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GTL-Healthmob: Simulation platform for urban mobility and epidemic control

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Abstract

The GTL-Healthmob is an online simulation platform which aims at visualizing the population movement, simulating epidemic propagation and optimizing the mobility restrictions to limit the epidemic spread in the Grenoble metropolis. The platform takes user inputs for different epidemic and mobility control parameters and shows the results in terms of plots and heatmaps overlaid onto the map of the metropolis. The platform is being developed in the context of the ERC project Scale-FreeBack and the INRIA project Healthy-Mobility, to showcase the mobility and epidemic models, developed within the team by adapting and implementing them to the Grenoble metropolis, which can also enable policymakers to devise optimal mobility restriction policies.

Keywords: Simulation platform, Urban human mobility, Epidemic-mobility, Optimal lockdown, Grenoble metropolis

1 Introduction

Although human mobility plays a vital role in a country's economy, it facilitates the spread of disease in the event of an epidemic by allowing contact between infected and susceptible populations. Therefore, controlling human mobility during an epidemic is a fundamental issue faced by policymakers. Such control can only be done optimally if human mobility is adequately modeled at the scale of a city or metropolis. Although, there is a large literature concerning epidemic spread and control of mobility, most of which focuses on control inter-city mobility or the epidemic spread in a single location. Although research exist for control of mobility for epidemic mitigation for urban cities, their implementation and extension on a large-scale urban mobility network is rarely available.

In this paper, we present and describe the GTL-Ville experimental platform, available through the link <http://gtlville.inrialpes.fr/covid-19>. It is being developed as an academic platform where users can a) simulate different scenarios of epidemic spread, b) simulate different scenarios of mobility restrictions and visualize its effect on epidemic spread c) simulate the optimal mobility restriction aimed at limiting epidemic spread and maximizing economy. This platform is part of the Grenoble Traffic Lab (GTL), which considers the Grenoble metropolis as a case study. Grenoble is metropolitan city in France located in the valley of Alpes mountain range. A metropolis is an administrative entity in France, in which several communes cooperate, and which has the right to levy local taxes. Grenoble metropolis is centered on the city of Grenoble. The considered area includes 55 communes including all the 49 communes in Grenoble metropolis and 6 communes in Gresivaudan, which are of economic importance to the Grenoble metropolis. The population of this area is about 500000 and has a surface area of about 600 km^2 .

This paper is organized as follows: Section 2 presents an overview of the structure and main modules and submodules of the platform. Section 3 describes the methods and models used to calculate the evolution of epidemics and mobility, optimal policies based on the scientific work performed by the research team. Section 4 lists the datasets and their sources used to calibrate the models. Section 5 describes the user interface, features, and functionality available in the platform, and how they can be accessed by the general public. Finally, Section 6 concludes the paper.

2 Platform Overview

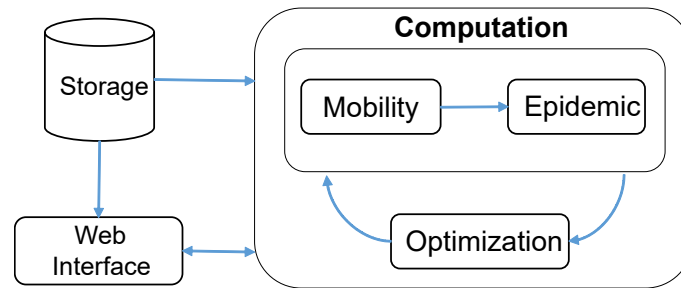


Figure 1: Modules and submodules of the GTL-Healthmob

Figure 1 shows the basic structure of the GTL-Healthmob platform. It is composed of the following modules:

- The **Storage** module deals with the database and the transmission of static data to the Computation and the Web Interface modules. The static data mainly comprises of the location of the origin and destination nodes, Population of communes and capacities of places of interests called destinations, OD matrices and time-dependent functions.
- The **Web Interface** module allows to visualise the mobility network, origin and destination nodes and also facilitates the users to choose input parameters and visualise the computed results.
- The **Computation** module takes the parameters given as inputs by the users on the Web Interface module and static data from the Storage module to simulate the mobility and epidemic models and compute the evolution of mobility and epidemic spread. The results is then passed on to the Web interface for visualization. It is composed of three submodules:
 - Mobility - Using different control and input parameters provided by the user, it computes the number of people present at each location at different times for each day during the simulation period.
 - Epidemic - Using the epidemic parameters provided by the user and the number of people present at any location, given by mobility submodule, it computes the evolution of epidemic spread at each location.
 - Optimization - Using the results from mobility and epidemic submodules, it computes the optimal mobility restriction that keeps maximum infection below the user defined threshold.

