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Diffusion of influenza during the winter of 1889-1890 in Switzerland

1. INTRODUCTION

The influenza of the winter of 1889-1890, sometimes called the Russian influenza, was one of the first epidemics for which the spread was followed all over the world (Parsons, 1891a; Burnett and Clark, 1942; Pyle, 1986; Valleron *et al*., 2010). Its origin has been localized in Siberia in May 1889, and it diffused first during the summer to some populations of Northern Canada and Greenland. The primary path of diffusion during the winter of 1889-90 was, however, via Russia; Tomsk in Siberia was reached at the beginning of October and Saint-Petersburg at the end of that month (Clemow and Edin, 1894). From Russia, the epidemic reached Paris at the beginning of November and diffused quickly in France (Bertillon, 1892). Berlin and Vienna were reached at the end of November and London at the end of December. At the same time, the eastern part of North America was touched. San Francisco, Mexico and Guatemala were hit in January 1890, as were Egypt, Palestine, and Persia. South American countries on one side and India on the other were affected between February and April. The epidemic spread into Australia and New Zealand between March and May 1890 (Burnett and Clark, 1942).

This pandemic was characterized by a low mortality rate and a high morbidity rate, except in some places like Sheffield, England where the mortality rate was also high (Honigsbaum, 2010). For Valleron *et al*. (2010), this influenza looked like most of the pandemics of the 20th century, especially those of 1957 and 1968. In the history of influenza, this epidemic definitively marks the transition in the medical milieu, especially in Anglo-Saxon countries, from the paradigm of a spread due to a bad atmosphere or a bad air (the miasmatic theory) of the disease to the paradigm of the transmission by close contact of an affected human with a non-affected person (Pyle, 1986). Several reasons can be proposed for this transition in the perception of the influenza by physicians. First, influenza was not considered an important disease before 1889. The last big epidemic occurred in Europe in 1847, and new generations of physicians were not prepared for an explosion of this disease. Until the Russian epidemic, influenza was often considered a benign seasonal disease related to the weather. Furthermore, physicians and hygienists were more focused on

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cholera, a disease that periodically occurred in all countries of Europe and provoked many deaths (Bourdelais and Dodin, 1987). Koch recently isolated the infectious agent of cholera in 1884 and subsequent discoveries in microbiology allowed for the creation of vaccines. A bacillus was similarly suspected by Pfeiffer in 1892 to be the infectious agent of influenza (Pyle, 1987)[1]. A lot of papers published just after the occurrence of the influenza are ambiguous in their explanations of the epidemic, shifting between the miasmatic and the contagious theory. For example, in his paper on the epidemic in France, Bertillon (1892) quotes a physician who pointed out that the barometer was always decreasing, such an interest for meteorology being typical of a miasmatic approach. However, several British physicians, especially Parsons in several papers and reports (Parsons 1891a, 1891b, 1893), claimed that influenza was a contagious disease. A lot of practitioners observed that the individuals who first became ill in an area were travellers who had arrived or came back recently from a place already infected (Sisley and Lond, 1891). A relationship was established between the geographical spread of the epidemic and transportation networks. Lines of transport, especially railway networks and marine ship lines, and their flows of passengers were considered vectors of propagation. A reconstitution of the diffusion of the influenza in Siberia showed that it spread along railways (Clemow and Edin, 1894). It was in favour of the theory of contagion that the speed of its diffusion along railways between Siberian and Russian cities was not higher than the speed of trains.

Such an interest about the diffusion of the Russian influenza along the railways was shared by several authors in Europe: not only Parsons in Great Britain, but also Linroth in Sweden (Parsons, 1891a, 1891b; Linroth, 1890, quoted by Skog *et al*., 2008). In Switzerland, this hypothesis was defended by Schmid (1850-1916), Chief of the Swiss Office of Health, in a report of more than 250 pages which was simultaneously published in German as a book and in the *Journal de Statistique Suisse*[2] in 1895 (Schmid, 1895). This report was written on the basis of a questionnaire sent to Swiss physicians, in which they were asked questions about the date of appearance of the influenza in the place they had their office and the period during which they had to treat ill persons. Physicians were also asked to express their observations about symptoms as well as about the propagation. Some of them transmitted detailed data about the transmission of the influenza in households, schools and even in some firms. Furthermore, Schmid also directly contacted some institutions, like railway companies or the postal administration, in order to collect data on absen-

[1] However, the virus of influenza was isolated only in the 1930s.
[2] This review is the ancestor of the actual Swiss Review of Statistics and Economy. Note that a preliminary report was published in the Swiss statistical yearbook (*Annuaire de la statistique Suisse*) in 1893 (Schmid 1893).

teeism in their offices during the months of the epidemic. In addition to the analysis of the diffusion process, in his report, Schmid also developed an analysis of the impact of the disease on the mortality as well as analyses of other influenza epidemics of the winters from 1890 to 1894, which were much weaker.

The Russian influenza appeared in Switzerland in a context in which the spatial structure was radically changing because of the development of new communication lines, especially the railway network. One of the consequences of the development of the railway since 1840 (Bauer, 1949) was to organize Swiss communities (towns and villages) into two levels. The first level was composed of communities interconnected with the railway, while the second level grouped communities subordinated to those of the first level. Schmid (1895) developed the hypothesis that influenza diffused first along the railway network and second from communities with a station to communities without. One can note that the epidemic of the winter of 1889-1890 happened in a context of the industrialization and urbanization of Switzerland. A lot of young people migrated from the countryside to a city, but preserved links with their family of origin. Schmid (1895) mentions several cases in which young workers were reached by the influenza at their place of work and who, obligated to take time off, went back to their family, to which they then transmitted the illness. With the modernization of transportation, travel by diseased persons fuelled the contagion.

In this paper, our goals are to refine Schmid's hypothesis and to test it with contemporary statistical techniques, especially the technique of event history analysis developed for the purpose of diffusion analysis (Strang, 1991; Strang and Tuma, 1993). The second section of this paper develops the hypothesis of the links between the epidemic and the railway. The third section presents data about the railway network when the influenza reached Switzerland in November 1889 and data collected by Schmid about the diffusion of the epidemic. The fourth section includes a model of event history analysis to be estimated for the analysis of the diffusion of influenza in Switzerland, while the fifth and sixth sections are devoted to results of the estimations from these models and conclusions.

