UNIVERSITÉ DE LORRAINE

lgipm
Laboratoire de Génie Informatique, de Production et de Maintenance

UNIVERSITY OF NAIROBI

School of Mathematics

Utilisation de modèles épidémiologiques pour l'étude de la propagation d'aléas au sein de systèmes (système de production, réseau informatique, etc.)

Sophie HENNEQUIN - Daniel ROY

Aimé NYOUNGUE - Josephine KAGUNDA WAIRIMU

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Introduction

- **Background**

Similarity between biological systems and industrial systems has been largely studied

→For example, industrial ecologists believe we should aspire to imitate mature ecosystems, which operate efficiently, recycling materials and emit little waste

→Industrial symbiosis derives directly from natural symbioses

→in a different direction of studies, biological processes and industrial production systems have been reconciled (cyber-physical systems)

Introduction

- **Objective**

→To adapt epidemiological models to evaluate propagation of disruptions in industrial systems and networks

→ To solve existing tedious research methods (done analytically or through simulation)

→ To analyze dynamics in industrial system with reference to random disruptive events

Indeed, the dynamics of failure propagation and the threats it generates are far from being solved by the traditionally used methods (trees and analysis graphs)

Literature review

- Infectious disease (in a population or an individual) has the capability of growing into an epidemic if the infection rate is sufficiently larger than the rate of recovery
- The sample population used to study the disease propagation is categorized into different stages depending on the disease manifestation
- Each stage represented by a variable e.g. *S*, *I* , *R*…, possesses similar characteristics at time *t* → various models such as SIS, SIR, etc.

Literature review

- Important features of these models:

→highly variable in terms of infectious profiles, parameter values, and time-scales

→Data are observed at discrete intervals, thus statistical inference may be easier

→3 main directions of application of epidemiological models to non-biological systems: network security (computer, electrical), social networks and the global economy

Literature review

- **Applications of epidemiological models to non-biological systems**

→ Application of epidemiological models in the study of phenomena of propagation of threats (such as malware) has been treated by different authors for different applications in peer-to-peer networks [1] and electricity networks

→ To understand the propagation mechanism of these computer viruses

from a variety of epidemiological models epidemiological models generally based on fully connected networks fully connected networks [2]

[1] Piqueira, J. R. C., Navarro, B. F., & Monteiro, L. H. A. (2005). Epidemiological models applied to viruses in computer networks. Journal of Computer Science, 1(1), 31–34.
[2] Rodrigues, H. S. (2016). Application of sir epidemiological model: new trends. arXiv preprint arXiv:1611.02565

Literature review

- **Applications of epidemiological models to non-biological systems**

→ Application of epidemiological models in the study of phenomena of propagation of threats (such as fake news, memes) has been treated by different authors for different applications in social networks like Facebook, Twitter, Instagram for the government's strategies [3]

→ Study how a viral marketing to popularize and sell products. Indeed, when a marketing marketing advertisement goes viral, it is analogous to an to an epidemic, as it involves the transmission of of a message from one person that eventually spreads to a spread throughout a population [4] [5]

[3] Cannarella, J., & Spechler, J. A. (2014). Epidemiological modeling of online social network dynamics. arXiv preprint arXiv:1401.4208.

[4] Kandhway, K., & Kuri, J. (2014). How to run a campaign: Optimal control of sis and sir information epidemics. Applied Mathematics and Computation, 231, 79–92.

[5] Bhattacharya S., Gaurav K. & Ghosh S. (2019). Viral marketing on social networks: An epidemiological perspective, Physica A: Statistical Mechanics and its Applications, 525(1) 478-490

Literature review

- **Applications of epidemiological models to non-biological systems**

→ Rational predictions in economics and the propagation of effects (such as a merger between companies, an economic crisis, etc.) on financial networks are major sectors of the economy that have broad applications of epidemiological (contamination of the banking network) [6]

→Similar strategies (based on behavioral implications) can be deployed at the health level with, for example, the definition of public health policies and the training of health personnel [7]

→. To protect public health, epidemiological models could be defined to mitigate ozone pollution [8]

[6] Bolos B. V. (2012). Financial Contagion Research through Epidemiological Means, Romania Case Study, Procedia Economics and Finance, 3, 902-907.

[7] Torre D., Malik T. & Marsiglio S. (2020). Optimal control of prevention and treatment in a basic macroeconomic–epidemiological model. Mathematical Social Sciences, 108, 100-108.

[8] Li A., Zhou Q. & Xu Q. (2021). Prospects for ozone pollution control in China: An epidemiological perspective, Environmental Pollution 285 (2021) 117670.

Analogy

Biological organisms and non biological systems share many characteristics

- Similarities

(i) Attack the defence: virus multiplication and attacks leads to weakening of defence cells and ultimately death → the failure propagation of industrial systems and networks

(ii) Replication: when one single cell is attacked, the virus replicates and infect other cells → In a complex system, when a one component fails, the rest of the system could come to a stand still

Analogy

(iii) Let secondary (or other) vectors do the work: virus is the infection that finishes the job in disease modelling → while in production systems, disruption which finishes the job arises due to poor maintenance, poor installation, overloading, overworking a machine among others

(iv) Suppression of multiplicity: drug treatment does not fully eradicate the HIV in the human system but suppress further replication of the virus to uncontrollable levels → maintenance is not perfect but rather helps the machine to operate at optimal level as intended by the manufacturer

Analogy

(v) Latency: virus infection does not make the body to stop operation at once but undergoes a latency (window) period during which it weakens slowly → this is a replica in industrial systems where components degradation takes place over a period of time before it is diagnosed or causes failure