A more detailed description of the Computation submodules and the collected input data is presented in the following sections.

3 Methods and models

3.1 Mobility and epidemic spread

The mobility model which has been implemented on GTL-Healthmob to compute the mobility patterns and epidemic spread is presented in [1] in discrete-time. Originally, this model was presented in [2] in continuous-time. This model captures the mobility in an urban area between different locations and also integrates epidemic spread by coupling the mobility process with an SIR(Susceptible, Infected and Recovered) compartmental model at each location as depicted in Figure 2.

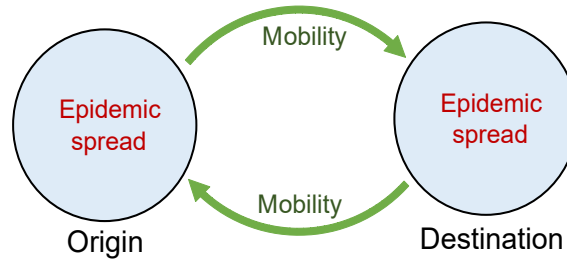


Figure 2: Depiction of mobility between different locations and epidemic spread inside each of them

The locations are of two types: origins and destinations. The origins correspond to the residential areas and the destinations correspond to the places of interest such as companies, research centers, schools, restaurants, cinemas, etc. The destinations have been grouped in different categories and subcategories. Every origin has a population and every destination has a capacity. The origins and destinations are connected by an origin-destination network. The urban human mobility is modeled on the network edges between different locations through flows and the epidemic spread is modeled locally at each location according to SIR model. Every day a certain number of people visit the destinations during specified time intervals and then return later on the same day and the epidemic spread at each location happens according to the SIR model [2]. The daily movements of people are captured through time dependent functions called demand gating profiles and supply gating functions which represent the demand and supply of each location on a given day of the week. Moreover, the mobility between origins and destinations can be controlled by tuning either the capacity of destinations or by tuning their opening and closing times. In this work, these controls have been applied according to the destinations categories. This model can take as input the simulation duration, gating profiles, capacity control and schedule control(enforced closing time) for different destination categories, initial infected cases, infection rate, recovery rate.

3.2 Optimization

The mobility can be controlled by tuning the capacities of different destinations using capacity control inputs on different categories. The GTL-Healthmob shows the optimal control policies for epidemic mitigation in Grenoble metropolis. The optimization problem which has been implemented in the interface is presented in [2] and an algorithm for solving it has been proposed in [3]. This optimization problem aims at maximizing the economy of a city by allowing as much people to visit different destination as possible while keeping the total infection below a bound, which reflects the hospitals bed capacity.

4 Model calibration and data

For the implementation and adaption of the mobility model to the Grenoble metropolis, we consider to have 55 communes, and have grouped the destinations into 5 categories and 15 subcategories. For the platform, several types of data are needed which are as follows:

1. Map of the *communes*.
2. Origin and destination nodes.
 - (i) Location
 - (ii) Population of origins and capacities of destinations.
3. Origin-Destination network.
4. For destination in each subcategory for each day of the week.
 - (i) Time schedules
 - (ii) Demand Gating Profiles for and Supply Gating Functions.
5. Average number of people visiting from an origin to a given destination.

The above-mentioned set of data is stored in Storage module which is imported by the Web Interface module for visualization of the nodes and the OD network and also for the simulation. A detailed description and methods to obtain these above mentioned datasets and construct the OD network using publicly available information have been presented in [1]. Some of the most prominent sources are Openstreetmap, INSEE, Academy Grenoble, data.gouv.fr, EMD travel surveys, etc. These methods have also been presented in [4].

5 User Interface

In this section we describe the interfaces and functionality of the web platform available to the general public. The welcome page of the GTL-Healthmob is shown in Figure 3. In the right panel, the map of Grenoble metropolis is shown with different buttons to visualise the network:

- **Borders** : It makes the border appear or disappear from the map.
- **Nodes** : A list of categories and subcategories appears. On selecting a category or a subcategory, the respective destination nodes are shown. When hovered over the nodes, their information pops up as in Figure 4. The 'aggregate' button aggregates the nodes in some subcategories which appear in italics. There are around 4000 destination nodes grouped in 5 categories and 15 subcategories but after aggregation, we have 374 destination nodes. For simulations, these aggregated nodes are used.

