The October 2019 riots in Santiago, mathematical modeling and its relationship with public transportation

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Abstract

This work is about the social outbreak in Chile during October 2019 and the public transport network's influence on its formation and development. In particular, the riots that occurred in Santiago will be analyzed. Despite showing a typical temporal evolution of this type of situation, its spatial distribution is far from any report on riots in other locations, such as the racial riotsof the 1960s in the United States or the revolts in France in 2005. In addition, the efforts madeto reproduce, through numerical models, the behavior of the revolts in Santiago will be shown. These works indicate that the influence of the Santiago public transport system, especially the subway network, is vital to explain the distribution of disorders. Besides, there is a significant amount of evidence indicating that any model that intends to reproduce these disorders requires the implementation of a mechanism that allows large amounts of population to be transferred between different areas of the city.

Keywords| *social conflict, transportation models, networks*

1 Introduction

The social unrest of 2019 in Chile was a series of widespread protests that began on October 18, 2019. The demonstrations were triggered by a rise in the rates on the Santiago's subway, (Rojas & Acosta, 2020), but also to protest against inequality and social injustice, (Sehnbruch & Donoso, 2020). The signs of violence led to a number of government reforms, including an increase in minimum wages and improvements in the health system. The riots lasted for several months, continuing until April 2020. At its highest point, the protests gathered 1.2 million people in the center of Santiago, endorsing the largest mobilization in Chilean history, (La-Tercera, 2019). The economic cost of the explosion was estimated at about 4.6 billion US dollars, equivalent to 1.1% of Chile's gross domestic product, (Hribernik & Haynes, 2020). This figure includes the cost of lost business, private and public ownership and government spending on control and clean-up efforts.

The disturbances are characterized by a major wave of violence, which disrupts peace and results in the participation of a group of civilians. It is generally manifested as public devolution and destruction of private and public property, even leading to deaths due to violence. These ordersmay be triggered spontaneously, due to environmental conditions, or intentionally initiated as a political act or protest.

The first quantitative approaches to the problem, such as the work of (Spilerman, 1970), revealed that a widespread disorder depends on many factors, with poverty and social exclusion being the most important. The mathematical modelling of the problem begins with the pioneering work of (Burbeck et al., 1978) who, using an epidemiological model, were able to capture the temporary evolution of racial disorders experienced in the USA, during the 1960s. Later (Granovetter & Soong, 1983) introduced the revolutionary idea that potential participants in a disturbance make ananalysis of costs and benefits when deciding, in a rational way, whether to join or not. Subsequent formulations as (Epstein, 2002), which make use of Agent Based Models (ABM) were able to reproduce more detailed character isticas of the disturbances, such as periods of calm, followed by eruptions of violence, The effects of wealth distribution in the population on the intensity of disorders, by (Ormazábal et al., 2017), and the appearance of a phase transition between violent and political behaviour, (Goode & Pires, 2022; Ormazábal et al., 2022).

Later approaches to the same problem use partial differential equations, for example (T. P. Davies et al., 2013) succeeded in reproducing the space–time dynamic observed during the 2011 London riots. This result was obtained from a model that takes into consideration the costs and benefits of someone willing to join the riots, (Baudains et al., 2013). This mechanism is based on the way criminals decide to commit common crimes, (Bernasco & Nieuwbeerta, 2004; Clare et al., 2009; T. Davies & Marchione, 2015). Another model based on differential equations is the one developed by (Bonnasse-Gahot et al., 2018), used to reproduce the riots in France during 2005, using a non-local epidemiological model. This model successfully reproduced the contagious nature of the riots, (Petrovskii et al., 2020), and its spatial propagation in the city, forming travelling wave fronts, (Berestycki et al., 2015).