2. SPATIAL STRUCTURE OF DIFFUSION

Literature on spatial diffusion of an epidemic, and more generally, of an innovation, a rumour, and even a social group, etc. shows that spatial context plays an important role on diffusion pattern (Cliff *et al.*, 1981; Cliff *et al.*, 1986; Hägerstrand, 1967). Kuo and Fukui (2007) use the term geographical structure to point out patterns of interaction between environment and humans in a local area. From a social sciences perspective, Strang (1991) uses the more general term of social structure that he defines as channels of connection between actors. A process of diffusion occurs in the function of the structure of one or several channels.

Pioneering studies of Hägerstrand (1967) on spatial diffusion of innovations like the automobile or agricultural techniques insist on processes that spread like wildfire. In these cases, channels of diffusion are composed of interconnected neighbours. In demography, Bocquet-Appel and Jakobi (1997) show that fertility transition, i.e., adoption of contraceptive behaviours in order to limit births, followed this pattern of diffusion in Great Britain during the 19th century. Other patterns of spatial diffusion, however, have been observed. For example, Bocquet-Appel *et al*. (2002) show that the fertility transition in India during the second half of the 20th century followed another pattern than the one observed in Great Britain. The diffusion can be here described by a parallel decrease in fertility in several big cities, this decline propagating after a decrease in surrounding areas. Such a pattern indicates a spatial structure hierarchized between urban and rural areas. This pattern of diffusion has also been observed in the cases of spatial diffusion of influenza by Cliff *et al*. (1986). The authors designate this pattern of diffusion as a mixed pattern of diffusion, which means that the spread follows a vertical or hierarchical pattern of diffusion and a horizontal pattern of diffusion, from neighbourhood to neighbourhood (Bocquet-Appel *et al*., 2002; Cliff *et al*., 1981).

However, the process of diffusion also depends on the properties of the object that diffuses. If this object is a contagious disease, the diffusion depends on the quantity of contacts between persons, while it depends more on the quality of contacts in the case of the diffusion of an innovation. In the case of an idea, a rumour or an innovation, the diffusion occurs by mechanisms of persuasion, imitation, social learning or social influence, etc. (Montgomery and Casterline, 1996; Bongaarts and Cott Watkins, 1996). Today, there is no longer the necessity of closed contacts between transmitters and receptors (Strang, 1991). Networks of communication, like the media, telephones, and Internet networks are the main channels of diffusion. In case of illness transmitted by an infectious agent, networks of transportation play a major role. Each kind of network links together an infected person to a non-infected individual by the intermediary of an infectious agent. The contact created by the infected agent can be indirect if the infectious agent is accommodated by one or several hosts or if it is transported by water. Morris (1993) notes, for example, that the great plague of the Middle Ages quickly diffused along the lines of communication and transport of the epoch. Transmission of the influenza virus differs in the sense that it necessitates a strong proximity between affected and non-affected persons. This implies that influenza diffuses in channels in which persons are in close proximity (Cliff *et al*., 1986; Pyle, 1986). However, even in this case, networks of transport play a role in the diffusion within a territory. One example is the influence of the creation of the domestic flight network between Reykjavik and other cities in Iceland after the Second World War on the diffusion pattern of influenza. Before the creation of these lines, diffusion was rather horizontal, linked to connections in the network of coastal navigation. The pattern became more representative of a mixed model of diffusion, with the influenza spreading from Reykjavik to the cities connected through air services and from each of these cities to their surrounding regions. Change in the mode of diffusion in Iceland reflects the evolution of person flows between communities or cities.

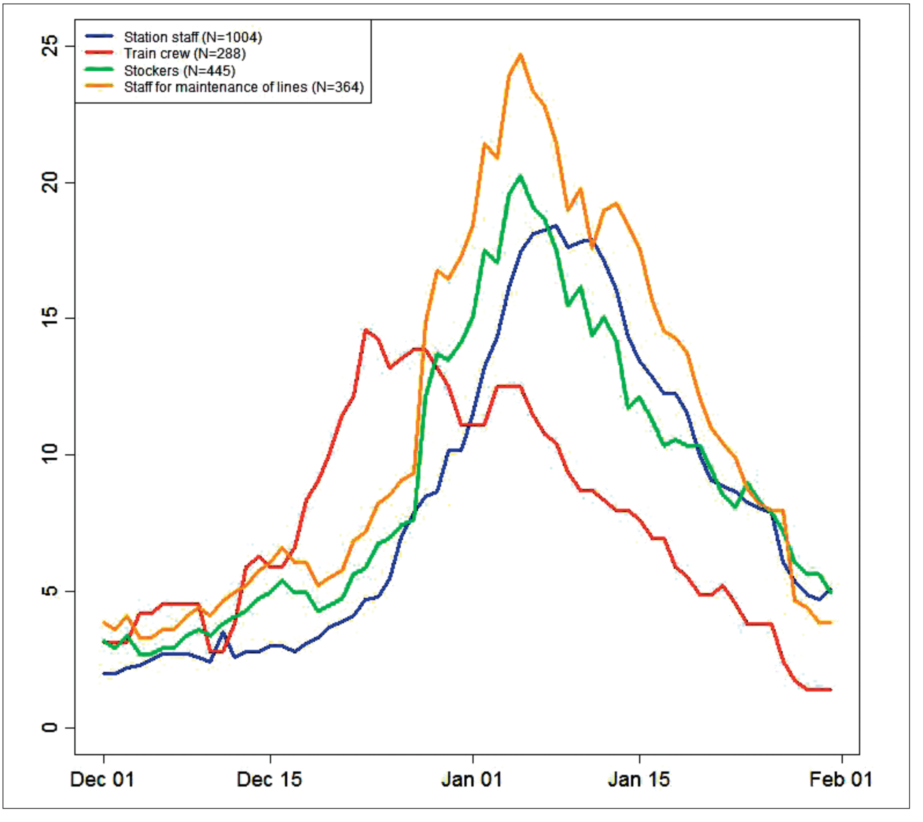
Of the data collected by Schmid on the influenza of 1889-1890, those about the relation between the influenza and railway are particularly interesting. His main hypothesis was that trains transported infected travellers and that railway employees who had contact with travellers were, among all employees, infected first. The author then asked Swiss railway companies about the propagation of the disease in their workforce. Figure 1 shows the absenteeism rate at the *Nordostbahn* Company each day between December 1, 1889 and January 31, 1890. This company was the most important railway company at the end of the 19th century in Switzerland. This figure indicates that the disease first reached the train crew (i.e., ticket collectors). If the peak of absenteeism was higher in the case of other categories of personnel (stokers, station staff and staff for maintenance of lines), it occurred later than in the case of the train crew. Statistics collected by Schmid (1895) for other companies showed similar results. As the train crew was personnel directly in contact with passengers, results thus argued for the diffusion agent theory rather than for the miasmatic theory of propagation of the disease. The latter theory would indeed have been supported if employees that were the more exposed to climactic variations, for example, those affected by the maintenance of lines, had become ill first[3].

