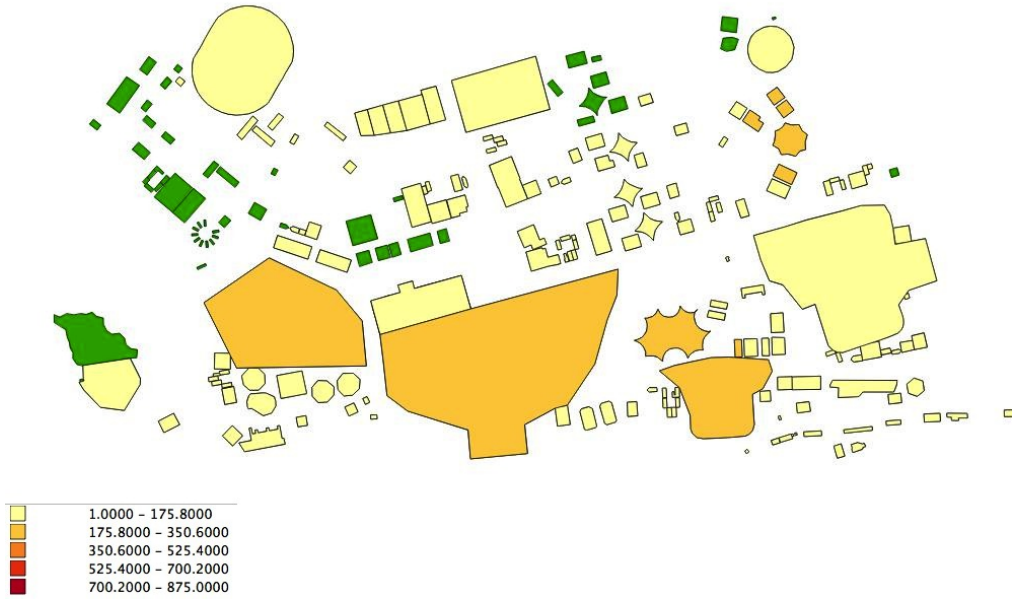



Figure 3.7: Appearance of potential destinations from midnight to 1 a.m.

# Chapter 4

# Paléo Attendees Localization

## 4.1 GPS Agents Localization

The accuracy of the GPS measurements lies around 30 meters. If it was calculated to be higher it was taken to be 30 meters, as we can see in Figure 3.2 that the dots have good precision. Therefore the domain of data relevance ($DDR$) was taken to be the minimum between the accuracy radius and 30 meters, i.e. $DDR = \min(acc, 30)$.
There is an average of 5.5 possible destinations per GPS location of each agent. And without surprise, the destinations which appear the most as potential destinations of the GPS agents are la Grande-Scène, le Chapiteau and the Club Tent, which are the places where the most wanted concerts take place and are not too far from the entry of the festival.
On the other hand, the destinations appearing the least frequently are around the Détour scene and Miélimélo. More generally those are the destinations further from the entry of the festival, near its border.
The attendees' speed has been assumed to be constant to simplify the problem, but it is known that it depends highly on congestion.

## 4.2 Installed Software

A few programs were installed to be able to get the results:

- PostGIS with PgAdmin3
- Quantum GIS
- PyDev extension for python programming in Eclipse

A stackbuilder was used to be able to have an internal server running directly on the laptop, so that the access to the Paléo database was minimal. Quantum GIS is used for the map visualizations. The main code is implemented in Python.

# Chapter 5

# Results

In this chapter, results with different parametrizations will be shown for two agents and two festival attendees traced by their Bluetooth devices. The other results can be found in the Appendix 7.1 and 7.2.

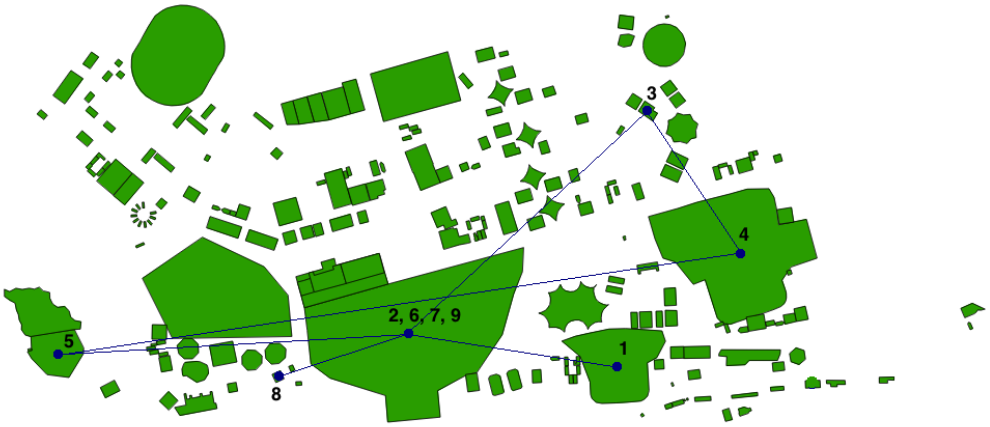
## 5.1 Parameters

The following parameters were used in the code for the GPS and the Bluetooth traces:

- Speed : 1.34m/s
- Shortest path defined as distance between two destinations
- Threshold of 5 and 15 minutes for visiting a destination
- $DDR = \min(accuracy, 30)$
- Prior depending on potential affluence of destinations and on distance to destination