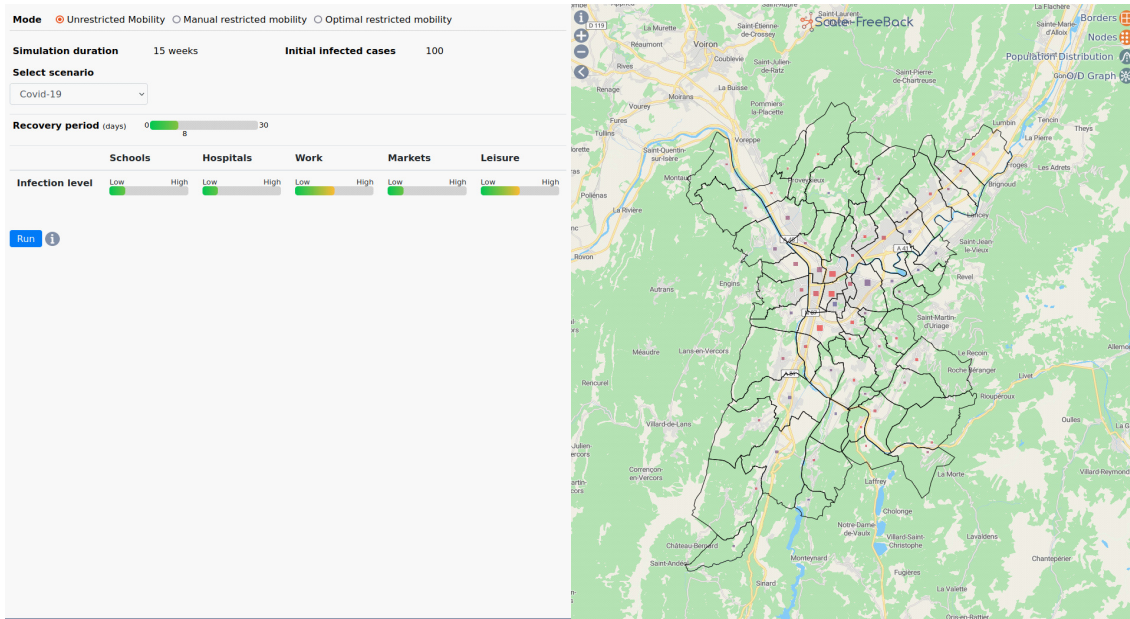


Figure 3: Welcome page of the GTL-Healthmob platform. In the left panel, there are different modes and parameters which an user can set to simulate different scenarios. In the right panel, users can visualise mobility-network related information and the heatmap animations for infection and mobility after the simulation.

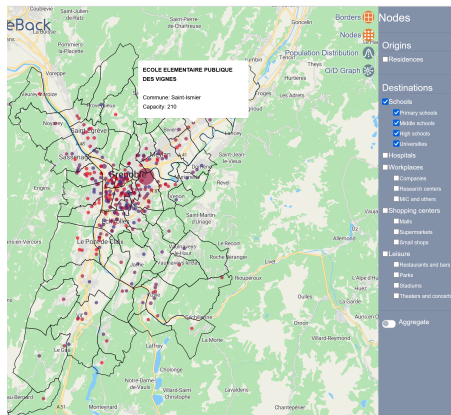


Figure 4: Node menu in GTL-Healthmob platform.

- **Population distribution** : Shows the population distribution using a heatmap when origine is selected and distribution of capacities when destination subcategory is selected. See Figure 5a.
- **O/D Graph** : Shows the OD connections between different origins and the aggregated destination nodes. Figure 5b shows the connections for schools.

In the left panel of the welcome page, the user has different options for simulations. The options are : 1. Unrestricted mobility, 2. Manual restricted mobility 3. Optimal restricted mobility. On running the simulations, the user can visualise the results with the help of plots and heatmap animations which will be discussed in upcoming sections.

