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MATHEMATICAL MODELLING OF COVID-19

Understanding the dynamics of decision making amidst political, public, socio-economical national and regional challenges and interests

By

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Outline

- Background to the study
- Mathematical modelling framework
- Findings
- Recommendations

Study background

- The study develops a mathematical framework to assist government of Uganda to study the transmission dynamics of COVID-19 and use it to provide informative forecast and appropriate policy-based support on the timing and effectiveness of intervention measures
- The model helps in understanding the dynamics of decision making amidst political, public, socio-economical national and regional challenges and interests
- Uganda has a unique set up comprised of resource-constrained economy, politically diverse regional neighbourhood and home to refuge crisis that comes from long and protracted conflicts of the great lakes region

Study background (2)

- In Uganda, the devastation of the pandemic is likely to be (or is already) escalated by the mentioned circumstances with expectations of the impact of the disease being severe

- Easing of lockdown has been the most challenging decision to make; people need basic services but the covid-19 projections and trend remain elusive

- The disease was relatively well-managed in Uganda with the number of cases only rising after a surge in the number of imported cases. As of 4th June 2020, there were 522 cases, 0 deaths and 82 recoveries reported

Study background (3)

- The most worrying challenge for Uganda was and still is on the healthcare system capacity
- The indicators of the pandemic from other countries showed that the matter requires and indeed required huge healthcare support
- The number of patients would soon overwhelm Uganda's facilities and capacity in form of intensive care units (ICUs), personal protective equipment (PPE), isolation and quarantine centres, hospital beds as well as medical and allied manpower e.g., ambulances, service vehicles etc.

Modelling framework (1)

- The basics and fundamentals of the model dynamics are built on the characteristics of COVID-19 recruitments, recovery, importation of cases, contact tracing efforts and isolation of susceptible individuals

- The population of Uganda is divided into epidemiological classes as follows:
  - Susceptible individuals (those with no disease but are at risk of getting it)
  - Latently infected (those infected but, by standard epidemiological definition, can neither spread the disease nor be detected by clinical sign screening and tests)
  - Asymptomatic infectious (infected individuals who may never show symptoms of the disease)
  - Symptomatic infectious (infected individuals that show symptoms of disease)
  - the hospitalized cases, and the recovered individuals

Modelling framework (2)

- We then use the model to make projections of the disease burden of:
  - undetected transmissions
  - imported cases cargo truck drivers
  - hospital-care and demand
  - quarantine and isolations
  - surveillance and contact tracing
  - timing of easing of lockdowns
- Focusing their impact on two selected disease burden indicators namely, the number of hospitalized and undetected infected cases in the community

Key model assumptions (1)

- The model carters for the fact that there are substantial and best-practice intervention strategies that are in place, that the model now would measure their levels of responsiveness

- The model also assumes measures similar to those in place to mitigate hospital acquired infections are also in place to mitigate quarantine-acquired infections while in institutional quarantine

Key model assumptions (2)