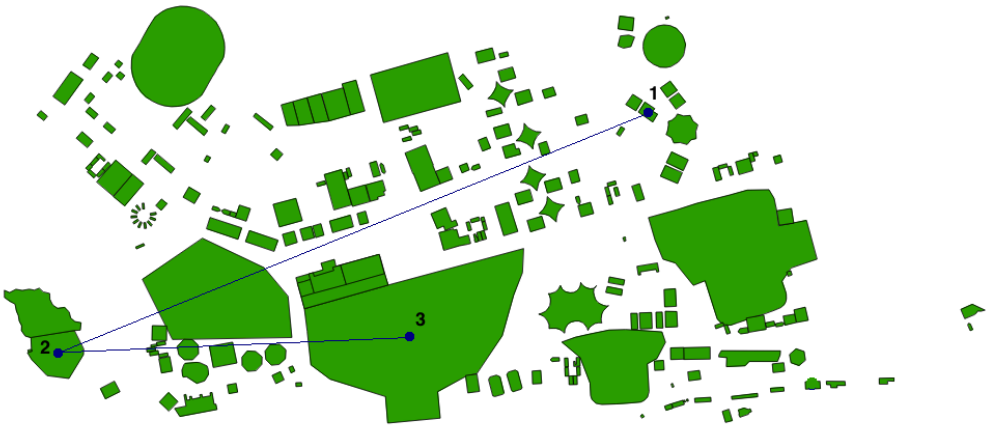
## 5.2 Agent 1

Figure 5.1 shows the resulting trace for the first agent and the precise timestamps, using a threshold of 5 minutes of minimum time spend at a place for it to become a destination. For the threshold of 15 minutes, the results are in figure 5.2. Notice that in this case, it might be too narrow a limit, as a lot of destinations are taken out when using this parametrization.




| # | Time start | Time end | Name | Type | Concert |
|---|---|---|---|---|---|
| 1 | 20:12:28 | 20:30:03 | Club Tent | Stage | No |
| 2 | 21:05:40 | 21:20:22 | Grande Scène | Stage | Yes |
| 3 | 21:43:03 | 22:22:51 | None | Table | - |
| 4 | 22:31:12 | 22:41:59 | Chapiteau | Stage | Yes |
| 5 | 22:56:02 | 23:27:12 | La Ruche | Stage | Yes |
| 6 | 23:35:08 | 23:42:57 | Grande Scène | Stage | Yes |
| 7 | 23:48:00 | 23:57:03 | Grande Scène | Stage | Yes |
| 8 | 23:57:18 | 00:12:19 | Alimentation | Bar | - |
| 9 | 00:29:02 | 00:36:05 | Grande Scène | Stage | Yes |

Figure 5.1: Visited destinations by agent 1, 5 minutes threshold

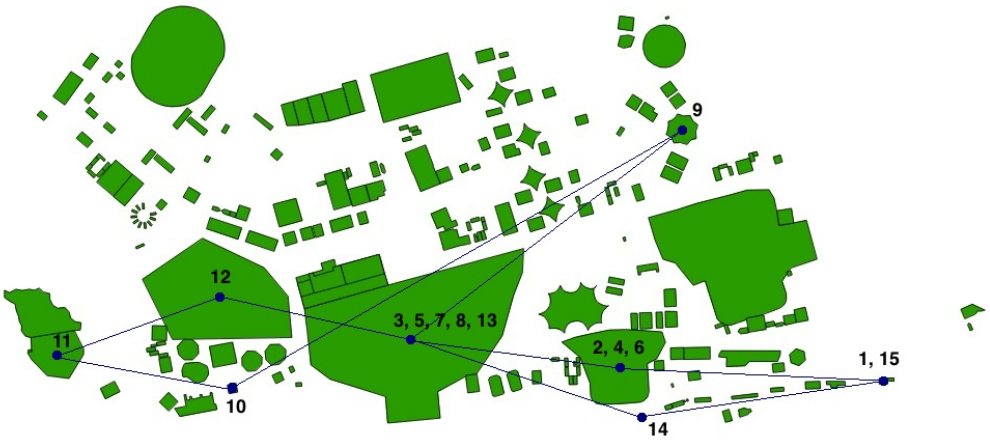



| # | Time start | Time end | Name | Type | Concert |
|---|---|---|---|---|---|
| 1 | 21:43:03 | 22:29:12 | None | Table | - |
| 2 | 22:56:02 | 23:27:12 | La Ruche | Stage | Yes |
| 3 | 23:48:00 | 00:12:07 | Grande Scène | Stage | Yes |

Figure 5.2: Visited destinations by agent 1, 15 minutes threshold

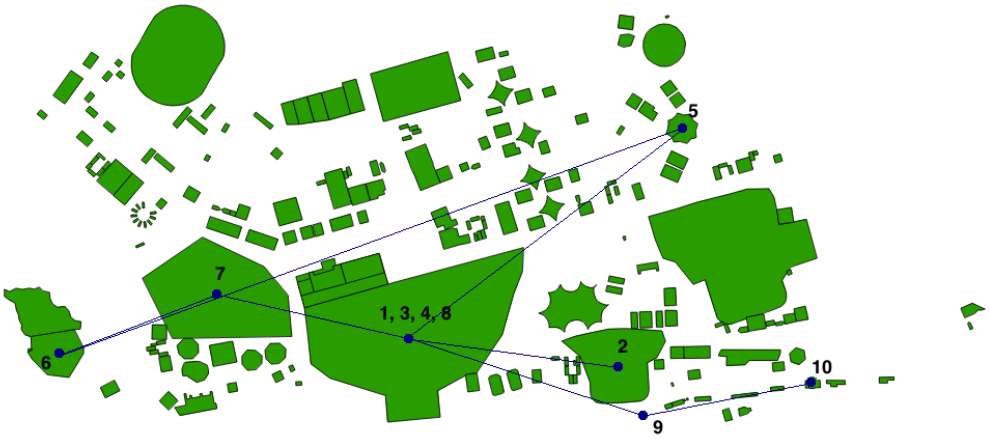
## 5.3 Agent 2

The resulting traces with 5 minutes threshold for the second agent and the precise timestamps and destinations are described in figure 5.3. Figure 5.4 show the results for a 15 minutes threshold.
Notice that the selection seems to be more accurate, as when a stage is visited, it is when a show is running on it.