As a result of the riots that occurred in Chile during 2019, new works have appeared, which try to reproduce the activity of the desorption. For example (Caroca Soto et al., 2020) showed that the temporal behavior of the aggregate activity of the withdrawals produced in Chile during October 2019 follows the epidemiological model proposed by Burbeck. In order to reproduce at least some of the spatial characteristics of the riots (Cartes & Davies, 2021), they developed a formula incorporating a simple transport network over a prototypical pattern of a Latin American city, proposed by (Griffin & Ford, 1980). It is important to point out that the orders made in Santiago were accumulated around the subway stations, even though their distribution is linked to the income of the residents of the affected areas, as shown (Cartes et al., 2022). Later (Cartes, 2022)used geographic data of Santiago, concerning its population distribution and entry, in conjunction with the epidemiological form of Bonnasse-Gahot, to try to reproduceThe distribution of the time space of disturbances observed in that city. The author found that although the model managedto reproduce the temporal distribution of disturbances adequately, the epidemiological formulationfailed when it came to spatial distribution. The author concluded that to achieve the distribution observed in Santiago it was necessary to have a transport mechanism, which would be able to move the population within the city.

This work aims to describe the main characteristics of the riots that took place in Santiago during October 2019. Attempts to reproduce the spatial behavior of the disorders are also shown, using different numerical models. The first of these is the extension of the model for the 2011 London riots, carried out by (Cartes & Davies, 2021), this model seeks to reproduce the population flows that form between the residences of demonstrators and the places where they gather protests or looting, behaviour is controlled by an analysis of costs and benefits. While the second is an extension of the non-local epidemiological model of the 2005 French riots, carried out by (Cartes, 2022). This formulation is based on the Burbeck model which explains the formation of disturbances as the contagion of a pattern of behaviour. The proposed extension allows the spread of preferential addresses between different regions of a city, but does not allow the movement of population.

Finally, the strengths and weaknesses of both models will be analyzed, and possible strategies discussed in order to obtain results that better represent the observations made during the social outburst of October 2019.

2 Riot's empirical observations

In this section we review the main results of an analysis, carried out by (Cartes et al., 2022), corresponding to the first days of the riots, which occurred in Santiago in October 2019. The data used was provided by SOSAFE, which consists of an on-line platform that allows its users to report any event they consider relevant. The platform records the instant, position and geography of the event in question and a brief description of the event. The severity of the reported events is very wide, ranging from relatively harmless, such as temporary traffic disruption, to very serious ones, such as intentional fires in public and private infrastructure. The data in question are available in public form (SOSAFE, 2019). The surface analysed corresponds to the same area covered by the public transport system of Santiago. Specifically the area is limited by the parallels -33.32° and -33.67° latitude South and the meridians -70.49° and -70.87° longitude West.

The data showed that the temporal evolution of the disturbances follows approximately the dynamic described by the Burbeck model, as shown in Figure 1. The frequency of events shows an exponential growth, followed by a gradual When the maximum is reached. The activity is highest around 22h, while the minimum occurs around 8h.

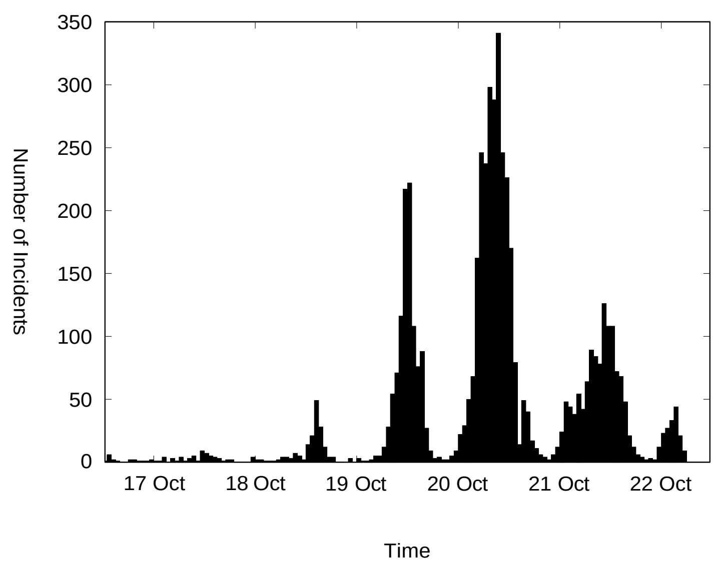

Figure 1: Temporary, hourly behavior of the events reported in Santiago during the first days of the riots in October 2019.

