Modelling in Public Health

Modelling in Public Health
SE Scientific Communication
Summer 2019

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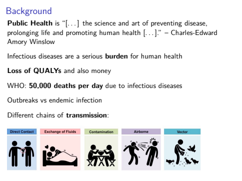
28. June 2019

Good morning and welcome to my brief introduction into modelling in the world of public health.

Content



Charles-Edward Amory Winslow - American **bacteriologist** and **public health expert 1920**

responsible for loss of QUALY = quality-adjusted life year – sick leave, treatment

The most severe outcome is DEATH

many are preventable (vaccines or other interventions) or curable

outbreak: is the occurrence of disease cases in excess of normal expectancy

endemic: infection is constantly maintained at a baseline level in a geographic area without external inputs (steady state)

Direct contact: Plague
Exchange of Fluids: HIV
Contamination: Salmonella
Airborne: Influenza
Vector: TBE (FSME)

Outbreaks

Influenza pandemic "swine flu"
Global, 2009–2010, 100,000 – 400,000 deaths

Ebola
West Africa, 2014–2016, 11,000 deaths
DRC, since 2018, 1,900 deaths

Zika Virus
Brazil, 2015–2016, estimated 1 Mio cases in Brazil only and 2,000 confirmed severe complications in newborns

Measles
Europe, 2019, ca. 6,300 cases from Jan–Apr
Austria, 2019, more than 130 cases up to this week

Flu: 2009 not more than usual season (see also Spanish flu 1918 with 20-50 Mio deaths), but unexpectedly early, 10-15 weeks earlier then normal
AT: 1000 – 4400 (2016/2017) deaths per season

Ebola (2015 strain): CFR up to 40–60%

Measles EU: Romania, Lithuania, Italy, Poland, Bulgaria, Czech Republic, France, Greece, Slovakia

How can modellers help?

Outbreak situations:

- **Exploit** all available data
- **Inform** response team in real time
- **Prioritise** interventions

Non outbreak situations:

- **Evaluate** health programmes (vaccination, WHO elimination targets)
- Find **high impact and cost-effective** interventions
- Allow **evidence** based decisions

Benefits of modelling:

- **Low cost!** Clinical trials are expensive and seldom large enough
- Often little or no data to analyse (new emerging diseases)

help to prioritise interventions

WHO elimination target for HIV-AIDS, Hepatitis C

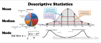
mathematical models can help to assess potential threats and impacts early in the process, and later aid in interpreting data

Public health programmes are usually implemented over a long period of time with broad benefits to many in the community.

WHO: over 30 new diseases emerged in the last 20 years

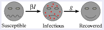
Types of models

Statistical



- Descriptive
- Regression
- Bayesian statistics
- Spatial models

Mathematical



- Dynamic, compartmental (SIR)
- Stochastic - Markov chain
- Deterministic
- Agent-based

Statistical: we will see an example for time series regression shortly

Stat models like Poisson used to calculate attack rates, risk rations, etc in Foodborne outbreaks

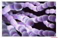
Dynamic models: origin is in the early 20th century

Modelling: higher influence with increasing computer power

Also used to predict the future (forecasts)

Intervention effect – Invasive Pneumococcal Disease (IPD)

Caused by ***Streptococcus pneumoniae***



90 distinct pneumococcal serotypes

Highest burden: **infants** and **elderly**

Vaccine introduced in 2012 in AT for children

Vaccine effect? Direct? Indirect (elderly)?

Lets move on to the first example, the evaluation of an intervention on invasive pneumococcal disease

s. pneumoniae: bacteria

Serotypes: Only a small number cause severe disease like IPD

can result in: **meningitis, pneumonia, sepsis**

Risk: <2 and $50+$

vaccine: covering 10 serotypes (PCV10)

3 doses in the first year (3rd, 5th, 12th month)

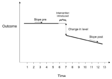
IPD – A Segmented Regression Model

Serfling-like Model

$$\begin{aligned}\log(Y_t) &= \beta_0 + \beta_1 t + \beta_2 \sin\left(\frac{2\pi t}{12}\right) + \beta_3 \cos\left(\frac{2\pi t}{12}\right) \\ &\quad + \beta_5 (t - t_0)^+ + \mathbb{1}_{t-t_0>0}\left[\beta_4 + \beta_6 \sin\left(\frac{2\pi t}{12}\right) + \beta_7 \cos\left(\frac{2\pi t}{12}\right)\right] \\ &\quad + \log(pop_t)\end{aligned}$$

with

$$(x)^+ = \begin{cases} x, & \text{if } x > 0, \\ 0, & \text{otherwise.} \end{cases}$$



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GLM-related – NB regression

2 segments

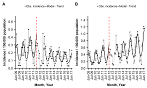
pre-, post-period

get an estimate (incl CI) for intervention effect

offset log(pop) to get incidence rate estimates

IPD – Results

Figure: Monthly incidence of (A) **vaccine type** IPD (B) **non vaccine type** IPD, among the $\geq$**50 years old**, observed and modelled, Austria



The vaccine type IPD was **reduced by 67%** (95% CI: 32%; 84%).