| # | Time start | Time end | Name | Type | Concert |
|---|---|---|---|---|---|
| 1 | 18:38:24 | 18:45:12 | None | Table | - |
| 2 | 18:53:39 | 18:58:23 | Club Tent | Stage | No |
| 3 | 18:58:53 | 19:17:34 | Grande Scène | Stage | Yes |
| 4 | 19:24:52 | 19:55:25 | Club Tent | Stage | Yes |
| 5 | 19:56:15 | 20:16:43 | Grande Scène | Stage | Yes |
| 6 | 20:17:29 | 20:21:44 | Club Tent | Stage | No |
| 7 | 20:34:51 | 21:06:11 | Grande Scène | Stage | No |
| 8 | 21:07:30 | 21:19:26 | Grande Scène | Stage | Yes |
| 9 | 21:34:14 | 23:06:43 | None | Tent | - |
| 10 | 23:46:47 | 23:47:02 | Alimentation | Stall | - |
| 11 | 23:48:16 | 00:14:30 | La Ruche | Stage | Yes |
| 12 | 00:20:28 | 01:07:13 | Monic la Mouche | Stage | - |
| 13 | 01:09:21 | 01:28:53 | Grande Scène | Stage | Yes |
| 14 | 01:39:29 | 03:27:23 | None | Stall | - |
| 15 | 03:40:22 | 03:42:12 | None | Table | - |

Figure 5.3: Visited destinations by agent 2, 5 minutes threshold

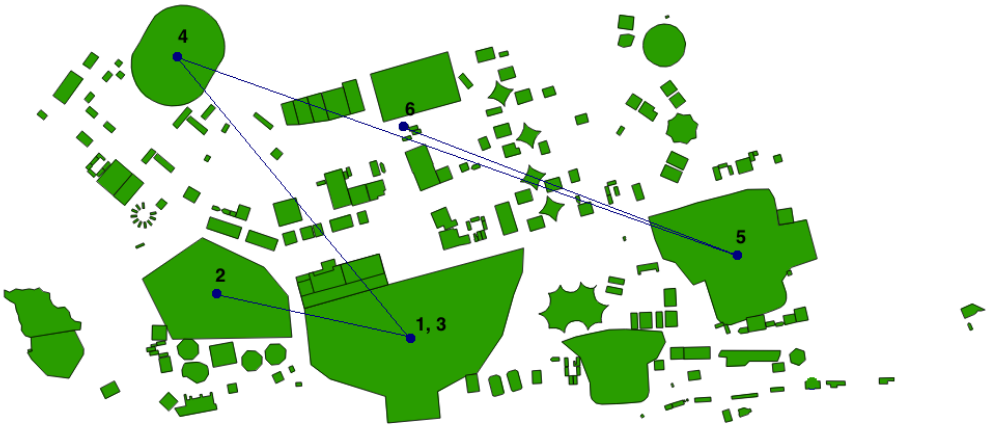



| # | Time start | Time end | Name | Type | Concert |
|---|---|---|---|---|---|
| 1 | 19:00:18 | 19:18:23 | Grande Scène | Stage | Yes |
| 2 | 19:24:52 | 19:55:25 | Club Tent | Stage | Yes |
| 3 | 19:56:15 | 20:16:43 | Grande Scène | Stage | Yes |
| 4 | 20:34:56 | 21:06:11 | Grande Scène | Stage | No |
| 5 | 21:34:14 | 23:06:43 | None | Tent | - |
| 6 | 23:47:55 | 00:14:30 | La Ruche | Stage | Yes |
| 7 | 00:20:28 | 01:07:13 | Monic la Mouche | Stage | - |
| 8 | 01:09:21 | 01:28:53 | Grande Scène | Stage | Yes |
| 9 | 01:39:29 | 03:27:23 | None | Stall | - |
| 10 | 03:36:47 | 03:42:12 | None | Table | - |

Figure 5.4: Visited destinations by agent 2, 15 minutes threshold

## 5.4 Bluetooth Traces 1

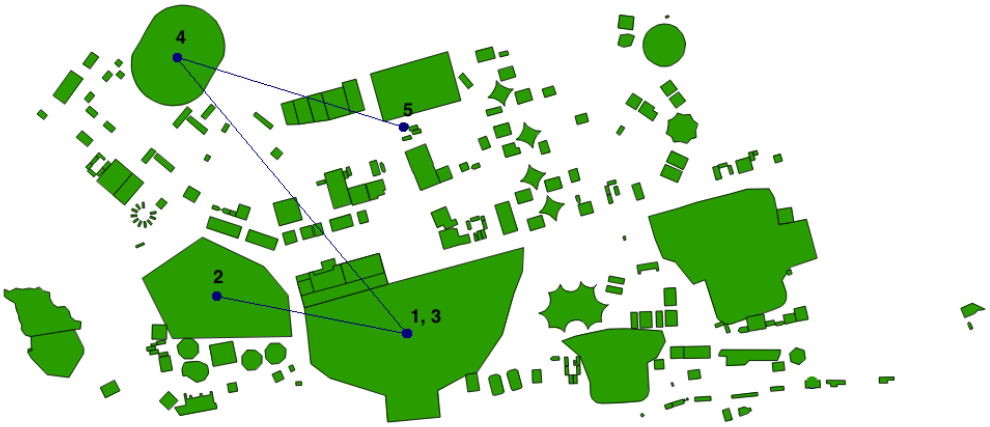
An example of traces derived from the collected Bluetooth data is presented in this section in figures 5.5 and 5.6. It can be guessed that the attendee which trace is considered here was at the festival for longer than what is seen, but has not been traced by the agents after 21:20.




| # | T-LB | T-UB | T+LB | T+UB | DB | Name | Type | Show |
|---|---|---|---|---|---|---|---|---|
| 1 | 18:20:46 | 18:20:46 | 18:20:46 | 19:59:53 | Grande-Scène | 0 | scène | No |
| 2 | 18:20:53 | 20:00:01 | 20:01:21 | 20:02:33 | Monic la Mouche | 8 | scène | - |
| 3 | 20:01:28 | 20:02:41 | 20:32:42 | 20:58:53 | Grande-Scène | 0 | scène | Yes |
| 4 | 20:34:41 | 21:00:53 | 21:02:13 | 21:02:24 | Dôme | 1 | scène | Yes |
| 5 | 21:04:57 | 21:04:57 | 21:04:57 | 21:17:18 | Chapiteau | 2 | scène | Yes |
| 6 | 21:07:07 | 21:19:29 | 21:19:29 | 21:19:29 | None | 91 | WC | - |

Figure 5.5: Visited destinations from Bluetooth traces 1, 5 minutes threshold

.