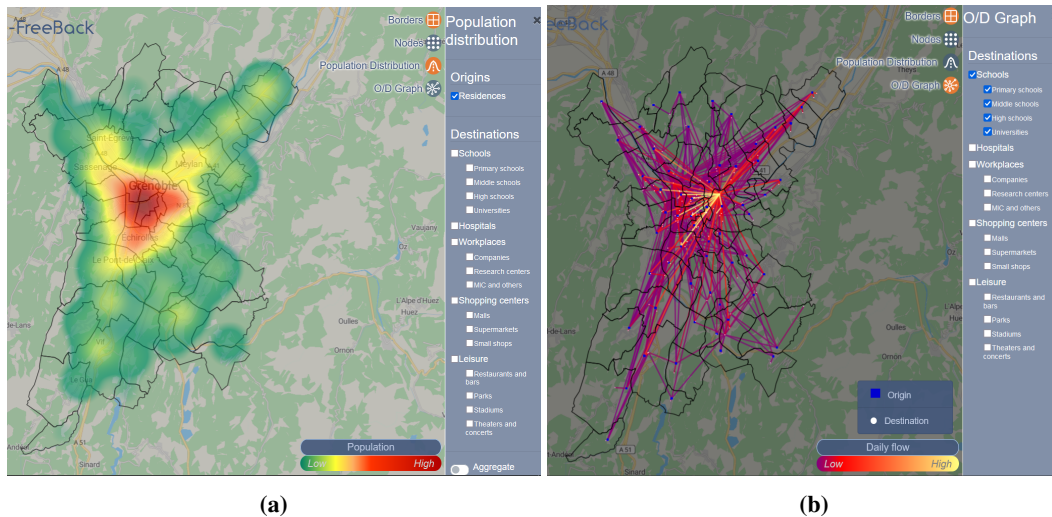


Figure 5: (a) Population distribution. (b) Mobility network for schools. Origins are denoted in blue color and the destination in white color. The color of the connecting edge ranges from magenta to yellow depending on the amount of average daily flow along them.

5.1 Unrestricted mobility

In this mode, user can visualise, how an epidemic, with different levels of infection rate and recovery rate, evolves in the Grenoble metropolis. The user has three epidemic scenarios to choose from. For all these scenarios, mobility is unrestricted but they differ in terms of infection level in various destination categories. The Parameters in the top left as can be seen in Figure 3 are:

- **Simulation duration:** The number of weeks the simulation runs. In this mode, it is fixed to be 15 weeks.
- **Initial infected cases :** The number of people initially infected.
- **Select scenario :** Choose the epidemic scenario. These scenarios mimic the behavior of different Covid-19 variants.
- **Recovery period :** This represents the number of days required for a person to recover if he is infected. It depends on the epidemic scenario.
- **Infection level :** This represents the rate at which an infected person might infect others. It ranges from low to high in different categories depending on the epidemic scenario.

5.1.1 Result visualization

When the run button is clicked, three plot visualization and animation of three heatmaps are shown. The simulation uses the discrete-time SIR-mobility model presented in [2]. In the left panel, user can see the following plots as can be seen in Figure 6.

- **Epidemic evolution :** Weekly average of proportion of infected people.
- **mobility :** Mobility patterns of people in each category for a week.
- **ICU bed occupancy :** Occupancy of the ICU beds in the hospitals of Grenoble metropolis.

Apart from the plots, user can choose to see the heatmap animations for mobility and infection evolution. For infections, heatmap is shown in absolute numbers and relative as well.