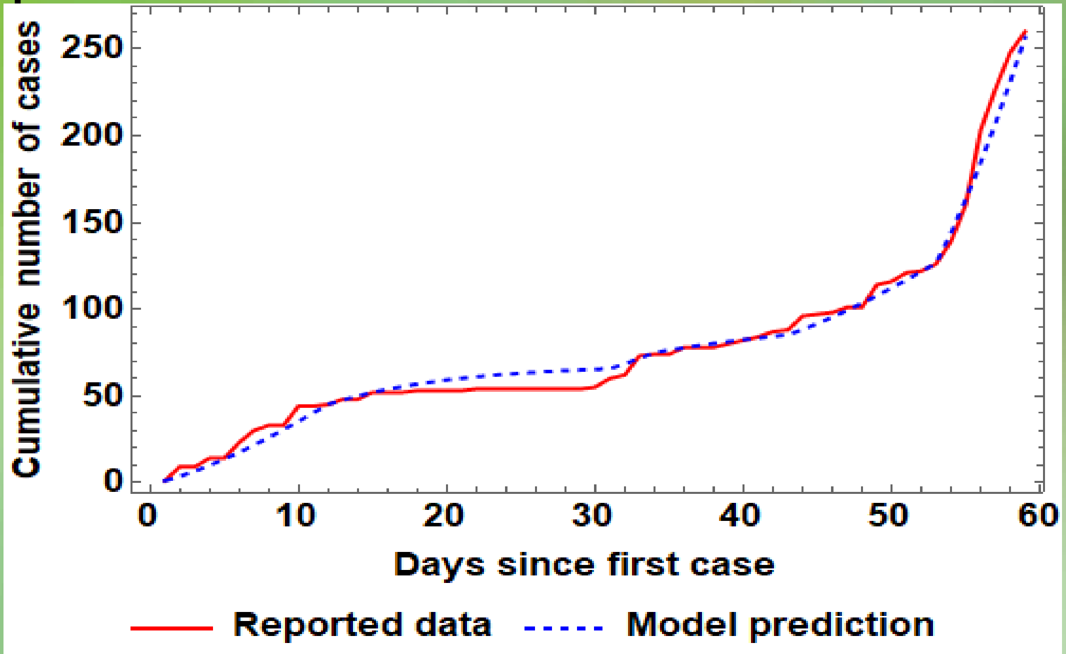
- On post disease recovery, there is a global debate on whether the disease confers immunity (everyone is anxious about this)

- The model has been formulated with a parameter that can capture situations at simulation level where; no immunity, temporary immunity, or permanent immunity is conferred

- There is potential for hospital-acquired infections to occur albeit at a lower rate than the community occurring infections (this therefore requires health personnel to remain in one isolation point in order not to aggravate community transmission

Findings - Biological feasibility

- Understanding whether the model serves the purpose, we fit the model with reported data and observe the behavior. The results on fitting are indicated in the figure below – the two match