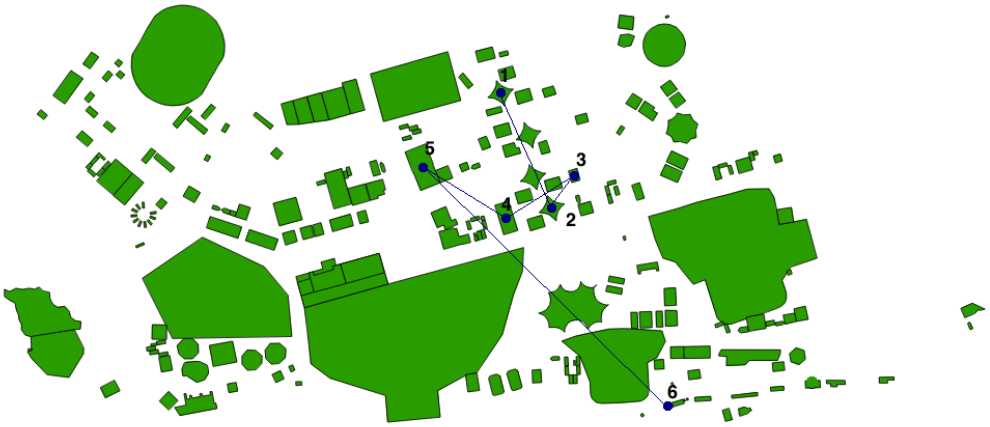



| # | T-LB | T-UB | T+LB | T+UB | DB | Name | Type | Show |
|---|---|---|---|---|---|---|---|---|
| 1 | 18:20:46 | 18:20:46 | 18:20:46 | 19:59:53 | Grande-Scène | 0 | scène | No |
| 2 | 18:20:53 | 20:00:01 | 20:01:21 | 20:02:33 | Monic la Mouche | 8 | scène | - |
| 3 | 20:01:28 | 20:02:41 | 20:32:42 | 20:58:53 | Grande-Scène | 0 | scène | Yes |
| 4 | 20:34:41 | 21:00:53 | 21:02:13 | 21:02:24 | Dôme | 1 | scène | Yes |
| 5 | 21:07:34 | 21:19:29 | 21:19:29 | 21:19:29 | None | 91 | WC | - |

Figure 5.6: Visited destinations from Bluetooth traces 1, 15 minutes threshold

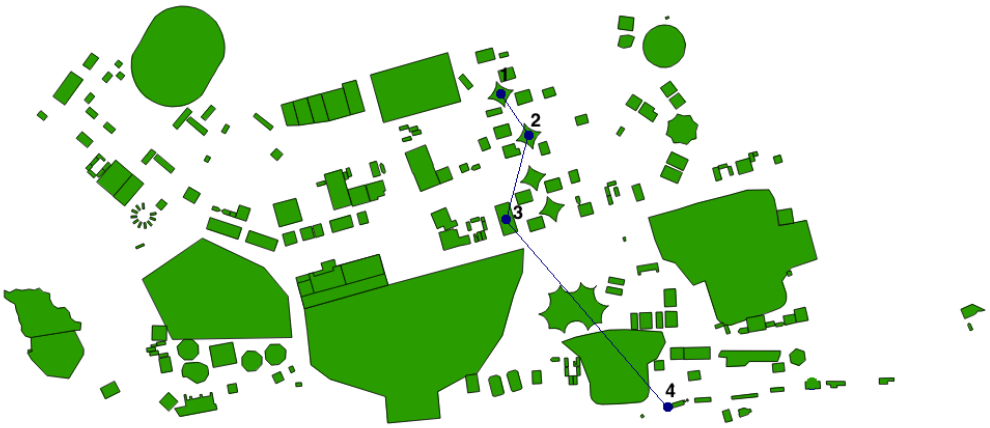
## 5.5 Bluetooth Traces 2

A second example of traces from Bluetooth data is shown in figures 5.7 and 5.8. This is an example of limitation of the procedure, as by seeing the results it could be concluded that this attendee did not see any concerts, whereas actually there might be no traces of him between 20:18 and 23:45, therefore no conclusions about his behaviour can be made.




| # | T-LB | T-UB | T+LB | T+UB | DB | Name | Type | Show |
|---|---|---|---|---|---|---|---|---|
| 1 | 19:47:02 | 19:47:02 | 19:47:02 | 20:17:06 | None | 117 | tente | - |
| 2 | 19:47:52 | 20:17:57 | 20:17:57 | 20:17:57 | None | 114 | tente | - |
| 3 | 20:17:57 | 20:17:57 | 20:17:57 | 23:41:10 | Alimentation | 109 | bar | - |
| 4 | 20:18:30 | 23:41:44 | 23:41:44 | 23:41:44 | Alimentation | 101 | bar | - |
| 5 | 23:41:44 | 23:41:44 | 23:41:44 | 01:55:33 | Commerce | 98 | bar | - |
| 6 | 23:44:26 | 01:58:16 | 01:58:16 | 01:58:16 | garderie | 160 | paleo | - |