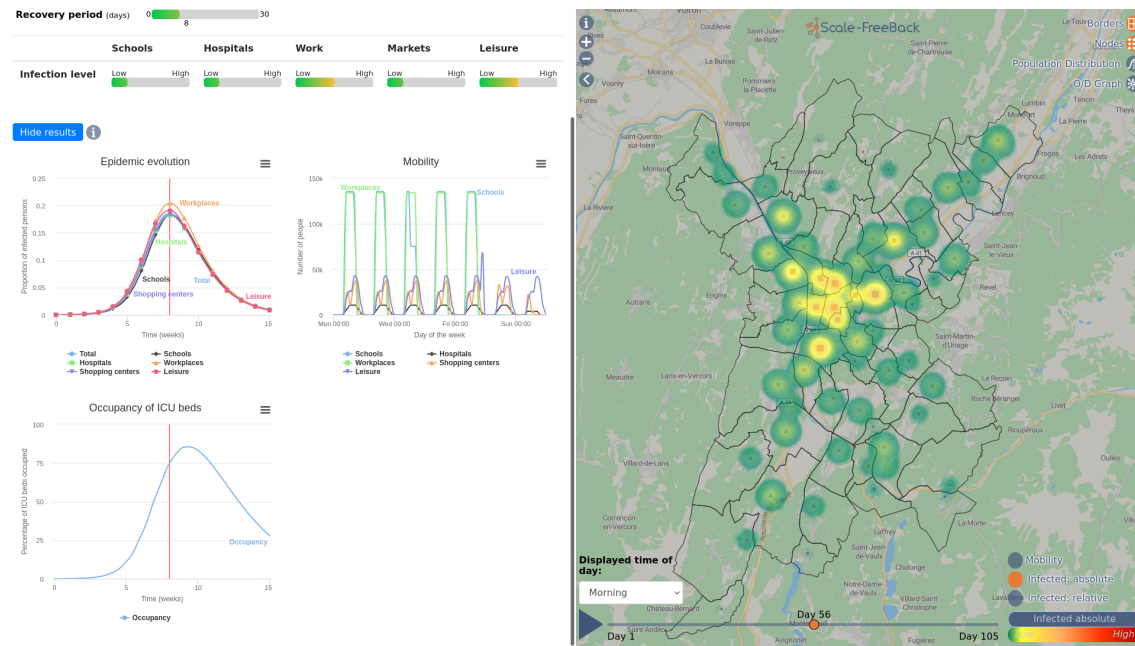


Figure 6: Unrestricted mobility: plots showing evolution of epidemic, mobility patterns and ICU occupancy and the right panel shows the heatmap for infection in absolute numbers at different locations on the day of infection peak during morning. Here, the selected scenario is similar to that of Covid19.

5.2 Manual restricted mobility:

In this mode, the user can choose to simulate mobility and epidemic scenario with parameters and controls of his choice. The parameters as can be seen in Figure 7 are:

- Simulation duration : The duration in weeks for which to run the simulation.
- Recovery period : Number of days, a person takes to recover after getting infected.
- Infection probability : The probability by which an infected person would infect a susceptible person.
- Initial infected cases : Initial number of infected persons.
- Allowed capacity : With its value in the interval $[0, 1]$ for each category, user can impose restriction on mobility by restricting the capacity of destinations in different categories.
- Closing hours : With their value in the range $[6, 24]$ for each destination category, user can simulate partial or full closure of the destinations by forcing them to close before the nominal closing hours.
- Contact rate : Average number of contacts people make in different categories.

5.2.1 Result visualization:

The results are visualised using the same plots and heatmaps described in Section 5.1.1. The simulation uses the discrete-time SIR-mobility model presented in [1]. Plots and heatmap can be seen in Figure 7 for a simulation done for 15 weeks, when schools are running at half their capacities.

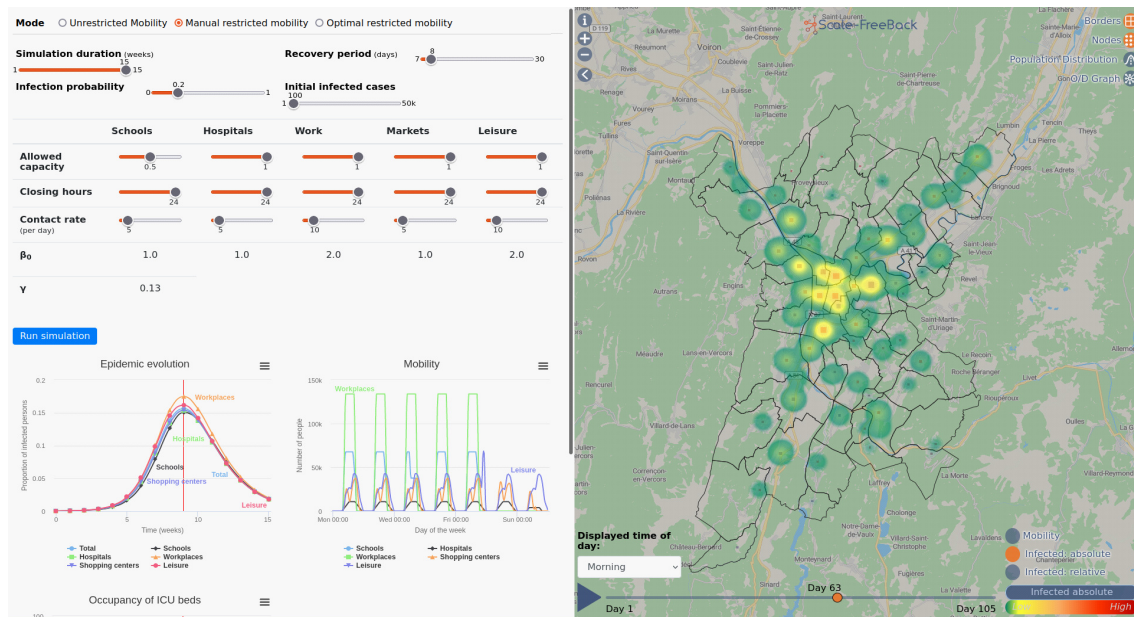


Figure 7: Interface with manual restricted mobility mode. Here, we can see different parameters and control which an user can select for a simulation. It shows the results of a simulation when Schools are running at half their capacities.