The spatial distribution shows a high concentration of events around the stations of the Santiago's subway. About 50% of events were reported at 1km or less from subway stations and 80% at 3km or less, as shown in Figure 2. In Figure 3, there 0 represents the places without disturbances where the value 1 is the maximum reported. This accumulation of activity, apart from subway stations, was significant in high and low income neighbourhoods. It is important to mention that this accumulation of activity in high income neighborhoods has not been reported before, all previous work always associates the disturbances with areas of the city with high poverty rates. In addition, the work of (Cartes et al., 2022) proposed a measure of structural accessibility, with the aim of quantifying the distance to reach the different areas of Santiago. This measure also found that the most accessible areas of the city were the most affected. The authors of the paper proposed the hypothesis, to be proved, that participants in the Santiago riots move within the city by means of public transport.

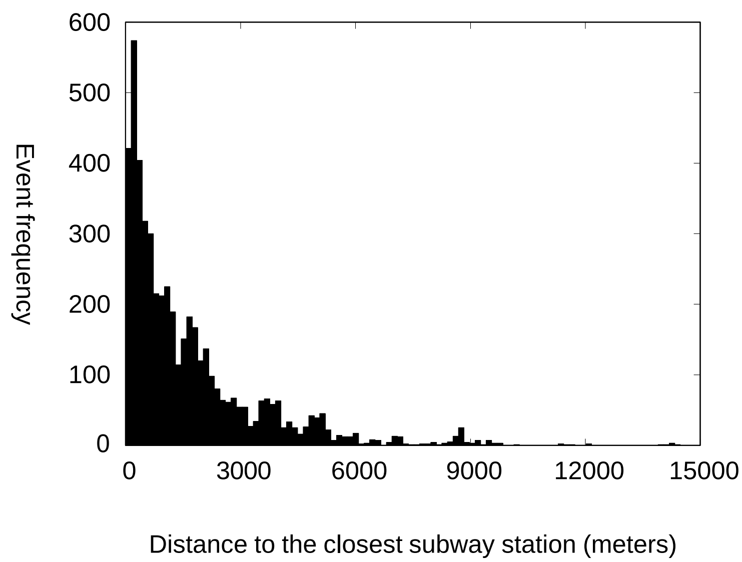

Figure 2: Histogram of the frequency of events, as function of the distance to the stations of the Santiago Metro.

3 Mathematical Models

3.1 Model for the London riots of 2011

This model was introduced by (T. P. Davies et al., 2013) in order to reproduce the spatio-temporal distribution of the London riots during 2011. The original formulation consists of two sets of locations: residential areas and riot targets. The model seeks to describe population flows between the dwellings of city dwellers and potential targets. The formulation consists of three stages for participants in the riots:

- The decision to participate in the riot.
- The choice of place to travel.
- Possible arrest by the police.

The first two stages depend on the attractiveness of the site in question. This attribute depends on an analysis of the costs and benefits of joining the riot. The benefits in this model depend on the