Figure 5.7: Visited destinations from Bluetooth traces 2, 5 minutes threshold




| # | T-LB | T-UB | T+LB | T+UB | DB | Name | Type | Show |
|---|---|---|---|---|---|---|---|---|
| 1 | 20:17:57 | 20:17:57 | 20:17:57 | 23:41:31 | None | 117 | tente | - |
| 2 | 20:18:09 | 23:41:44 | 23:41:44 | 23:41:44 | None | 116 | tente | - |
| 3 | 23:41:44 | 23:41:44 | 23:41:44 | 01:56:18 | Alimentation | 101 | bar | - |
| 4 | 23:43:41 | 01:58:16 | 01:58:16 | 01:58:16 | garderie | 160 | paleo | - |

Figure 5.8: Visited destinations from Bluetooth traces 2, 15 minutes threshold

# Chapter 6

# Conclusion

## 6.1 Conclusion

The tracking of Paléo festival attendees was implemented and executed on the GPS and Bluetooth data sets, using different sets of parameters. The methodology of Danalet et al. [2012] was adapted to this case study.
It would be a great advantage to have another dataset or case study at the Paléo festival to be able to compare the results, and therefore to have a scale of accuracy of the results other than intuition.

## 6.2 Further Work

There are a few ways to improve the results. One way is to enhance the shortest path calculation: in this project, it was taken to be the distance between two destinations. One solution to improve it is to use the crowd density and the fundamental diagram, so that the speed changes depending on the congestion. Another solution is to take the obstacles into account, such as the stalls and the geographic obstacles.
Another improvement would be to collect WiFi traces during the festival instead of Bluetooth traces. Indeed, there would be a higher percentage of traced attendees, as WiFi technology is wider used than Bluetooth, and therefore a larger dataset would be available. The tracing of attendees would also be more precise if more agents scanned the area, or if static detectors were used at strategic places, such as near stages and on crossroads.

# Bibliography

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Farid Movahedi Naini, Olivier Drousse, Patrick Thiran, and Martin Vetterli. Population Size Estimation Using a Few Individuals as Agents. *IEEE International Symposium on Information Theory Proceedings*, 2011.

M. Versichele, T. Neutens, M. Delafontaine, and N. Van de Weghe. The Use of Bluetooth for Analyzing Spatiotemporal Dymamics of Human Movement at Mass Events: a Case Study of the Ghent Festivities. *Applied Geography*, 2012.

# Chapter 7

# Appendix

Detailed results for all agents and all Bluetooth traces are shown in this section, as well as the list of chosen pedestrian destinations and the Python code.

## 7.1 Results of all Agents: 5 Minutes Threshold

Table 7.1: Visited destinations by agent 1, 5 minutes threshold

| # | T-LB | T-UB | T+LB | T+UB | DB | Name | Type |
|---|---|---|---|---|---|---|---|
| 1 | 20:12:28 | 20:12:28 | 20:30:03 | 20:30:03 | Club Tent | 4 | scène |
| 2 | 21:05:40 | 21:05:40 | 21:20:22 | 21:20:22 | Grande-Scène | 0 | scène |
| 3 | 21:43:03 | 21:43:03 | 22:22:51 | 22:22:51 | None | 131 | tables |
| 4 | 22:31:12 | 22:31:12 | 22:41:59 | 22:44:56 | Chapiteau | 2 | scène |
| 5 | 22:56:02 | 22:56:02 | 23:27:12 | 23:27:12 | MAZALDA | 21 | scène |
| 6 | 23:35:08 | 23:35:08 | 23:42:57 | 23:44:03 | Grande-Scène | 0 | scène |
| 7 | 23:48:00 | 23:49:39 | 23:57:03 | 00:12:03 | Grande-Scène | 0 | scène |
| 8 | 23:57:18 | 00:12:19 | 00:12:19 | 00:12:19 | Alimentation | 60 | bar |
| 9 | 00:29:02 | 00:30:04 | 00:36:05 | 00:38:43 | Grande-Scène | 0 | scène |

Table 7.2: Visited destinations by agent 2, 5 minutes threshold

| # | T-LB | T-UB | T+LB | T+UB | DB | Name | Type |
|---|---|---|---|---|---|---|---|
| 1 | 18:38:24 | 18:38:24 | 18:45:12 | 18:45:12 | None | 166 | tables |
| 2 | 18:53:39 | 18:54:03 | 18:58:23 | 18:59:47 | Club Tent | 4 | scène |
| 3 | 18:58:53 | 19:00:18 | 19:17:34 | 19:18:23 | Grande-Scène | 0 | scène |
| 4 | 19:24:52 | 19:25:15 | 19:55:25 | 19:55:25 | Club Tent | 4 | scène |
| 5 | 19:56:15 | 19:56:15 | 20:16:43 | 20:16:43 | Grande-Scène | 0 | scène |
| 6 | 20:17:29 | 20:17:33 | 20:21:44 | 20:24:08 | Club Tent | 4 | scène |
| 7 | 20:34:51 | 20:34:56 | 21:06:11 | 21:06:11 | Grande-Scène | 0 | scène |
| 8 | 21:07:30 | 21:14:59 | 21:19:26 | 21:23:00 | Grande-Scène | 0 | scène |
| 9 | 21:34:14 | 21:34:15 | 23:06:43 | 23:06:53 | None | 113 | tente |
| 10 | 23:46:47 | 23:47:02 | 23:47:02 | 00:13:15 | Alimentation | 30 | stand |
| 11 | 23:48:16 | 00:14:30 | 00:14:30 | 00:14:30 | La Ruche | 22 | scène |
| 12 | 00:20:28 | 00:20:32 | 01:07:13 | 01:07:13 | Monic la Mouche | 8 | scène |
| 13 | 01:09:21 | 01:10:40 | 01:28:53 | 01:28:53 | Grande-Scène | 0 | scène |
| 14 | 01:39:29 | 01:39:29 | 03:27:23 | 03:27:26 | cabane | 162 | divers |