5.3 Optimal restricted mobility

This mode takes into account the implementation of the optimization problem presented in [2] to the Grenoble metropolis. Here, the user can visualise optimal mobility restriction policies by restricting the capacities of destinations depending on epidemic status during the simulation period. The parameters are simulation duration, initial infected, recovery period, infection level and infection threshold. Infection threshold is a bound on maximum infection during the epidemic. This threshold reflects the hospital bed capacity. The rest of the parameters have been explained in previous sections. In this mode, the user has two options in terms of how the capacity control policies are applied :

- **Category-free :** Here, the same capacity control is applied to all the destinations irrespective of the category while maximising the economy and keeping the infection below a threshold. It is given by the algorithm developed in [3].
- **Category-dependent :** Here, different capacity controls are applied to different the destinations in destination categories.

5.3.1 Result Visualization

The results are visualised through the following plots as shown in Figure 8:

- **Capacity control :** It shows the optimal capacity control inputs to be applied during different weeks for simulation to keep the infection in check and to protect the economy.
- **Infection evolution :** It shows the comparison between infections in uncontrolled case and the case when the optimal capacity control is applied.
- **Mobility :** It shows weekly mobility patterns. It is shown by an animation as the mobility pattern is subject to change with respect change in the capacity control.

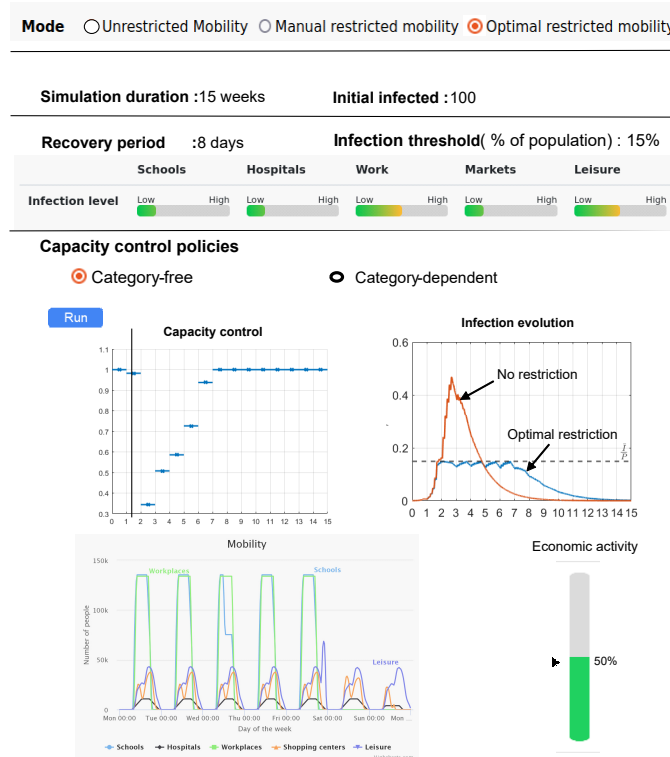


Figure 8: Left panel of the Web Interface, when the mode “optimal restricted mobility” is selected. It shows the results in terms of plots and bar for category-free capacity control policy in case when the simulation duration is 15 weeks and infection threshold is set to 15% of the total population.

- Economic activity : It is depicted by a bar, which shows, in terms of percentage, how much economic activity under optimal mobility restriction was done with respect to that in case of unrestricted mobility.
- The animation for heatmap for mobility, absolute infection, and relative infection is shown as in the previous cases.

6 Conclusion and perspective

In this paper, we presented the main framework of the GTL-Healthmob simulation platform and functionality of its different components. The main objective of this platform is to facilitate other users to simulate different scenarios of epidemic spread or mobility restrictions to visualise the mobility patterns and its effect on the epidemic spread in Grenoble metropolis. Using it, an user can also get an overview of the current situation during an epidemic. Moreover, the platform uses different visualization techniques to make even a layman user to understand the trends of the mobility patterns and epidemic spread. It can also serve as a testbench for validating upcoming results.

Since, this platform is still under development, more features and improvements will appear in coming days. Finally, one of the perspective is to extend the mobility model to analyze the spatial distribution of the energy consumption of vehicles in a city.

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