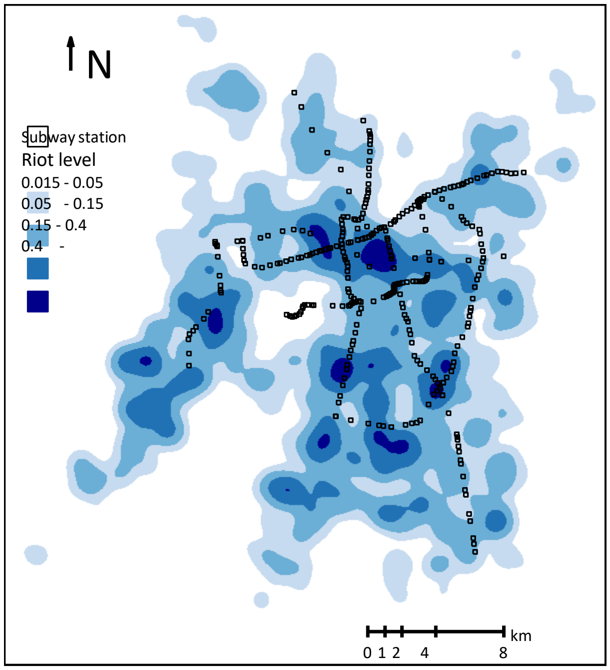

Figure 3: Normalized density of disturbances in Santiago, alongside Santiago's subway stations.

monetary gain from looting the site, while the costs correspond to the effort made to travel to the site and the probability of being arrested, (Wilson, 1971). The second cost is defined by the ratio between the number of demonstrators and police forces in the area attacked, the model stresses that for arrests to exist the number of police must be greater than the number of participants inthe riots, (Wilensky, 2004).

The decision to participate in a riot depends, in addition to the costs and benefits, on the poverty condition in which the population is located, (Baudains et al., 2013). On the other hand, the distribution of police forces is carried out by means of a survey of demand at each site. This amount depends on the location of the attack, the number of demonstrators and the number of order forces already present.

Finally, the arrests of demonstrators depend on the ratio between protesters and police forces in place. The smaller this quantity is, the greater the chance of capture.

The extension of the model by (Cartes & Davies, 2021) was the inclusion of transport networks. In the model, these consist of a change in effective distance, since the operation of a transport network effectively modifies the travel times. In this new formulation distances are calculated by means of a graph, which includes the transport network and the starting and destination positions. The shortest distances are calculated by using the algorithm A*, developed by (Hart et al., 1968). This formulation was applied to a prototype of a Latin American city, originally proposed by (Griffin & Ford, 1980) and then updated by (Ford, 1996). This pattern consists of a "spine" whichis where the high-income inhabitants live, this area is surrounded by three concentric regions wherethe infrastructure, public services and quality of life decline as we move away from the centre, a geographical representation is shown in Figure 4. Although the decline in population growth rates has alleviated many of the negative effects of this distribution, as shown (Borsdorf, 2003). The works from (Sabatini et al., 2001; Schteingart, 2001; Torres, 2001; Villaça, 1998) still report high levels of segregation in major Latin American cities. In the particular case of Santiago, the work on mobility (Dannemann et al., 2018), points out that most of the population is restricted to moving near their residence, being the only meeting point at the city centre.

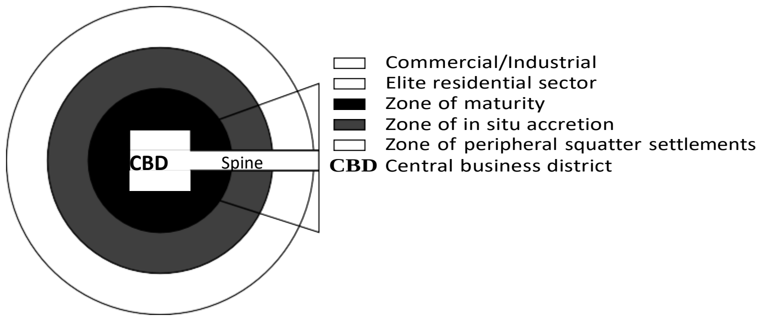

Figure 4: Prototype of a Latin American city, based on (Griffin & Ford, 1980).