In his desire to prove the contagiousness property of the influenza, Schmid (1895) quotes a comment made by the chief physician of the sanitary service of the canton of Vaud, who indicated (p. 524[4]):

The epidemic germ seems to have been generally brought by railway workers and travellers (Ste-Croix, Echallens, Nyon, Payerne, Aubonne). In Cossonay, the houses reached first are those at the neighbourhood of the rail station. Influenza generally transmitted by direct contagion. It raged along communication lines. It generally radiated in each district from a populous central point into neighbouring localities.

[3] Similar comments were pointed out by Parsons (1891a) in the context of Great Britain.
[4] Originally in French in the text and translated by us.

Figure 1 – *Absenteeism according to the workforce composition in the Nordostbahn railway company from December 1st 1889 to January 31st 1890*

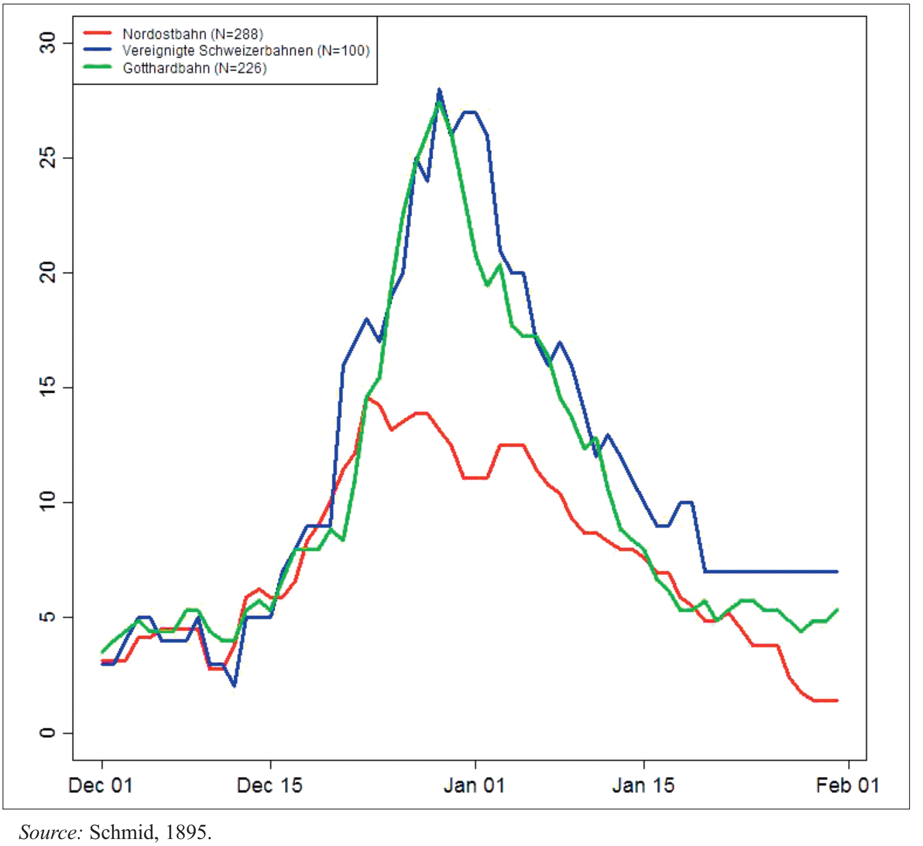


Source: Schmid, 1895.

Such a description strongly corresponds to the mixed model of spatial diffusion, in which the railway disseminates influenza throughout the country. However, this mixed model means also that the territory of Switzerland is organized into two strata. The first strata groups communities with a train station and potentially other places in Switzerland connected with the railway, while the second strata groups communities without stations and subordinated to communities of the first strata. For Schmid (1895), influenza diffused first between cities served by a railway connection and second from these cities to surrounding cities without stations via a process of horizontal diffusion.

With this hypothesis in mind, this paper seeks to analyse the diffusion of the influenza by dividing the Swiss territory into two parts: 1) a network of "central" communes interconnected with the railway and 2) a group of non-interconnected "peripheral" communes linked to a central commune. However, the paper examines this hypothesis in more depth. At the time of the spread of the influenza, the overall railway network was shared by five big companies that operated in different regions of Switzerland. Very few communes were served by two or more companies, which meant that possibilities of connections between these companies were rare. A comparison of the absenteeism in the train crew in three of these companies (the *Vereignigte Schweizerbahnen*, the *Gotthardbahn* and the *Nordostbahn*) for which Schmid collected data show that the peak did not occur at the same time (Figure 2). In the *Vereignigte Schweizerbahnen* and in the *Gotthardbahn*, the disease's peak occurred during the last days of December, while it occurred on the 22nd of December in the case of the *Nordostbahn*. We can then expect that the pattern of diffusion of the influenza within the Swiss territory was also driven by the geographical structure drawn by the network operated by each railway company.

Figure 2 – *Absenteeism from the train crew workforce according to the railway company from December 1st 1889 to January 31st 1890*



Source: Schmid, 1895.

3. DATA

Data used in this paper came from two main sources. The first source is comprised of data collected by Schmid on the spatial diffusion of the influenza. The second source is about the railway network at the beginning of the 1890s. This second source, the structure of the Swiss territory, will be described before the geographic pattern of diffusion of the influenza within the territory.

3.1 The railway network in Switzerland

The first railway line in Switzerland was inaugurated between Zürich and Baden in 1847, a little later than in other European countries (Bauer, 1949). The railway network extended very quickly during the second half of the 19th century. Switzerland is a very mountainous region with the Alps in the South and the Jura in the North. Between these two mountain ranges lies a kind of plateau from Lake Geneva to Lake Constance. Before the development of the railway, these natural barriers structured the movements in the East and the West, while the more mountainous regions were very isolated. The railway partially disrupted this initial structure of displacements. Swiss engineers developed different techniques to build up mountain lines. Moreover, different tunnels were dug. The Gothard tunnel which connects the Italian-speaking part of Switzerland to Zürich (and by extension, Germany with Italy) was opened in 1882 (Duc, 2010). However, during the winter of 1889-90, the Simplon tunnel connecting the French-speaking part of Switzerland and France with Italy was not yet open[5].