Table 7.3: Visited destinations by agent 3, 5 minutes threshold

| # | T-LB | T-UB | T+LB | T+UB | DB | Name | Type |
|---|---|---|---|---|---|---|---|
| 1 | 18:44:13 | 18:44:13 | 18:44:13 | 18:57:13 | Club Tent | 4 | scène |
| 2 | 18:44:41 | 18:57:42 | 18:57:42 | 18:57:42 | Chapiteau | 2 | scène |
| 3 | 19:02:07 | 19:02:07 | 20:04:47 | 20:05:56 | Club Tent | 4 | scène |
| 4 | 20:59:02 | 20:59:02 | 21:05:01 | 21:05:01 | Dôme | 1 | scène |
| 5 | 21:07:20 | 21:17:01 | 21:17:01 | 21:17:01 | None | 55 | divers |
| 6 | 21:34:12 | 21:34:12 | 21:34:12 | 21:44:38 | Le Détour | 5 | scène |
| 7 | 21:35:22 | 21:45:49 | 21:46:25 | 21:46:25 | Chapiteau | 2 | scène |

Table 7.4: Visited destinations by agent 4, 5 minutes threshold

| # | T-LB | T-UB | T+LB | T+UB | DB | Name | Type |
|---|---|---|---|---|---|---|---|
| 1 | 18:39:29 | 18:39:29 | 19:45:17 | 19:45:17 | Grande-Scène | 0 | scène |
| 2 | 19:55:35 | 19:55:39 | 19:55:39 | 20:34:34 | None | 114 | tente |
| 3 | 19:56:18 | 20:35:14 | 20:35:35 | 20:35:35 | Alimentation | 210 | stand |
| 4 | 20:53:44 | 20:55:24 | 22:14:01 | 22:34:45 | Grande-Scène | 0 | scène |
| 5 | 22:14:08 | 22:34:53 | 22:34:59 | 22:34:59 | Monic la Mouche | 8 | scène |
| 6 | 23:13:42 | 23:13:42 | 00:30:06 | 00:30:06 | Grande-Scène | 0 | scène |

Table 7.5: Visited destinations by agent 5, 5 minutes threshold

| # | T-LB | T-UB | T+LB | T+UB | DB | Name | Type |
|---|---|---|---|---|---|---|---|
| 1 | 19:59:59 | 19:59:59 | 20:13:49 | 20:30:10 | Club Tent | 4 | scène |
| 2 | 20:14:19 | 20:30:41 | 20:31:52 | 20:31:52 | Grande-Scène | 0 | scène |
| 3 | 20:43:02 | 20:50:43 | 20:50:43 | 20:50:43 | Dôme | 1 | scène |
| 4 | 20:55:14 | 20:55:14 | 21:14:27 | 21:14:27 | Monic la Mouche | 8 | scène |
| 5 | 22:05:15 | 22:05:17 | 22:05:17 | 22:22:09 | Club Tent | 4 | scène |
| 6 | 22:05:45 | 22:22:38 | 22:24:34 | 22:24:34 | Chapiteau | 2 | scène |
| 7 | 22:31:33 | 22:31:38 | 23:38:08 | 23:38:08 | Chapiteau | 2 | scène |
| 8 | 23:53:42 | 23:53:42 | 00:21:44 | 00:21:44 | Grande-Scène | 0 | scène |
| 9 | 00:50:12 | 00:51:18 | 01:07:24 | 01:07:57 | Dôme | 1 | scène |
| 10 | 01:22:20 | 01:22:25 | 02:03:22 | 02:03:22 | Chapiteau | 2 | scène |

Table 7.6: Visited destinations by agent 6, 5 minutes threshold

| # | T-LB | T-UB | T+LB | T+UB | DB | Name | Type |
|---|---|---|---|---|---|---|---|
| 1 | 18:20:10 | 18:20:10 | 20:07:16 | 20:08:10 | Grande-Scène | 0 | scène |
| 2 | 20:27:03 | 20:36:53 | 20:59:39 | 20:59:39 | None | 169 | divers |
| 3 | 21:06:04 | 21:06:04 | 21:55:36 | 21:56:25 | Chapiteau | 2 | scène |
| 4 | 21:57:01 | 21:57:01 | 22:52:16 | 22:52:22 | Chapiteau | 2 | scène |

Table 7.7: Visited destinations by agent 7, 5 minutes threshold

| # | T-LB | T-UB | T+LB | T+UB | DB | Name | Type |
|---|---|---|---|---|---|---|---|
| 1 | 19:32:58 | 19:32:58 | 19:32:58 | 19:54:46 | Club Tent | 4 | scène |
| 2 | 19:33:26 | 19:55:15 | 21:12:57 | 21:12:57 | Chapiteau | 2 | scène |
| 3 | 21:15:51 | 21:15:51 | 21:55:03 | 22:13:28 | Grande-Scène | 0 | scène |
| 4 | 21:55:33 | 22:13:59 | 22:15:05 | 22:15:05 | Club Tent | 4 | scène |
| 5 | 22:19:00 | 22:19:00 | 22:20:00 | 22:20:00 | None | 166 | tables |