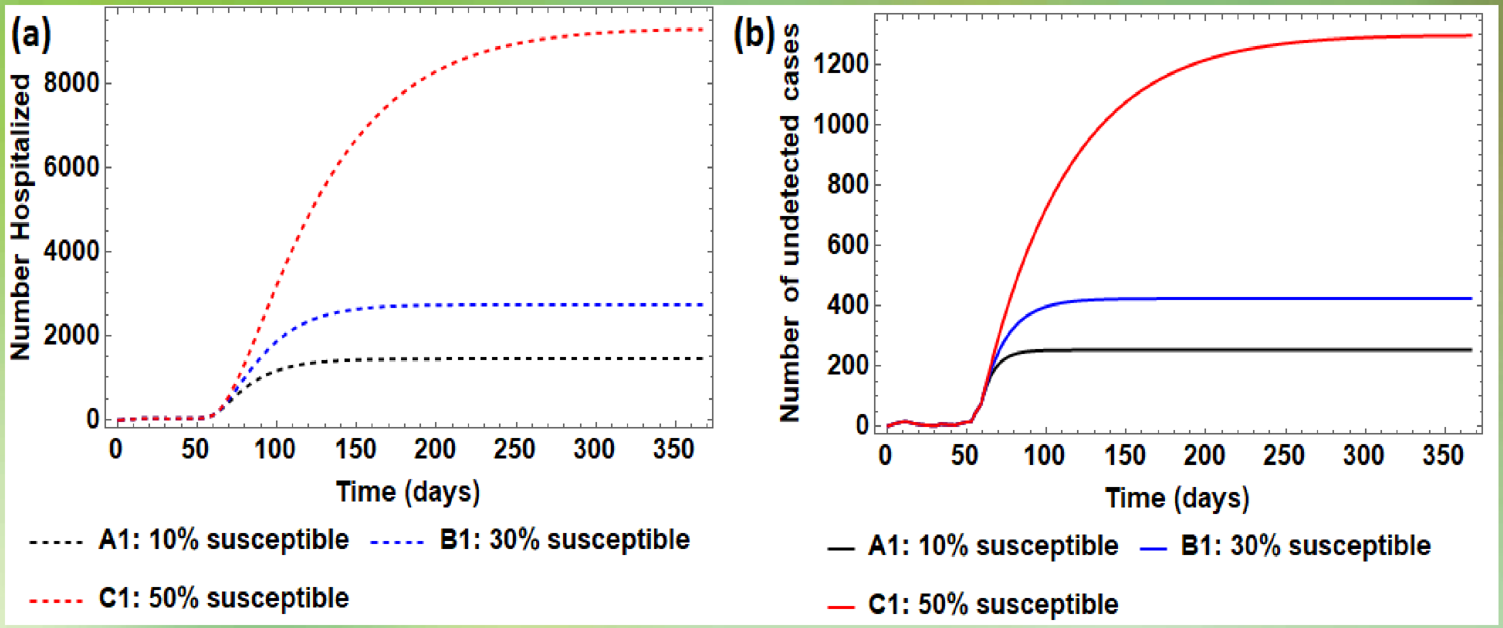


Findings – On the impact of lockdown (1)

- Lockdowns impact the disease dynamics through reducing the magnitude of the susceptible population thereby partially depriving the infection of susceptible individuals
- A small percentage of available susceptible population translates to more strict and effective lockdown measures
- In Uganda's strict lockdown, the few susceptibles arose from essential workers and non-adherent cases (you cant miss these out – police hunted for them in bars hidden etc.)

Findings – On the impact of lockdown (2)

- For varying levels lockdown strictness depict in the percentage of susceptible individuals available, model predicted results are shown below