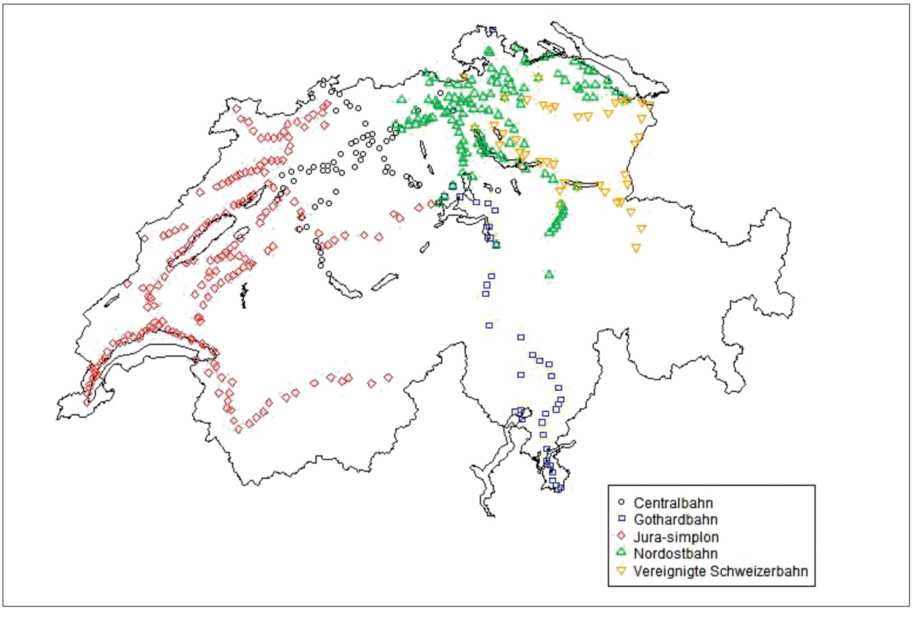
When the Russian influenza reached Switzerland, railways were shared by five big companies, the *Centralbahn*, the *Gotthardbahn*, the *Compagnie du Jura-Simplon*, the *Nordostbahn* and the *Vereignigte Schweizerbahnen*. In addition to these big companies, there were a lot of little companies that supervised one or two smaller lines, often mountain lines. Many of these companies were merged at the beginning of the 20th century. In the absence of road infrastructure, the railway in 1890 was the only important transport network in Switzerland. At that time, it consisted of nearly 3,100 km of railway track and was used by 30 million passengers (BFS, 1914).

This paper only takes into account the network of the five biggest companies and does not consider the lines of the smaller companies. The statistical yearbook of 1895 contains a very detailed document on the entire railway network (BFS, 1895). It indicated the communities on each line in which there was a rail station (Figure 3). Most of the stations of these big companies were in the least mountainous regions. The average altitude of cities served by one of these

[5] It was opened only in 1907.

five companies was 487 meters, while the mean for the overall 3,000 communities of Switzerland was 633 meters[6]. Note that very few cities were served by several companies (Zürich, Bern…).

Figure 3 – *Stations of the five principal railway companies in 1895*



Source: Swiss statistical yearbook, 1895.

3.2 The spatial diffusion of the influenza in Switzerland

Data about the diffusion of the influenza come from one of the tables published by Schmid on the period of epidemics in communities, based on physicians' responses to his questionnaire. The questionnaire was addressed to all physicians in Switzerland (around 1,500) at the beginning of February 1890. The survey was solicited by the Federal Council. The aim of this survey was to count persons reached by influenza in each commune according to their age, to count the number of deaths due to influenza and other causes during the period, and to collect dates of the beginning and the end of the epidemic in a commune as well as the date of the peak of the disease. The questionnaire was also designed to analyse the progress of the epidemic in closed or semi-closed institutions such

[6] A t-test in which we suppose that the average altitude of communes deserved by a train-station correspond to the average observed in overall communes (null hypothesis) is rejected at the level of 5%.

as jails, asylums, caserns or schools. Open-ended questions were also asked in the questionnaire, reserved primarily for observations and remarks by physicians on aetiology, incubation, immunity, etc. According to Smith, about 50% of all physicians responded. One possible reason for the 50% non-response rate was an aversion to the theory of contagion among many physicians. However, in contradiction to this hypothesis, Schmid transcribed several meteorological observations made by surveyed physicians[7], which suggests that physicians believing in the miasmatic theory answered the questionnaire as well as those who believed in the theory of an agent of diffusion. In some rare cases, like in the canton of Neuchâtel, answers were given by a cantonal commission of physicians. The table published by Schmid indicates for each commune the date of the first known case, the date of the peak of the epidemic and the date of the last case observed. Exact dates should be interpreted with caution. In many cases, the week of the appearance of the disease is more definitive. In addition to these date in the table, the number of physicians practicing in a commune and the number of those that answered the questionnaire were also included. Physicians' estimation of the prevalence of the disease is also indicated, but this estimation seems to be very unreliable.

We have reliable information on the diffusion of the influenza in only 611 communities out of almost 3,000. Missing information occurs in several communities in which no physician answered or in which there was no physician[8]. The map of communities in which the epidemic was observed shows some white spots, for example, in the cantons of Valais, Fribourg, Solothurn, or Grisons, for which Schmid collected very little information (Figure 4). These regions often belonged to the most mountainous and isolated area of Switzerland. It is possible that some of these regions were not reached by the epidemic. A study in the Swiss mountainous region of Switzerland, conducted by Seitz, which aimed to show the contagious character of the illness through close contact between persons indicates, however, that it was rare to find places not reached by the influenza even in montainous regions (Seitz, 1891, quoted by Reuss, 1893).

However, this reason cannot be invoked in the case of the canton of Fribourg, since this canton is largely situated on the plateau. The lack of reliable information for this canton, which is on the border of the French- and the German-speaking areas of Switzerland, prevents us from analysing the diffusion of the epidemic between the two linguistic regions.

[7] With aims that were often contradictory.

[8] In some cases, however, information was given by a physician living in a neighbouring commune.