This pattern is based on a very simple transport network, consisting of only 2 lines of nodes in a cross-shaped configuration, which connects the city centre with the periphery. The model results, in the presence of a functioning transport network, show high activity starting at the city centre, exactly at the point of intersection. This activity then expands into the periferic zones, forming traveling waves similar to those found by the works of (Berestycki et al., 2015; Berestycki et al., 2020; Bonnasse-Gahot et al., 2018). The distribution of activity is shown in Figures 5 and 6, whereit is possible to see the time-space evolution of the horizontal and vertical target distributions disturbances, respectively. In these figures the horizontal distribution coincides with the transport line which crosses the city from east to west, passing through its centre and entering the high-income residential area. While the vertical distribution coincides with the transport line that crosses the city from north to south, passing through its center. In these figures, the colour scale indicates the number of demonstrators, the positions are measured according to the grid elements (their scale is between 0 and 63) and the time scale is in arbitrary units.

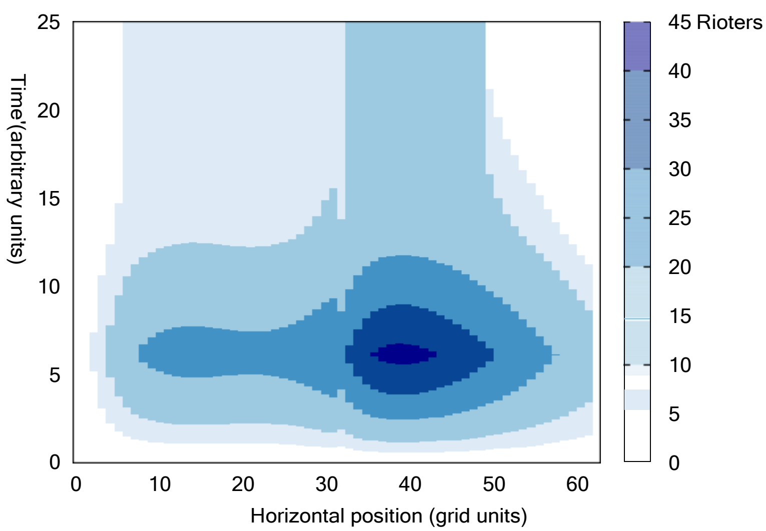

Figure 5: Horizontal distribution of the density of riots.

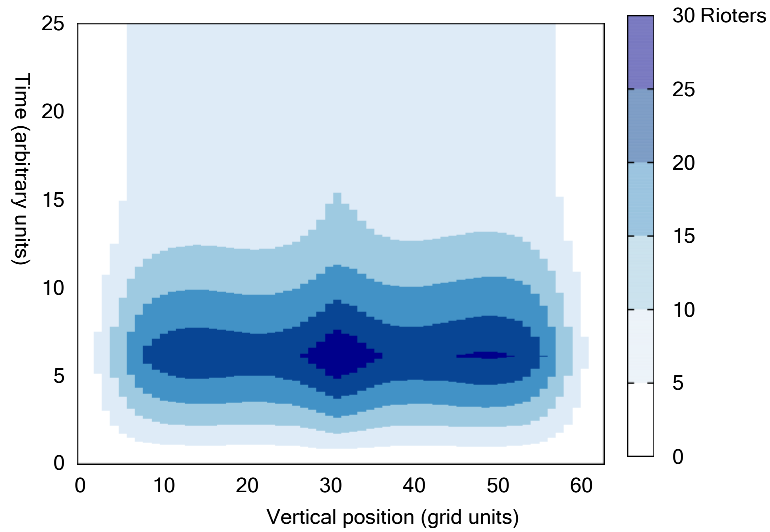

Figure 6: Vertical distribution of the density of riots.

This extremely simple model retains the characteristic attributes of the disorders of Santiago, during October 2019. This is a high concentration around the nodes of the transport network, being the closest located in the best connected area of the city.