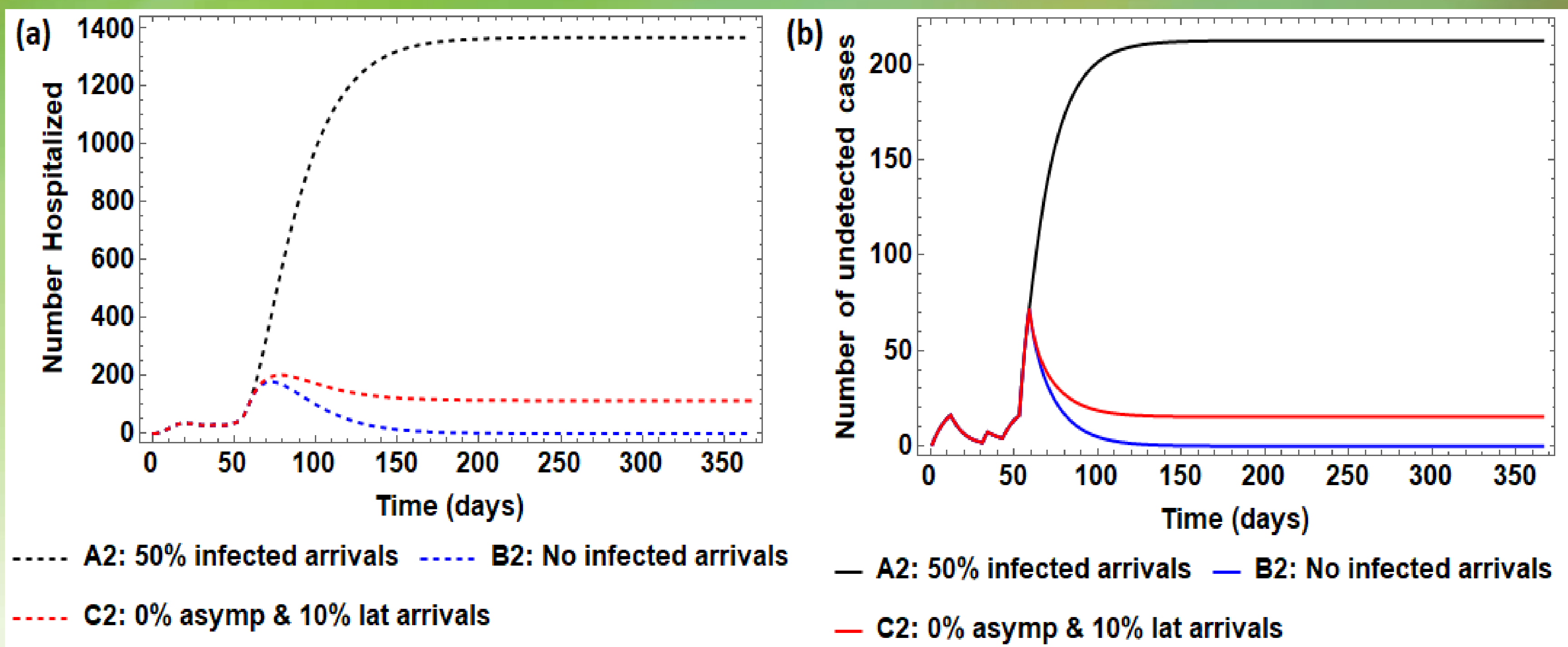


Findings – On the impact of lockdown (3)

- The effect of reducing the proportion of susceptible population after two months of lockdown since the reporting of the first confirmed COVID-19 case in Uganda is assessed
- The results show that the disease burden is directly and heavily dependent on the proportion of the susceptible individuals available
- In the ideal situation of maintaining only 10% of susceptible population available, the hospitalization requirements would be close to 1000 beds by 100 days post reporting of first case
- If the available proportion is increased from the initial 10% to 50% after two months, then within 365 days, the hospitalized cases on a given day would reach very high levels (close to 10,000), and the undetected infectious individuals will be high at close to 1400 on a given day

Findings – On number of imported cases (1)

- We also assess the burden of the imported cases under partially lifted lockdown and the results are below



Findings – On number of imported cases (2)

- Model results reveal that the disease will remain persist in Uganda for as long as we still have imported cases no matter how few
- Even more worrying is the fact that the endemic level would be higher at bigger levels of susceptibility (enhanced lockdown)
- The only scenario in which the disease would be wiped out in one year is when there were no more imported cases after two months and this would be achieved after 200 days if all other measures in place are strictly observed

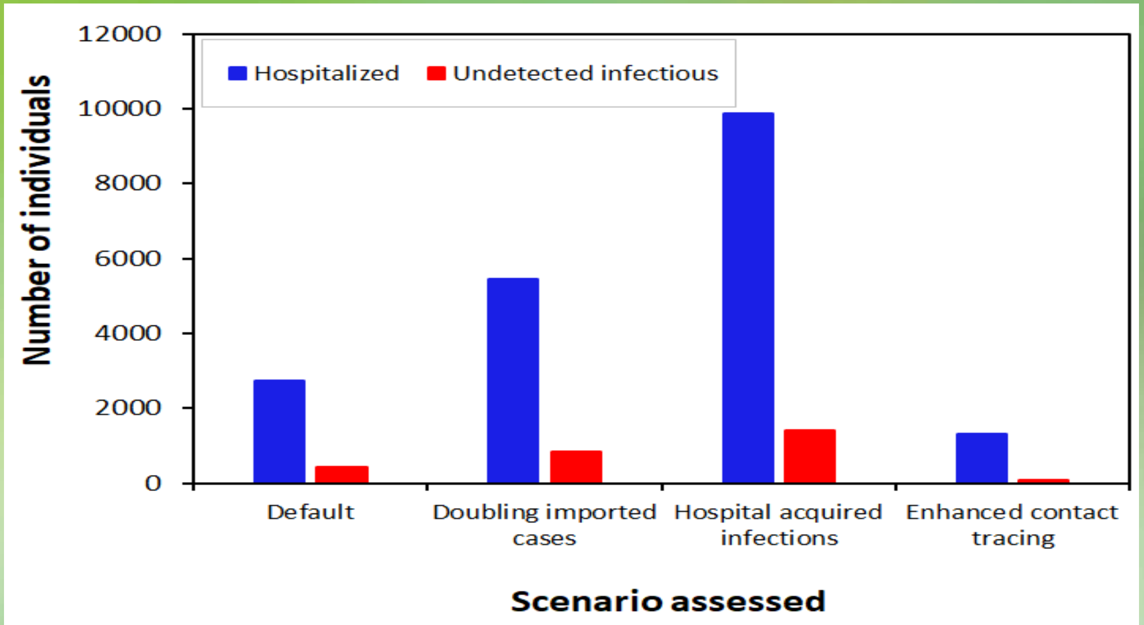
Findings – On number of imported cases (3)