Maps show the progression of the influenza virus within the Swiss territory from different sources of infection (Figure 4). The canton of Neuchâtel was the first canton reached, just before the middle of November 1889. Schmid did not give information about the origin of its arrival. At this time, the influenza was not very widespread in Europe. It raged in St. Petersburg, while Paris had just being reached. Since the *département* of Doubs in France, which juxtaposes the canton of Neuchatel, was not yet reached when the epidemic started in the canton of Neuchâtel, we suspect that the arrival of the influenza in this canton is due to one or a few travellers coming from Russia or from Paris. Epidemics diffused quickly in the canton before reaching the neighbouring cantons of the French-speaking area of Switzerland (Vaud and Geneva) and the French-speaking part of the Bern canton. Communities from the canton of Valais (in the southwest of Switzerland), which is very mountainous and for which Schmid did not have a lot of information, were reached later. In the German-speaking area of Switzerland, three sources of epidemics started near the end of November, one in Thurgovia, the second in Zurich, which quickly spread into the centre of Switzerland, and the third in the canton of Grisons, in the south east of the country. In the case of the first two sources, Schmid does not specify whether the start of the epidemic was due to travellers coming from the French-speaking part of Switzerland or

Figure 4 – *Diffusion of influenza in Swiss communes*

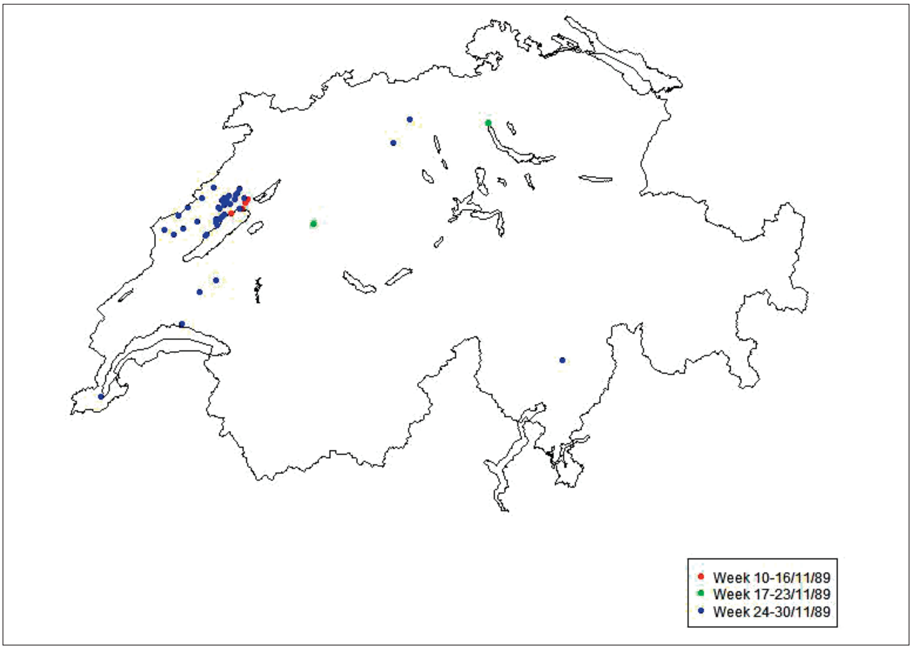


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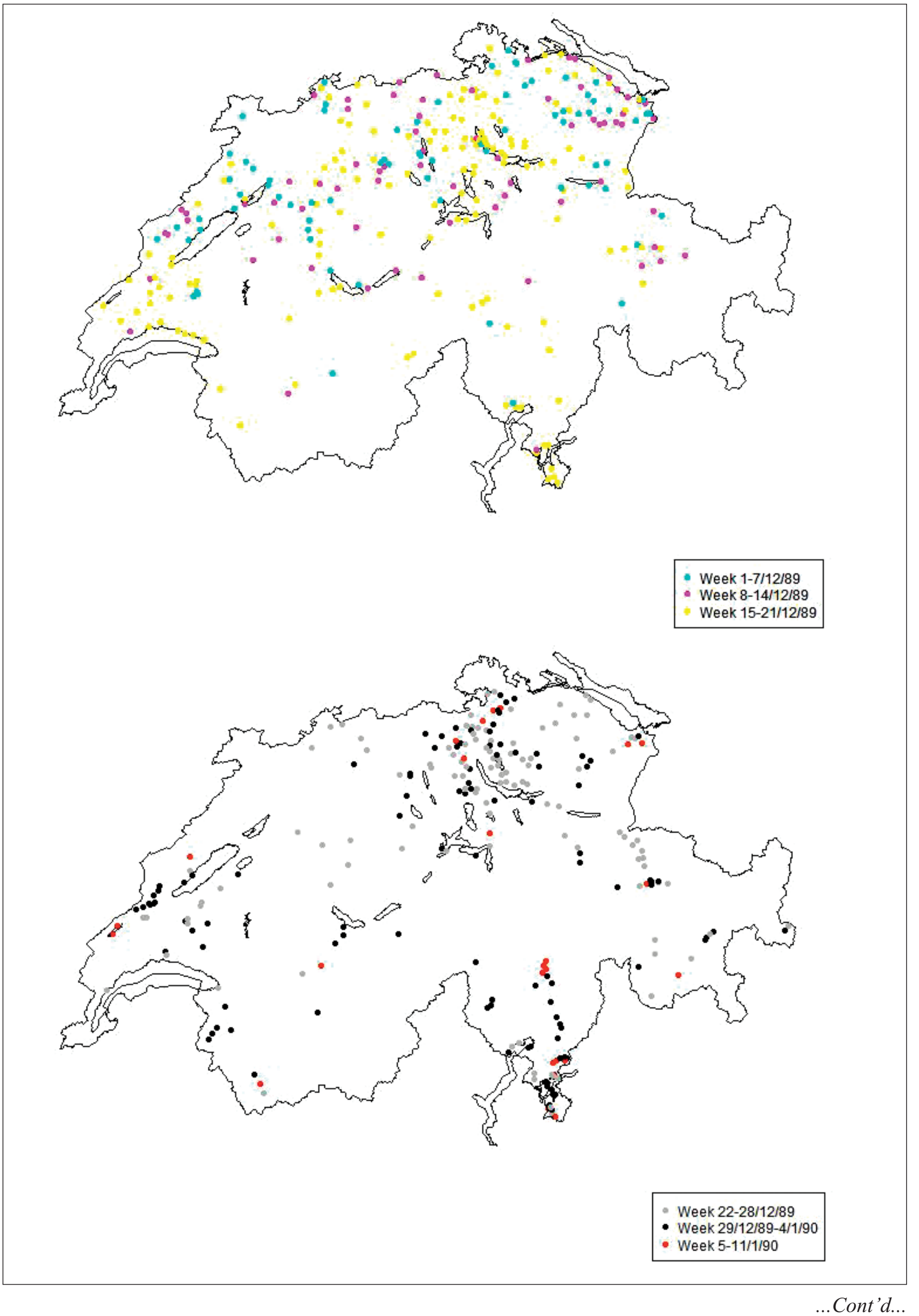
Figure 4 – *Cont'd*