Table 7.8: Visited destinations by agent 8, 5 minutes threshold

| # | T-LB | T-UB | T+LB | T+UB | DB | Name | Type |
|---|---|---|---|---|---|---|---|
| 1 | 18:22:53 | 18:22:53 | 18:22:53 | 18:38:07 | Alimentation | 59 | bar |
| 2 | 18:25:27 | 18:40:42 | 18:40:42 | 18:40:42 | Grande-Scène | 0 | scène |
| 3 | 18:43:13 | 18:43:18 | 19:27:27 | 19:27:27 | Grande-Scène | 0 | scène |
| 4 | 19:37:35 | 19:37:39 | 20:12:28 | 20:31:59 | None | 116 | tente |
| 5 | 20:13:38 | 20:33:10 | 20:37:35 | 22:10:30 | Forum | 7 | divers |
| 6 | 20:37:49 | 22:10:45 | 22:15:11 | 22:18:46 | Grande-Scène | 0 | scène |
| 7 | 22:21:15 | 22:21:15 | 22:57:10 | 23:11:05 | Chapiteau | 2 | scène |
| 8 | 22:57:38 | 23:11:34 | 23:15:59 | 23:33:29 | Club Tent | 4 | scène |
| 9 | 23:16:29 | 23:34:00 | 23:48:24 | 23:51:09 | Grande-Scène | 0 | scène |
| 10 | 00:26:21 | 00:34:38 | 00:34:43 | 00:34:43 | None | 113 | tente |

Table 7.9: Visited destinations by agent 9, 5 minutes threshold

| # | T-LB | T-UB | T+LB | T+UB | DB | Name | Type |
|---|---|---|---|---|---|---|---|
| 1 | 21:27:14 | 21:27:14 | 21:34:29 | 21:34:29 | Grande-Scène | 0 | scène |
| 2 | 22:02:48 | 22:02:50 | 22:07:05 | 22:55:21 | Dôme | 1 | scène |
| 3 | 22:07:24 | 22:55:41 | 22:55:51 | 22:55:51 | None | 52 | stand |
| 4 | 23:02:33 | 23:02:49 | 00:02:29 | 00:02:29 | Grande-Scène | 0 | scène |
| 5 | 00:08:14 | 00:08:14 | 00:45:25 | 00:45:25 | Club Tent | 4 | scène |
| 6 | 00:55:03 | 00:55:08 | 00:55:08 | 01:19:07 | Club Tent | 4 | scène |
| 7 | 00:55:36 | 01:19:36 | 02:04:22 | 02:49:17 | Chapiteau | 2 | scène |
| 8 | 02:04:50 | 02:49:46 | 02:51:56 | 02:51:56 | Club Tent | 4 | scène |

Table 7.10: Visited destinations by agent 10, 5 minutes threshold

| # | T-LB | T-UB | T+LB | T+UB | DB | Name | Type |
|---|---|---|---|---|---|---|---|
| 1 | 20:17:30 | 20:17:30 | 20:30:16 | 20:30:16 | Club Tent | 4 | scène |
| 2 | 20:30:36 | 20:30:36 | 21:05:00 | 21:05:00 | Grande-Scène | 0 | scène |
| 3 | 21:05:05 | 21:05:05 | 21:13:36 | 21:26:35 | Forum | 7 | divers |
| 4 | 21:14:09 | 21:27:09 | 21:28:15 | 21:28:15 | Commerce | 107 | paleo |
| 5 | 21:48:57 | 21:48:57 | 21:54:37 | 21:54:37 | Chapiteau | 2 | scène |
| 6 | 22:59:11 | 22:59:11 | 22:59:11 | 23:18:00 | None | 113 | tente |
| 7 | 23:00:10 | 23:19:00 | 23:19:16 | 23:19:16 | None | 121 | tables |
| 8 | 23:30:31 | 23:30:31 | 23:35:35 | 23:35:35 | Grande-Scène | 0 | scène |
| 9 | 23:52:34 | 23:52:34 | 01:08:43 | 01:08:43 | Monic la Mouche | 8 | scène |
| 10 | 01:08:48 | 01:08:48 | 01:25:25 | 01:25:30 | Terrasse | 6 | divers |
| 11 | 01:30:00 | 01:30:00 | 01:35:22 | 01:35:22 | Chapiteau | 2 | scène |
| 12 | 01:39:36 | 01:39:36 | 01:40:16 | 02:46:10 | cabane | 162 | divers |
| 13 | 01:41:35 | 02:47:30 | 02:48:21 | 02:48:21 | None | 72 | divers |

## 7.2 15 Minutes Threshold

The results for parametrization of 15 minutes threshold for a destination.

Table 7.11: Visited destinations by agent 1, 15 minutes threshold

| # | T-LB | T-UB | T+LB | T+UB | DB | Name | Type |
|---|---|---|---|---|---|---|---|
| 1 | 21:43:03 | 21:43:03 | 22:29:12 | 22:29:12 | None | 131 | tables |
| 2 | 22:56:02 | 22:56:02 | 23:27:12 | 23:27:12 | MAZALDA | 21 | scène |
| 3 | 23:48:00 | 23:49:39 | 23:57:03 | 00:12:07 | Grande-Scène | 0 | scène |

Table 7.12: Visited destinations by agent 2, 15 minutes threshold

| # | T-LB | T-UB | T+LB | T+UB | DB | Name | Type |
|---|---|---|---|---|---|---|---|
| 1 | 19:00:18 | 19:00:18 | 19:17:34 | 19:18:23 | Grande-Scène | 0 | scène |
| 2 | 19:24:52 | 19:25:15 | 19:55:25 | 19:55:25 | Club Tent | 4 | scène |
| 3 | 19:56:15 | 19:56:15 | 20:16:43 | 20:16:43 | Grande-Scène | 0 | scène |
| 4 | 20:34:56 | 20:46:46 | 21:06:11 | 21:06:11 | Grande-Scène | 0 | scène |
| 5 | 21:34:14 | 21:34:15 | 23:06:43 | 23:06:53 | None | 113 | tente |
| 6 | 23:47:55 | 00:14:30 | 00:14:30 | 00:14:30 | La Ruche | 22 | scène |
| 7 | 00:20:27 | 00:20:32 | 01:07:13 | 01:07:13 | Monic la Mouche | 8 | scène |
| 8 | 01:09:21 | 01:10:40 | 01:28:53 | 01:28:53 | Grande-Scène | 0 | scène |
| 9 | 01:39:29 | 01:39:29 | 03:27:23 | 03:27:26 | cabane | 162 | divers |