- The disease can only be wiped out within the simulated period of 365 days if the latently infected are **also** blocked from entry. This can be done/achieved through adoption of alternative non-risky means of essential cargo delivery (e.g. by rail and ship services)

- One would block the latently infected individuals by effective screening at entry point – asking then the travel origin history and if from high risk neighboring countries areas then deny entry

Findings – On contact tracing and hospital acquired infections (1)

- The figure below depicts simulation results on the role of contact tracing and effect of hospital acquired infections on disease burden



Findings - On contact tracing and hospital acquired infections (2)

On enhanced contact tracing:

- Contract tracing also helps to remove latently infected individuals from the community before they become infectious

- By ensuring that after two months twice as many latently infected individuals are traced and all other infectious individuals are traced within one day (as was subsequently done for truck drivers), then 52% of peak hospitalization needs and 83% of undetected cases would be averted

Findings - On contact tracing and hospital acquired infections (3)

On hospital-acquired infections:

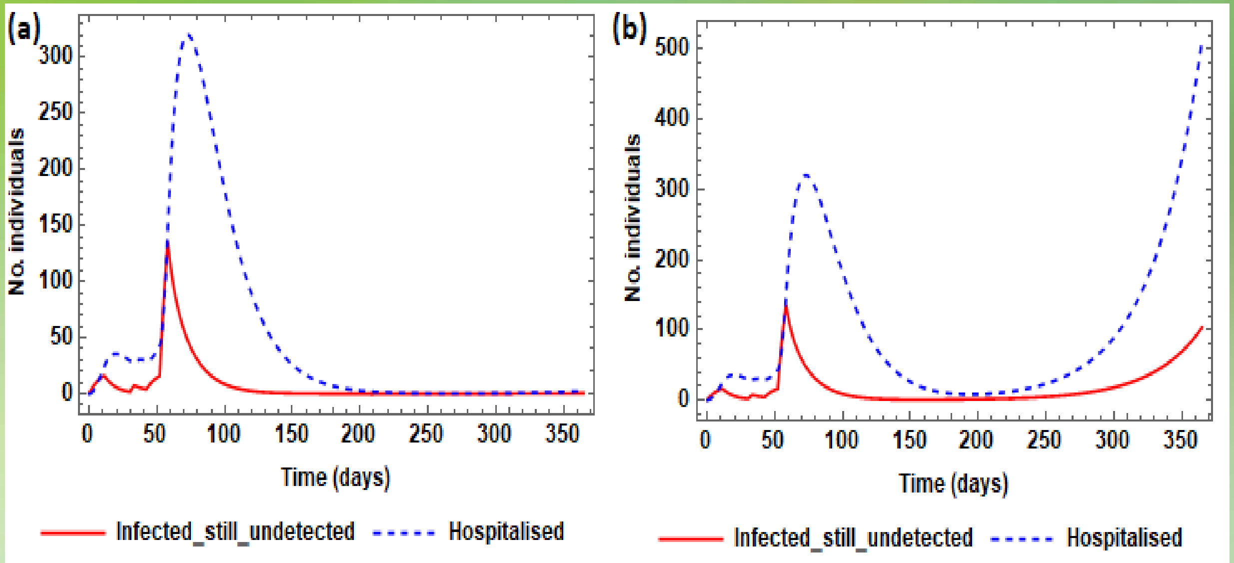
- The government's early mitigation of hospital acquired infections may have averted thousands of subsequent hospitalizations
- Introducing hospital-acquired infections at a mere 12% rate compared with the un-hospitalized infectious after two months would increase the maximum number of hospitalized on a given day to 10,000 and the undetected infected cases to 2000 within 300 days from the first case

Findings - On contact tracing and hospital acquired infections (4)