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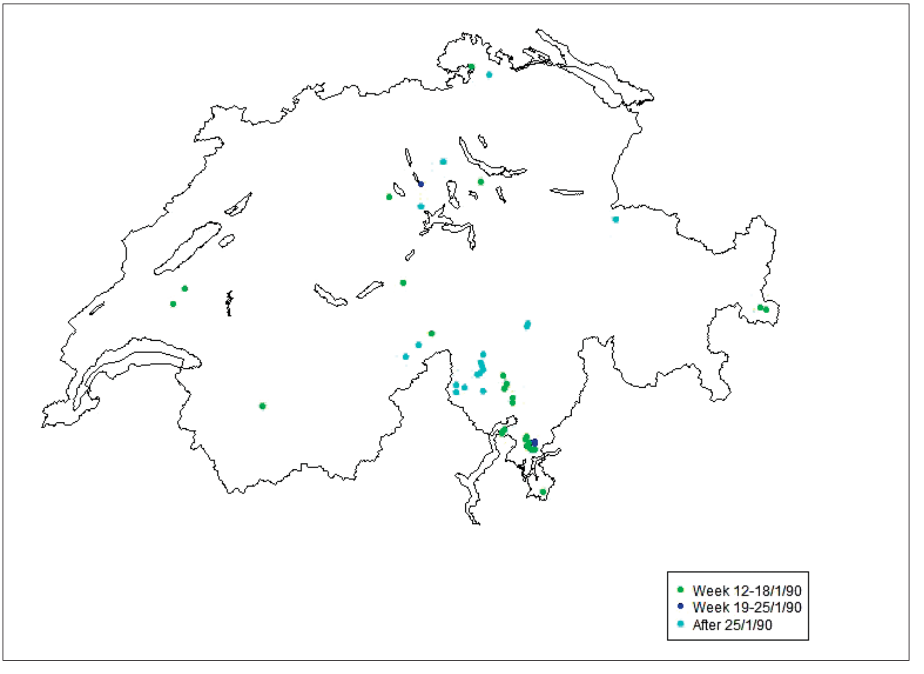
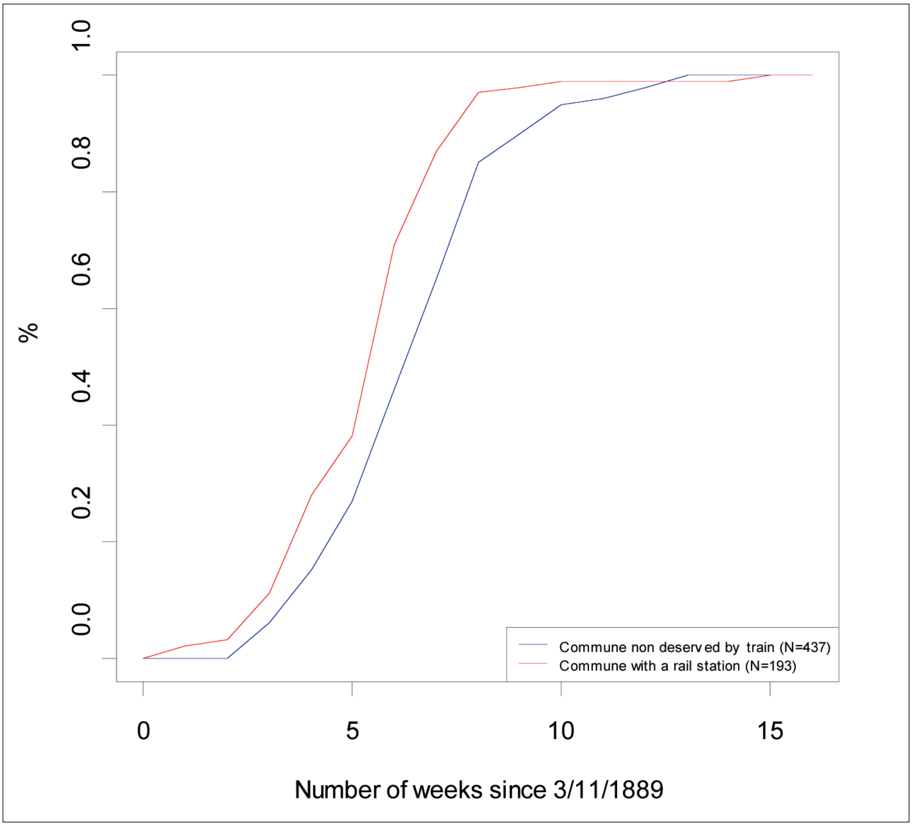


Source: Schmid, 1895

from Germany. The second hypothesis is very plausible since there were a lot of exchanges between these regions, especially with the railway network. In the case of Grison, which is a very mountainous region, one physician surveyed by Schmid mentioned that the start of the epidemic was due to travellers coming from the neighbouring Tirol in Austria. The Italian-speaking area was also reached by the epidemics. According to a physician surveyed by Schmid, the epidemic came from the centre of Switzerland by way of the Gothard tunnel. The diffusion to the western and most mountainous part of the Italian-speaking area of Switzerland was slow. It was the last region to be reached by the epidemics in the middle of January 1890.

Figure 5 shows that communities served by one of the five big railway companies were reached by the influenza before communities without a train station. This result seems to support our hypothesis that influenza diffused first in communities served by a train station. However, this result is very general since the disease did not appear in the different regions at the same time, supporting instead the hypothesis of a regional structure of diffusion.

Figure 5– *Accumulated proportion of Swiss communes reached by influenza according to whether they are served by trains or not*



Source: Schmid, 1895

4. MODELS AND COVARIATES

In this paper, we estimate event history models which allow for the analysis of diffusion of an innovation or behaviour (Strang, 1991; Hedström, 1994; Hedström *et al*., 2000). The general issue of these models is to consider that the risk of adoption for an individual (a person, a firm, a region…) depends upon whether other individuals had already adopted it (Diekmann, 1989; Strang and Tuma, 1993).

In some diffusion event history models, the underlying hypothesis is that the risk of adoption at time *t* is a function of the accumulated proportion of those who already adopted before *t*. This kind of model has been proposed, for example, in the analysis of the diffusion of marriage in a cohort (Hernes, 1972;

Diekmann, 1989). The adoption of such a hypothesis for our investigations would also mean that the influenza can be propagated by each commune that has already been reached with an equal probability. It would mean that the risk of the appearance of influenza in a commune would therefore depend on the number of already reached communes, regardless of the distances between reached and not reached communes or whether they were crossed by a railway line or not. Such a hypothesis appears to conflict with the ones we developed before.