Table 7.13: Visited destinations by agent 3, 15 minutes threshold

| # | T-LB | T-UB | T+LB | T+UB | DB | Name | Type |
|---|---|---|---|---|---|---|---|
| 1 | 18:39:29 | 18:39:29 | 19:45:17 | 19:45:17 | Grande-Scène | 0 | scène |
| 2 | 19:55:35 | 19:55:39 | 19:55:39 | 20:34:34 | None | 114 | tente |
| 3 | 19:56:18 | 20:35:14 | 20:35:35 | 20:35:35 | Alimentation | 210 | stand |
| 4 | 20:53:49 | 20:55:24 | 22:14:01 | 22:33:15 | Grande-Scène | 0 | scène |
| 5 | 23:13:42 | 23:13:42 | 00:30:06 | 00:30:06 | Grande-Scène | 0 | scène |

Table 7.14: Visited destinations by agent 4, 15 minutes threshold

| # | T-LB | T-UB | T+LB | T+UB | DB | Name | Type |
|---|---|---|---|---|---|---|---|
| 1 | 19:24:55 | 19:24:55 | 20:04:47 | 20:05:50 | Club Tent | 4 | scène |
| 2 | 21:51:02 | 21:51:02 | 21:51:02 | 21:51:02 | None | 146 | tables |

Table 7.15: Visited destinations by agent 5, 15 minutes threshold

| # | T-LB | T-UB | T+LB | T+UB | DB | Name | Type |
|---|---|---|---|---|---|---|---|
| 1 | 22:31:38 | 22:31:38 | 23:38:08 | 23:38:08 | Chapiteau | 2 | scène |
| 2 | 23:53:42 | 23:53:42 | 00:21:44 | 00:21:44 | Grande-Scène | 0 | scène |
| 3 | 00:50:12 | 00:51:18 | 01:07:24 | 01:08:06 | Dôme | 1 | scène |
| 4 | 01:31:17 | 01:31:22 | 02:03:22 | 02:03:22 | Chapiteau | 2 | scène |

Table 7.16: Visited destinations by agent 6, 15 minutes threshold

| # | T-LB | T-UB | T+LB | T+UB | DB | Name | Type |
|---|---|---|---|---|---|---|---|
| 1 | 18:20:10 | 18:20:10 | 20:07:16 | 20:08:10 | Grande-Scène | 0 | scène |
| 2 | 21:06:04 | 21:06:04 | 21:55:36 | 21:56:42 | Chapiteau | 2 | scène |
| 3 | 21:56:53 | 21:57:01 | 22:37:56 | 22:38:01 | Chapiteau | 2 | scène |

Table 7.17: Visited destinations by agent 7, 15 minutes threshold

| # | T-LB | T-UB | T+LB | T+UB | DB | Name | Type |
|---|---|---|---|---|---|---|---|
| 1 | 19:55:47 | 19:55:47 | 21:12:57 | 21:12:57 | Chapiteau | 2 | scène |
| 2 | 21:15:51 | 21:15:51 | 21:55:03 | 22:13:31 | Grande-Scène | 0 | scène |
| 3 | 22:19:15 | 22:19:15 | 22:20:00 | 22:20:00 | None | 166 | tables |

Table 7.18: Visited destinations by agent 8, 15 minutes threshold

| # | T-LB | T-UB | T+LB | T+UB | DB | Name | Type |
|---|---|---|---|---|---|---|---|
| 1 | 18:43:18 | 18:43:18 | 19:27:27 | 19:27:27 | Grande-Scène | 0 | scène |
| 2 | 19:37:51 | 20:07:49 | 20:09:55 | 20:09:55 | None | 116 | tente |
| 3 | 20:37:35 | 20:37:35 | 20:37:35 | 22:10:30 | Forum | 7 | divers |
| 4 | 20:37:49 | 22:10:45 | 22:15:11 | 22:18:40 | Grande-Scène | 0 | scène |
| 5 | 22:21:13 | 22:21:15 | 22:57:10 | 23:10:18 | Chapiteau | 2 | scène |
| 6 | 23:34:06 | 23:34:06 | 23:48:24 | 23:51:09 | Grande-Scène | 0 | scène |

Table 7.19: Visited destinations by agent 9, 15 minutes threshold

| # | T-LB | T-UB | T+LB | T+UB | DB | Name | Type |
|---|---|---|---|---|---|---|---|
| 1 | 22:02:50 | 22:02:50 | 22:07:05 | 22:55:21 | Dôme | 1 | scène |
| 2 | 22:07:24 | 22:55:41 | 22:55:51 | 22:55:51 | None | 52 | stand |
| 3 | 23:02:33 | 23:02:49 | 00:02:29 | 00:02:29 | Grande-Scène | 0 | scène |
| 4 | 00:08:13 | 00:08:14 | 00:45:25 | 00:45:25 | Club Tent | 4 | scène |
| 5 | 00:55:38 | 01:19:36 | 02:04:22 | 02:49:17 | Chapiteau | 2 | scène |
| 6 | 02:04:50 | 02:49:46 | 02:51:56 | 02:51:56 | Club Tent | 4 | scène |

Table 7.20: Visited destinations by agent 10, 15 minutes threshold

| # | T-LB | T-UB | T+LB | T+UB | DB | Name | Type |
|---|---|---|---|---|---|---|---|
| 1 | 20:30:36 | 20:30:36 | 21:05:00 | 21:05:00 | Grande-Scène | 0 | scène |
| 2 | 23:52:32 | 23:52:34 | 01:06:33 | 01:06:33 | Monic la Mouche | 8 | scène |
| 3 | 01:39:26 | 01:39:26 | 01:40:16 | 02:46:20 | cabane | 162 | divers |
| 4 | 01:41:25 | 02:47:30 | 02:48:06 | 02:48:06 | Alimentation | 18 | bar |