Finally, it should be mentioned that where the transport network is not operational, the deployments are restricted to the poorer, more populated areas of the city. This less widespread geographical situation does not help to control the situation, on the contrary, the disorders are long-term, more intense and require a larger police force to be controlled. The work of (Cartes& Davies, 2021) concludes that, contrary to the intuition, the presence of a transport network helps to limit the time and control the situation more effectively. This is due to the reduction in participation of demonstrators, and also to the restriction on geographical extension, duration and number of police forces needed to control the disturbances.

3.2 Model for the French riots of 2005

This is an epidemiological model, based on the one proposed by (Burbeck et al., 1978), using a non-local extension carried out by (Bonnasse-Gahot et al., 2018), which allows to explain the space–time distribution of the disorders in France during 2005. This formulation is based on the fact that each city region has a certain number of demonstrators denoted by λ, also from a reserve of individuals willing to join a demonstration, designated by σ. These amounts depend on the retirement rate ω and the transmission Φ which is a function of the activity present in the surrounding areas, therefore it is a non-local term. The system of equations determining the riot evolution for site k is then

$$\frac{d\lambda_k}{dt} = -\omega_k\lambda_k + \sigma_k\Phi[\Lambda_k] \tag{1}$$

$$\frac{d\sigma_k}{dt} = -\sigma_k\Phi[\Lambda_k] .$$

The work from (Cartes, 2022) proposes to use this model in order to reproduce the spatial distributions of the Santiago riots during October 2019. For this purpose uses the geographical data of Santiago, together with the subway network and applies the equations (1). The author notes that the inclusion of the transport network only modifies the non-local coupling $\Phi\,[\Lambda_k]$, thatis how the distances between the sites are measured. These distances were calculated on a graph, bylooking for the shortest path, using the A^* algorithm formulated by (Hart et al., 1968). The author justifies including only the metro network in the model, instead of the complete transport network,on the premise that most of the disturbances were recorded near the metro stations. In addition, restricting the transport network makes the implementation of a model more straightforward. Sincethe model requires some initial activity to trigger disturbances, the author chooses to take the 20 locations that showed the greatest activity as a source.

The results of the temporal evolution of the number of demonstrators, which is a product of the simulation, can be seen in Figure 7. The results show a good agreement with the data in Figure 1 and the Burbeck model, as shown in the work of (Caroca Soto et al., 2020). The different fractions of the subway lines also indicate that while there is a mutual influence between the different areas ofthe city, the maximum intensity of the disturbances is greater, making them more destructive. On the other hand, the same transport network accelerates the temporal evolution of the disturbance, even though the activity lasts less time. Then the transport network has as a net effect the counter intuitive result of making the disorders easier to control, as shown by the work of (Cartes & Davies, 2021).

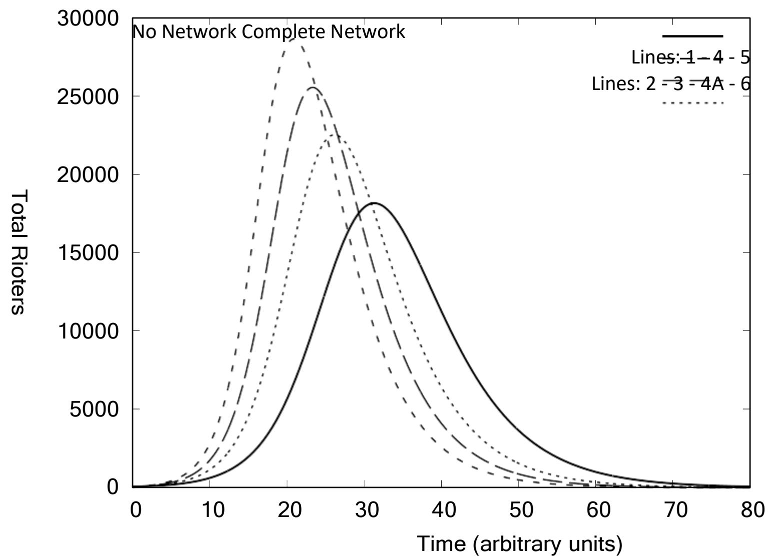

Figure 7: Temporary evolution of the number of demonstrators, using different fractions of the Santiago's subway network. Complete network means the seven lines (1, 2 , 3, 4, 4A, 5 and 6).