Strang (1991) proposes a model in which transmission occurs between interconnected individuals: the risk of experiencing an event depends upon the number of individuals with whom an individual is connected and who already have experienced the event. In the present case, we consider in a first step that all communes with a station are interconnected. The risk of appearance of the disease at time t in a commune belonging to the railway network of one of the five biggest companies will depend upon the proportion of communes with a station and already reached by the epidemics at time t-1. This proportion will be the first covariate to be tested in our event history model. This covariate is time-dependent according to the extension of the illness among communes deserved by a company. It will always be null in the case of a commune not served by a train.

In a second step, the hypothesis can be refined in relation to the fact that the five companies are independent (Bauer, 1949). Interconnections between the companies are rare. As mentioned before, the sources of diffusion did not appear at the same time (Figure 4). This happened first in the French-speaking area of Switzerland, in which train stations belong to the *Jura-Simplon* company that first spread the influenza. Epidemics started later in the German-speaking area and even later in the Italian-speaking area. We will then consider the hypothesis in which a commune with a station can be infected by the influenza only from a commune served by the same railway company. The covariate here will thus correspond to the proportion of communes served by a station of the same company and reached by the influenza. This covariate is equal to zero in the case of communes not served by this company or not reached by the illness.

The second main hypothesis is that the process of diffusion is horizontal in the case of communes not served by the railway. The assumption is that diffusion occurs from one commune to the next nearest commune. Hedström (1994) develops diffusion models in which the power of contagion of a region which has already experienced the event depends upon the physical distance between this region and another that has not yet experienced it: the higher the distance, the lower the possibility of transmission of the influenza from the former region to the latter one. In the present case of diffusion of influenza in Switzerland, this hypothesis appears to be very plausible, if we suppose that flows of persons are lower between two distant communes than between two proximate communes. Concretely, we suppose that a commune has an increased risk of being reached by the epidemic if there is at least one commune already hit at a distance of less than 10 km. By contrast, a distance higher than 10 km means that there is no possibility of transmission of the influenza between the two communes: this hypothesis considers that flow of people between these communes is rare. Ten km can be considered a short distance. One can argue that the process of horizontal diffusion of the influenza between proximate communes is due to persons travelling on foot or on horseback, who might be expected to travel more than 10 km in a short time. However, let us recall that Switzerland is a mountainous country, crossed by the Alps and the Jura. It was common in the context of the 19th century for two neighbouring valleys to lack connection as they were separated by high mountains.

In addition, two other covariates will be introduced in the models as control variables. The first is the population size of the commune, as measured in the Swiss 1888 census (BFS, 1892). The group of communes served by one of the five big railway companies differed in their average population size (4,120 inhabitants) in comparison with the group of communes without a train station (1,250 inhabitants). We suppose that the higher the population size was in a commune, the bigger the risk that this commune would be reached by influenza. The second covariate is the altitude of the commune. We expect that the higher the altitude of a commune; the lower the risk, because of the relationship between difficulties of interconnectedness and altitude, especially in the context of the winter climate.

Discrete time complementary log-log models, in which the unit of time is the week, were estimated. The complementary log-log link was chosen instead of the usual logistic link since it has been shown that estimated coefficients with these first models are the same as in the case of continuous hazard models (Allison, 1984). In the case of no distinction between companies, the model can be written as:

$$\log[-\log(1-P_i(t))] = \alpha + \sum_{2}^{11} \gamma \, week(t) + \beta_1 pop + \beta_2 alt + \beta_3 prox_{10}(t-1) + \beta_4 n_g (t-1) \quad [1]$$

where $P_i(t)$ represents the conditional probability that the commune i is reached by influenza during the week t; α is the intercept term and corresponds to the complementary log-log of the probability that the disease appears during the first week of observation (10 to 16 November 1889) for communes of reference; *week(t)* is the week of observation, between the second and the tenth; t =11 means all weeks after the tenth (from 19th January to 22th February 1890), and γ is the coefficient to be estimated associated with each of these weeks on the probability of appearance of the illness; β_1 is the coefficient to be estimated associated with the covariate *pop*, which represents the standardized variable of the logarithm of the population size of the commune in 1888; β_2 is the coefficient associated with the covariate *alt*, the standardized variable of the logarithm of the altitude of the commune; β_3 and β_4 are coefficients of diffusion to be estimated, associated with each mode of contagion; $prox_{10}(t\text{-}1)$ is a binary covariate that indicates if at least one commune located at less than 10 km from the commune *i* is reached by the influenza at time *t*-1; $n_g(t\text{-}1)$ represents the proportion of the commune served by the railway, whatever the company, and reached by influenza during the week *t*-1.

In a further model, interconnections according to railway companies are differentiated. The model can be written with an index *k* to the covariate $n_g(t\text{-}1)$; this index symbolizes that the model has taken into account the proportion of communes with a station served by the company *k* reached by influenza:

$$\log[-\log(1-P_i(t))] = \alpha + \sum_2 \gamma \; week(t) + \beta_1 pop + \beta_2 alt + \beta_3 prox_{10}(t-1) + \beta_4 n_{gk}(t-1) \quad [2]$$

In these two models, the proportion in the railway diffusion covariate is computed taking into account at each week the communes reached weeks before, diminished by the number of communes in which the epidemic had ended. When the end date of the epidemic in a commune was missing, it was imputed assuming a normal distribution with mean and variance of the observed distribution in the case of communes in which the ending week is observed. In the case of communes served by more than one railway company, the higher proportion among those observed in different companies was used.

The horizontal diffusion covariate takes on the value of 1 if one or several communes that are reached are situated at less than 10 km. As in the case of the railway diffusion covariate, this covariate is also computed taking into account that epidemics can cease in a commune. The time distribution of the appearance of the disease in observed communes and the descriptive statistics for the independent covariates are given in Table 1.

Table 1 – *Distribution of the reached communes by the epidemic and independent covariates*

Weeks	Communes contaminated	Communes served by a railway company	Numbers
10-16 Nov	4	Total	193
17-23 Nov	2	"Centralbahn"	25
24-30 Nov	38	"Gotthardbahn"	18
1-7 Dec	75	"Compagnie Jura-Simplon"	62
8-14 Dec	63	"Nordostbahn"	74
15-21 Dec	145	"VereignigteSweizerbahnen"	24

...Cont'd...

Table 1 – *Cont'd*

Weeks	Communes contaminated	Control covariates			
22-28 Dec	110				
29 dec-4 Jan	103				
5-11 Jan	23		min	mean(sd)	max
12-18 Jan	27	Population	35	2107 (4912)	69809
19-25 Jan	4				
26 Jan-1 Febr	8	Altitude	200	613.1 (295.7)	1954
2-8 Febr	7				
9-15 Febr	0				
16-22 Febr	2				
N (valid)	611				

5. RESULTS

Models were estimated with the R package. In the first model (Table 2, model 1), only the effect of time and other control covariates (population and altitude) is estimated. This model indicates an increased risk up until the eighth week (29 December 1889 to 4 January 1890) followed by a levelling off of the risk. As expected, the bigger the size of a commune, the higher the risk of this commune being reached by the disease. Contrary to expectations, however, the risk of a commune being contaminated by influenza is not related to its altitude.