Analogy

(vi) Host: virus possesses characteristics of living things thus affects living things → failure could be a defect resulting from improper lay out on the maintenance policies, and operation rules. But also could come from the industrial system

(vii) Components: virus contain genetic material (RNA or DNA) → the disturbances are due to the choice of materials and the structure of the system

An example

Failure propagation model of a manufacturing system:

→ efficiency, reliability and dependability of components deteriorate at different rates (degradation occurs with time whether the components are maintained or not)

→ if systems are used without inspection and maintenance, the rate of degradation is higher, otherwise the component could serve its purpose for an intended period of time with less failures in between

→ rate of degradation components (apart from lack of maintenance) also depends on external factors (vibration, temperature, humidity, dust…)

An example

Failure propagation model comprising three components: susceptible class *S*, infected class *I*, and protected class *P* (SIP model)

The model indicates the stages a component undergoes in a production resource from installation to the point of being rendered worthless

$$\left.\begin{aligned} \frac{dS}{dt} &= \lambda + \sigma I - (\mu_S + \beta + \delta)S \\ \frac{dI}{dt} &= \beta S - (\mu_I - \sigma)I \\ \frac{dP}{dt} &= \delta S - \mu_P P \end{aligned}\right\}$$

An example

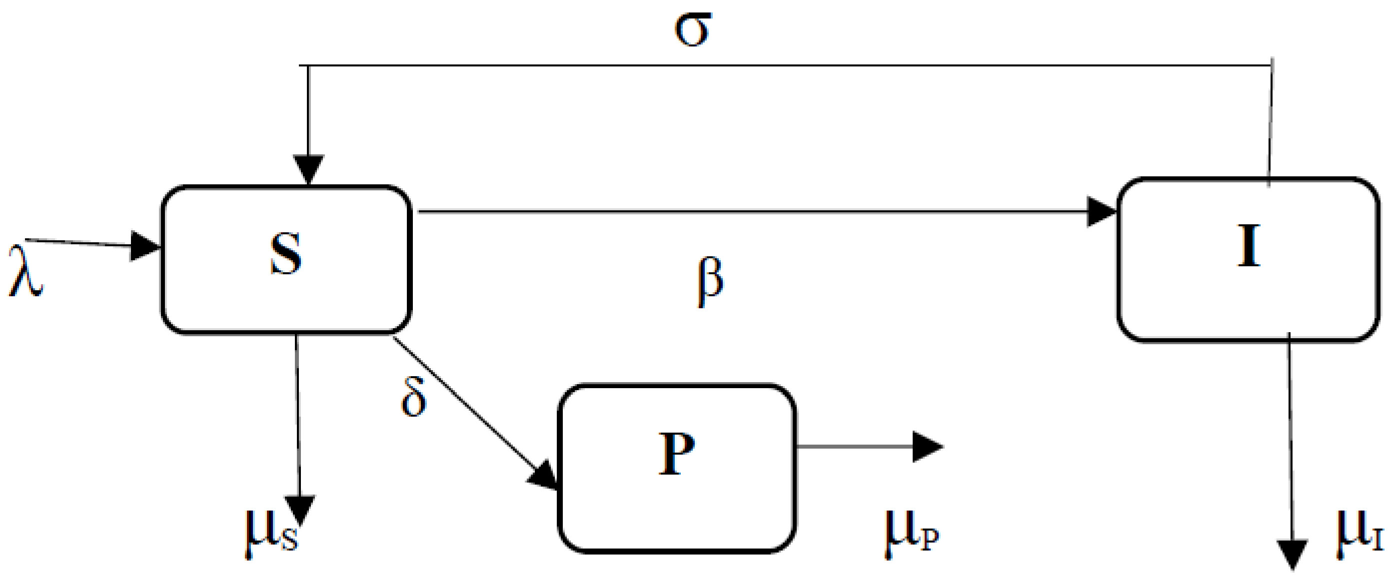
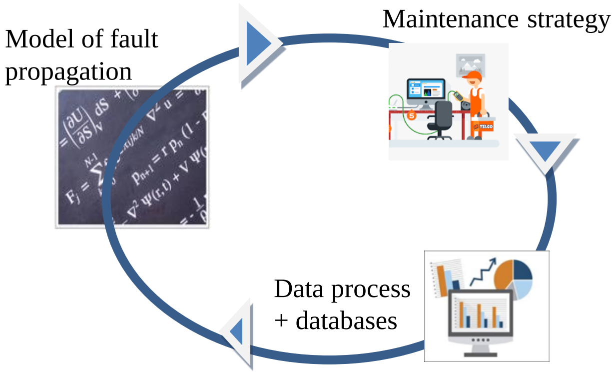


Figure: Schematic Representation of the Proposed Failure Propagation Model

An example

The study of the dynamic propagation of disruption could help to identify transitional states (before stopping)

During these transient states, overconsumption of energy, increased emission of pollutants and/or product defects can be visualized and an online predictive maintenance strategy can then be defined in order to avoid on the one hand the propagation of problems and on the other hand reduce the transient states



Conclusion

- The current market demand, environmental degradation (global warming) and the need to optimize energy, has led to rapid increase in capital investment towards multi-components production systems and logistics networks which are complex in structure and function

- This calls for inspection and prior detection to avert failures and problems through maintenance, use of improved technologies and sophisticated maintenance models and control policies to avert stoppages and ensure availability and reliability of the system

Conclusion

- For future work, we propose:
  - The study of effect propagation in supply chains like ripple effect (strategic risk which propagates in all the supply chain upstream and downstream)
  - The study of effect propagation in industrial symbiosis
  - The definition of e-maintenance strategies

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Merci pour votre attention
Avez-vous des questions ?

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