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The vaccine type IPD was **reduced by** 58% (95% CI: 30%; 74%) and **67%** (95% CI: 32%; 84%) among <5 and ≥ 50 years old

Elderlies seem to benefit the most

Besides the direct effect (not shown), we also see a **herd effect**.

By taking action on one group, we also safe another (risk) group.

Mathematical modelling – Zika Virus

Humans infected by **mosquitos**
- daytime-active *Aedes* family

Latin American Zika epidemic (Feb 2016)
- Summer Olympics in Rio
- **Global transmission** (75 countries)
- e.g. *A. albopictus* **found in AT** in 2012

Mostly **flu-like** or **no** symptoms

Dangerous for **foetuses and neonates**
- Brain malformations
- Microcephaly (small head)

Figure: *Aedes aegypti*

Source: Muhammad Mahdi Karim, Wikipedia

We continue with the second example – a mathematical model of an outbreak:

Zika Virus is a **Vector born disease**

prevalent in South America, Africa, Asia

The WHO declared the Latin America Zika epidemic to be **Public Health Emergency of International Concern** in Feb 2016

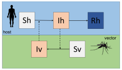
Summer Olympics: lots of worldwide travel

Policy suggestion/recommendation: delay pregnancy

To get better insight into this outbreak a mathematical model was developped

Transmission model of Zika Virus

Vars	Description
S_h	Susceptible Humans
I_h	Infected/Infectious humans
R_h	Humans recovered from infection (with lifelong immunity)
S_v	Susceptible vectors
E_v	Exposed vectors



adapted from https://www.reconlearn.org/ and **ferguson2016**

here: a little simplification of the model

stratified by age - only one layer shown

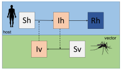
Transmission model of Zika Virus

Humans/Host

$$\frac{dS_h}{dt} = \mu_h N_h - \frac{\beta_h b}{N_h} S_h I_v - \mu_h S_h$$
$$\frac{dI_h}{dt} = \frac{\beta_h b}{N_h} S_h I_v - (\gamma_h + \mu_h) I_h$$
$$\frac{dR_h}{dt} = \gamma_h I_h - \mu_h I_h$$

Vectors

$$\frac{dS_v}{dt} = \mu_v N_v - \frac{\beta_v b}{N_h} I_h S_v - \mu_v S_v$$
$$\frac{dI_v}{dt} = \frac{\beta_v b}{N_h} I_h S_v - \mu_v I_v$$



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https://www.reconlearn.org/ and **ferguson2016**

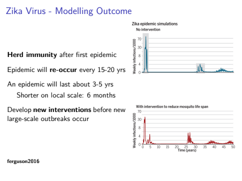
Write as the following system of ordinary differential equations

Parameters need to be estimated

either from **previous outbeaks, studies or data**

or from the outbreak itself (fit the model to current data)

b ... biting rate
β ... probability of transmission
μ ... mortality rate
γ ... recovery rate
N ... number of humans/vectors



Epidemic will re-occur when the reservoir of **susceptible** people grew big enough again

The outbreak “moves” spatially

intervention of mosquito control will reduce weekly infections

but smaller outbreaks likely to occur after

Also: less time between outbreaks (bc less people got infected and therefore higher amount of susceptible)

2019-06-27

Modelling in Public Health

└─Conclusion

└─Other Applications

Other Applications

- Sexually transmitted infections (STI)
- Ebola
- Malaria
- Influenza mortality
- Foodborne outbreaks
- Tuberculosis
- Hepatitis C elimination

Modelling **increasingly important**

Guide the most high **impact** and **cost-effective** preventions

Critical tool for public health action

Model limitations

Decision makers **benefit** - so does the population

Challenges need to be solved

We presented two examples of applied modelling in public health

Modelling plays an **increasingly important** role in helping to guide the most high **impact** and **cost-effective** preventions.

Can be a **Critical tool** for guiding public health action. Model limitations:

as other studies / models simplify the real world

computer power is benefitial

Still a number of **challenges** in achieving a successful interface between modelling and public health actors.

Any questions?

Thank you for your attention,
i wish you a nice and hot summer :)
and i am happy to answer your questions