The spatial distribution of disturbances is shown in Figure 8. It is evident from comparing these results with the observations shown in Figure 3, that the model fails to reproduce the data. The author acknowledges that the areas with the highest simulation activity are those which have the highest population density and lowest income of the city. These results are maintained even when the transport network is not present, or even when the influence of poverty is removed, making the total population equally susceptible to participation in disturbances.

The failure of this model is attributed to the lack of a population transport mechanism. This

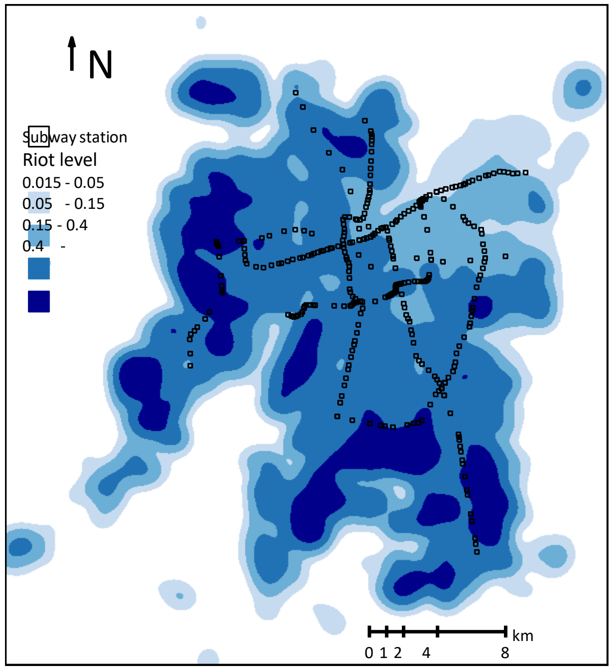

Figure 8: Spatial distribution of disturbances, obtained by simulation of a number of events,including the influence of the subway network.

seems to be vital in explaining the disorders observed at Santiago and is mentioned by the works of (Cartes et al., 2022; Cartes & Davies, 2021). This need to move the population around the city is what distinguishes the riots in Santiago from any other quantitative report on this activity.

The model also shows a high sensitivity to population density and a relative indifference to income of inhabitants or the transport network, Since the spatial distributions of the disturbances were almost identical in cases with and without the influence of the subway network, their only effect is relevant to the temporal evolution of the disturbances.

4 Conclusions

This paper analyses the riots that occurred in Santiago during October 2019. These were characterized by an unusual accumulation of activity around Santiago's subway, several of the most affected regions in the city are high-income areas. These are the only statistics of the Santiago riots, so far any other quantitative report always reports that most activity is restricted to poorer areas of the cities.

As for the results of numerical simulations, although they do not always give results close to observations and that, at present, the model which is adapted to reality does not have the geographical information incorporated in its formulation. One thing that these results make clear is that any model which seeks to reproduce the spatial distribution of the disturbances observed in Santiago, necessarily needs to incorporate a transport mechanism, capable of moving large amounts of population between different areas of the city. This mechanism, apparently, is not only relevant to the Chilean case, as the observed distribution shares several characteristics with the "Gillets

Jaunes" riots in several French cities during 2018, as reported by (Boyer et al., 2020).

The epidemiological model as proposed has the problem of not allowing movement the population between the different areas of the city, only allows for mutual influence. Thus the inclusion of the complete transport network will probably result in a poor quality of service, as shown in Figure 7, but as indicated by the results of (Cartes, 2022), there is no indication that the spatial distribution of the disturbances will be significantly modified by extending the transport network.

The natural continuation of these works will be to occupy the extension developed by (Cartes & Davies, 2021), this time using geographic data from Santiago. Because it is the formulation that, so far, delivers the best results.

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