Modelling delay dynamics on railway networks

B. Monechi[1], P. Gravino[2], R. Di Clemente[3], V.D.P. Servedio[4]

[1]ISI Foundation

[2]"Sapienza" University of Rome

[3]Massachusetts Institute of Technology

[4]Complexity Science Hub Vienna

Railways are a key infrastructure for any modern country, so that their state of development has even been used as a significant indicator of a country's economic advancement. Moreover, their importance has been growing in the last decades either because of the growing Railway Traffic and to governments investments, aiming at exploiting railways means to reduce CO2 emissions and hence global warming. To the present day, many extreme events (i.e. major disruptions and large delays compromising the correct functioning of the system) occurs on a daily basis. However these phenomena have been approached, so far, from a transportation engineering point of view while a general theoretical understanding is still lacking. A better comprehension of these critical situation from a theoretical point of view could be undoubtedly useful in order to improve traffic handling policies.

In this work we move toward this comprehension by proposing a model about train dynamics on railways network[1] aiming to unveil how delays spawn and spread among the network. By means of two datasets about Italian and German Railway traffic, we characterized the sources of delay as "endogenous (due to the interactions between the trains) and "exogenous (coming from adverse conditions such as bad weather and malfunctions). We show that exogenous delays can be modeled as a universal delay-generation mechanism depending on the topological properties of the Railway Networks and originated by the same amount of external sources, independently from the considered spot on the network. Inspired by models for epidemic spreading[2,3], we model the diffusion of delays among train as the diffusion of a contagion among a population of moving individuals, where the seeds of the contagion are represented by the spontaneous occurrence of exogenous delays.

The model reproduces adequately delays dynamics in the Italian and German systems, meaning that it captures its underlying key factors. In particular, our model predicts that the insurgence of clusters of stations with large delays is not due to external factors, but mainly to the interaction between different trains, suggesting that the reduction of such interaction is the main objective in order to reduce the occurrence of extreme adverse conditions.

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