- This study notes that even with a reduced transmissibility of only 12% within hospital settings, the resulting disease spill-over to the community would increase the maximum daily demand for hospital beds by 260% in a period of one year, while doubling of imported cases leads to 100% increase in the daily demand due to the associated secondary infections

Findings - On the possibility of a second wave of infection (1)

- Timing of effective phased-out ease of lockdown to avoid the possibility of re-emergence of a second wave of infection is everyone's worry. Results from our simulations gives the indicators of developing a second wave



Findings - On the possibility of a second wave of infection (2)

- Even in an ideal situation with neither new imported cases nor occurrence of hospital acquired infections after two months, 75% of population can only be effectively released from lockdown after 210 days (around October 2020) if the possibility of having a second wave of infection is to be mitigated

- Easing lockdown from 10% to 30% after two months followed by up to 75% susceptible after 150 days of lockdown (translating to around August 2020 is a case of too many and too soon) the remaining infected individuals are enough to initiate an even bigger second wave of infection

Key conclusions (1)

- Without significantly altering the current situation, measures on partial lockdowns and use of masks are insufficient to stop COVID-19 spread and as such the disease will remain endemic in the population for the entire simulated period of 365 days

- Among all the assessed scenarios, the disease would only be wiped out during the first year in the case where there are no infected arrivals beyond the first two months and in this case the disease would be wiped out within 200 days

Key conclusions (2)

- With the worrying situation of increasing reported cases in our neighbouring countries, the impact of Uganda's interventions would be greatly affected as results show that increasing the number of imported cases would almost triple both the maximum number of hospitalized individuals and the number of undetected infected cases

Key conclusions (3)

- Screening of truck drivers faces a challenge of reagent and kits limitation, imperfect test accuracy, arrival of asymptomatic and latently infected individuals that may pass as false negatives during screening as well as the porosity of some of the national borders. Thus, adoption of alternative less-risky means of essential cargo delivery (e.g., by rail and ship services) combined with quarantining of all entrants for a duration not shorter than the incubation period should be enforced

Key conclusions (4)

- Amidst challenges of social-economic impact of COVID-19, agitation of lifting lockdown may downplay the impact of intervention measures and the study findings highlight the importance of optimal timing and magnitude of easing of lockdown. Effectively phased-out ease of lockdown needs to be well studied and executed to avoid the possibility of a second wave of infection

- When lockdowns are hurriedly lifted to a 75% susceptible level, the yet-to-be detected cases in the community, no matter how few, have potential to start a second and more disastrous epidemic wave

Recommendations (1)

- It is not advisable to ease lockdown by releasing 50% of susceptible population for the Ugandan situation with current 3200 hospital beds and not all are of ICU-like capacity, because within 100 days the COVID-19 related hospitalization demand would have already overwhelmed the current resources

- Since the consequences of hospital acquired infections go beyond merely increasing the number of cases, their mitigation should be given high priority- provide well catered for isolation facilities for health workers, effective PPE, increase on number of health personnel to reduce overload and overwork, provide basic compensational incentives to all frontline workers for keeping up motivation

Recommendations (2)

- Enhanced surveillance and contact tracing, gradual easing lockdown by releasing smaller percentages of susceptible individuals from lockdown can still be safely executed sooner than the optimum 210 days for the attainment of up to 75% susceptible level

Recommendations (3)