In the second model, the horizontal diffusion covariate is introduced (model 2, covariate "Proximity"). The estimated coefficient associated with this covariate is positive and significant. This result suggests that the hypothesis of a horizontal diffusion process for influenza is valid.

In the third model, the railway diffusion covariate is introduced, first without the variable related to the horizontal diffusion (model 3a, covariate "Station") and secondly with the variable included (model 3b). In both cases, the covariate is not significant at the 5% level (albeit at the 10% level), which means that the hypothesis of a mixed diffusion process does not appear valid if we do not distinguish between railway companies. Note, however, that the covariate related to the diffusion by railway is significant when the control covariates related to the size of the population are removed, which is due to that communes with a station are also the most populated cities.

In the fourth model, a covariate which distinguishes the railway companies is included. As before, this covariate is introduced first without the covariate related to the horizontal diffusion (model 4a, covariate "Station-network"). As before, the covariate is not significant at the 5% level. However, it becomes positive and significant when the covariate related to the proximity (model 4b) is introduced. This time, the hypothesis of mixed diffusion of influenza appears to be verified, first diffusing in communes belonging to the same railway company, and secondly from these communes to their neighbouring communes. The comparison with the model that does not make the distinction between companies shows that it is also important to take into account the timing of diffusion, which differs according to the company: connections between them were not very numerous, which means they were relatively isolated from each other.

Table 2 – *Estimated models of influenza diffusion*

	Model 1	Model 2	Model 3a	Model3b	Model 4a	Model 4b
Intercept	-5.35***	-5.36***	-5.34***	-5.34***	-5.33***	-5.33***
Week:						
17-23 Nov	-0.68	-0.71	-0.67	-0.72	-0.68	-0.72***
24-30 Nov	2.32***	2.25***	2.31***	2.25***	2.31***	2.24***
1-7 Dec	3.17***	3.04***	3.15***	3.02***	3.14***	3.00***
8-14 Dec	3.21***	2.76***	3.16***	2.71***	3.16***	2.70***
15-21 Dec	4.43***	3.87***	4.37***	3.81***	4.37***	3.80***
22-28 Dec	4.78***	4.10***	4.71***	4.02***	4.70***	4.00***
29 Dec-4 Jan	5.56***	4.82***	5.49***	4.74***	5.50***	4.73***
5-11 Jan	4.84***	4.10***	4.77***	4.02***	4.77***	4.01***
12-18 Jan	5.66***	4.92***	5.59***	4.84***	5.59***	4.82***
19-25 Jan and after	5.23***	4.42***	5.12***	4.30***	5.13***	4.29***
log (population)	0.64***	0.65***	0.62***	0.63***	0.61***	0.62***
log (altitude)	-0.01	0.05	0.00	0.08	0.01	0.07
Proximity		0.78***		0.79***		0.79***
Station			0.33	0.38		
Station-network					0.34	0.42*
-2LL	2382.9	2340.3	2380.1	2336.7	2379.9	2335.8

Note: *** : significant at 0.001; **: significant at 0.01; * significant at 0.05.

6. CONCLUSION

In this paper, the diffusion of the Russian influenza in Switzerland was investigated. This epidemic, which spread all over Europe, the USA and other regions during the winter of 1889-90, occurred at a time of social change, especially in regards to the development of transport networks like railway and marine ship lines. Following several authors of the epoch and especially Schmid (1895) in Switzerland, we hypothesised a mixed pattern of diffusion of the influenza within the Swiss territory in relation to the geographical structure of the time. Railways expanded during the second half of the 19th century, creating connections between communes with train stations. We then supposed diffusion along the railway network, and from each commune with a train station, a horizontal diffusion to neighbouring communes.

The data we used came from a general survey organized by Schmid (1895) who sent a questionnaire to physicians practicing in Switzerland. Results confirm the main hypothesis only when a distinction between the railway companies was added. The railway network was shared in 1890 by five companies that were practically isolated from one another. The influenza diffused along the railway lines of each company with different timing. Patterns of diffusion of the influenza were then governed by three dimensions. The first one is the horizontal dimension of the spread, from neighbourhoods to neighbourhoods. The estimated effect of the horizontal diffusion from communes reached by the epidemics to neighbouring communes is high. It reveals that population flows at this time were important between neighbouring communes. The second is the diffusion through flows of contaminated persons travelling by rail. The third is the regionalization of the Swiss territory due to the division of the railway network into five main companies.

The Russian influenza has been identified as the first modern influenza epidemic (Pyle, 1987) because of its global spread and the high speed of this spread in relation to the development of transport networks. The influenza of 1889-1890 is also considered modern by historians for another reason related to its media coverage (Honigsbaum, 2010; Mussel, 2007; Smith, 1995). It was the first epidemic which was followed by newspapers from the beginning. English readers were progressively informed of its existence from its beginning in St. Petersburg as well as of its progression to the West and its arrival in London, sometimes causing dread. The spread of the virus along the railways was accompanied by the spread of its information along telegraph lines.

The mediatization of the 2009 swine influenza epidemic is similar since the spread of its initial source in Mexico has been largely covered by mass media (i.e. television, newspapers), etc. In this recent epidemic, railways have been replaced by airways, and the illness diffused very quickly from its source in a lot of countries. However, if the diffusion inside a country is considered equivalent to the horizontal diffusion of the Russian influenza, then this kind of diffusion appears to have been very weak, since this epidemic ultimately was not as prevalent as was expected by medical and health organizations when it first appeared. Such a weak horizontal diffusion could be due to prevention, isolation measures, and vaccination campaigns. It could also be hypothesized that geographic structures of developed countries at the beginning of the 21th century differed from ones at the end of the 19th century. In 1889-1890, workers were living in big cities or their proximate suburbs, but had links with their families that remained in the countryside. As mentioned in the introduction, when these workers became ill, several of them went back to their family and transmitted the illness. The organization of territory also differs in 2009. Schematically, nuclear families live in distant suburbs and flows of people are mainly directed between these suburbs and big town centres where they work, while horizontal flows from cities to neighbouring cities are less important. It is possible that the power of diffusion seen in the 19th century influenza epidemics weakened because of fewer people moved from place to a neighbouring place during the 20th century.

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