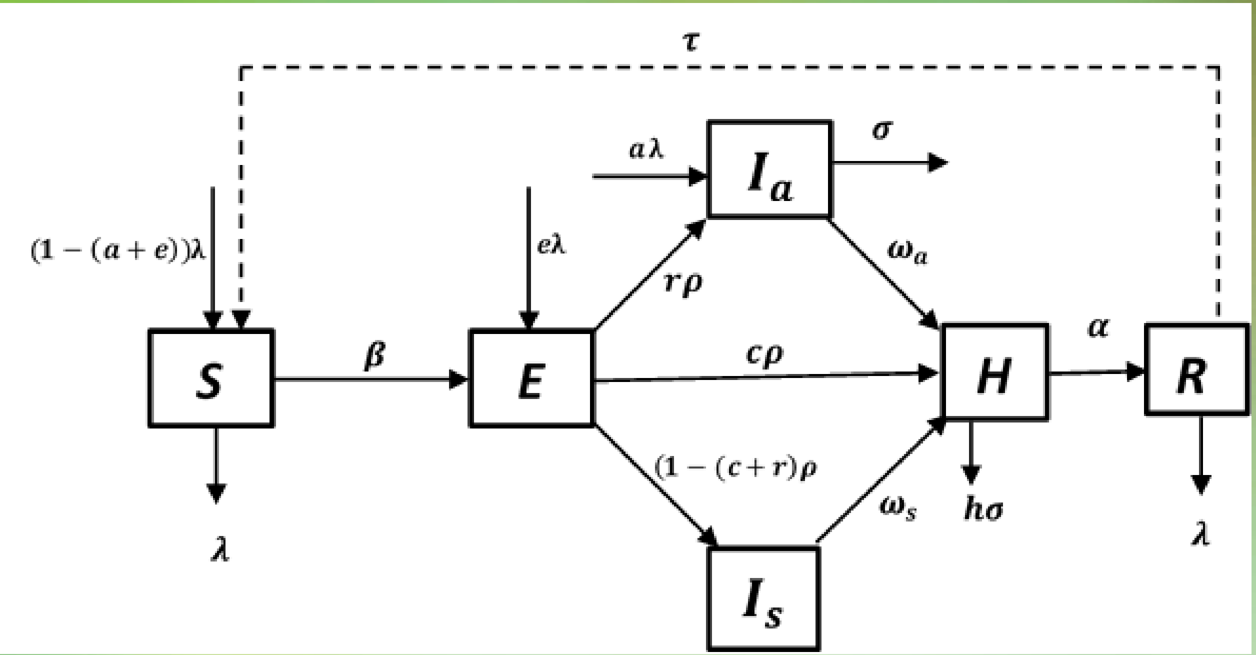
- The issue of eliminating truck drivers mingling at service and testing centres at border crossings should be reinforced – preferably, government should set up treatment and isolation facilities as close as possible to the testing border points not to; overwhelm the existing regional facilities, optimize deployment of the scarce resources and also to minimize stigma and community discontent and anxiety. This would in addition reduce the time that frontline workers are exposed to the risk of infection amidst lack of well-equipped facilities and ambulances

Recommendations (4)

On truck drivers: Since latently infected individuals can only be detected after surpassing the latent period, efforts should be put on obtaining information on where the drivers have been a few days before arrival to understand the risk of admitting persons from high risk regions of neighbouring countries

Where is Math Model?

Compartmental model for COVID-19 transmission dynamics



More Math Models?

- Based on the diagram we have following system of odes for the transmission dynamics of the disease in Uganda

$$\frac{dS}{dt} = \big(1-(a+e)\big)\lambda N - \frac{\beta b S(I_a + I_s + gH)}{N} + \tau R - \lambda S$$

$$\frac{dE}{dt} = e\lambda N + \frac{\beta b S(I_a + I_s + gH)}{N} - \rho E$$

$$\frac{dI_a}{dt} = a\lambda N + r\rho E - \sigma I_a - \omega_a I_a$$

$$\frac{dI_s}{dt} = \big(1-(c+r)\big)\rho E - \sigma I_s - \omega_s I_s$$

$$\frac{dH}{dt} = c\rho E + \omega_a I_a + \omega_s I_s - h\sigma H - \alpha H$$

$$\frac{dR}{dt} = \alpha H - \tau R - \lambda R$$

Project Team

- The study was led by Prof. Joseph Y.T. Mugisha (Department of Mathematics, Makerere University) as Principal Investigator

- Along with the following Co-Investigators:
  - Dr. Amos Ssematimba (Department of Mathematics, Gulu University)
  - Dr. Juliet Nakakawa Nsumba (Department of Mathematics, Makerere University)
  - Dr. Joseph Ssebuliba (Department of Mathematics, Makerere University)
  - Dr. Cliff Richard Kikawa (Department of Economics and Statistics, Kabale University)

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