The Role of Pet Ownership and Adoption on the Spread of Rabies Virus among Stray and Pet Dogs: A Latin Hypercube Sampling-Partial Rank Correlation Coefficient (LHS-PRCC) Sensitivity Analysis

Zython Paul T. Lachica[1,2*], Jaf Azriel Q. Duban[2], Natalia Claudia U. Uy[2], Patricia L. Monilar[2], Therese Marie A. Arceo[2], and May Anne E. Mata[1]

[1] Department of Mathematics, Physics, and Computer Science, University of the Philippines Mindanao, Davao City, Philippines and
[2] Senior High School Department, Davao Christian High School, V. Mapa Street, Davao City; ***ztlachica@up.edu.ph**

DARE TO
RESEARCH GRANT

BACKGROUND

- In the Philippines, about 200-300 human deaths are due to dog rabies infection and dog rabies cases continues to fluctuate (see Fig. 1).
- Public and private parties in Davao City are highlighting **Responsible Pet Ownership** and **Adopt-a-dog** Program to curb rabies transmission among dogs and humans.
- Objective: **To provide science-based support for the ordinance and program implementation of ARRPO** (see Fig. 2).

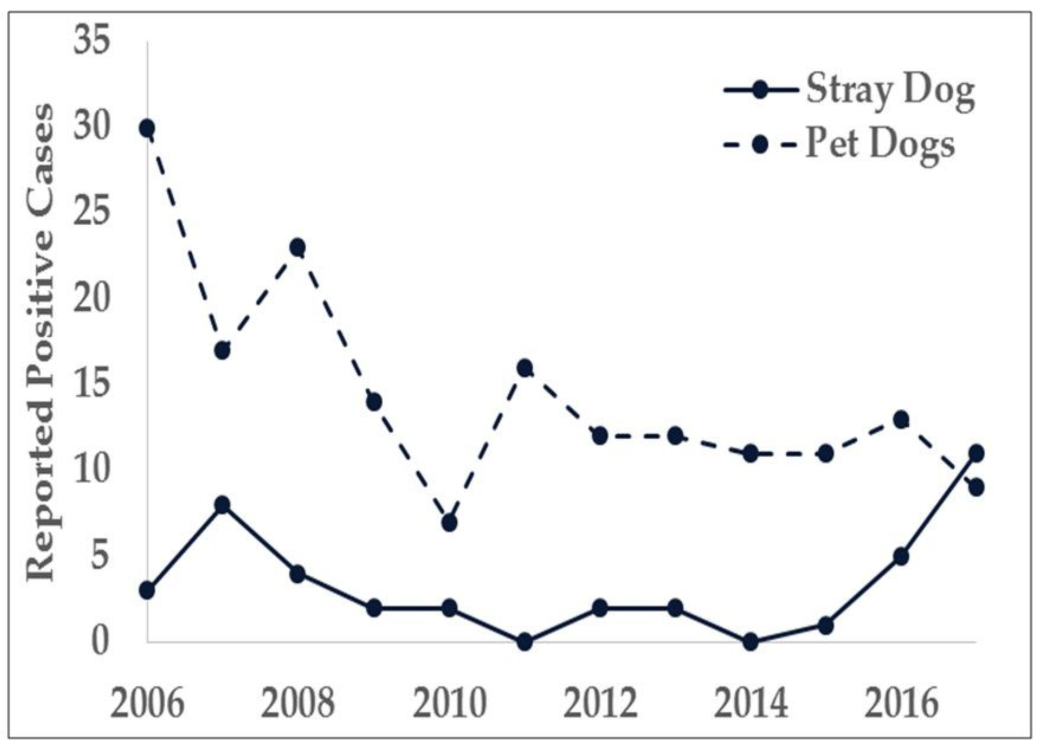

Fig. 1. Annual reported rabies cases in Davao City, Philippines from 2006 to 2007.

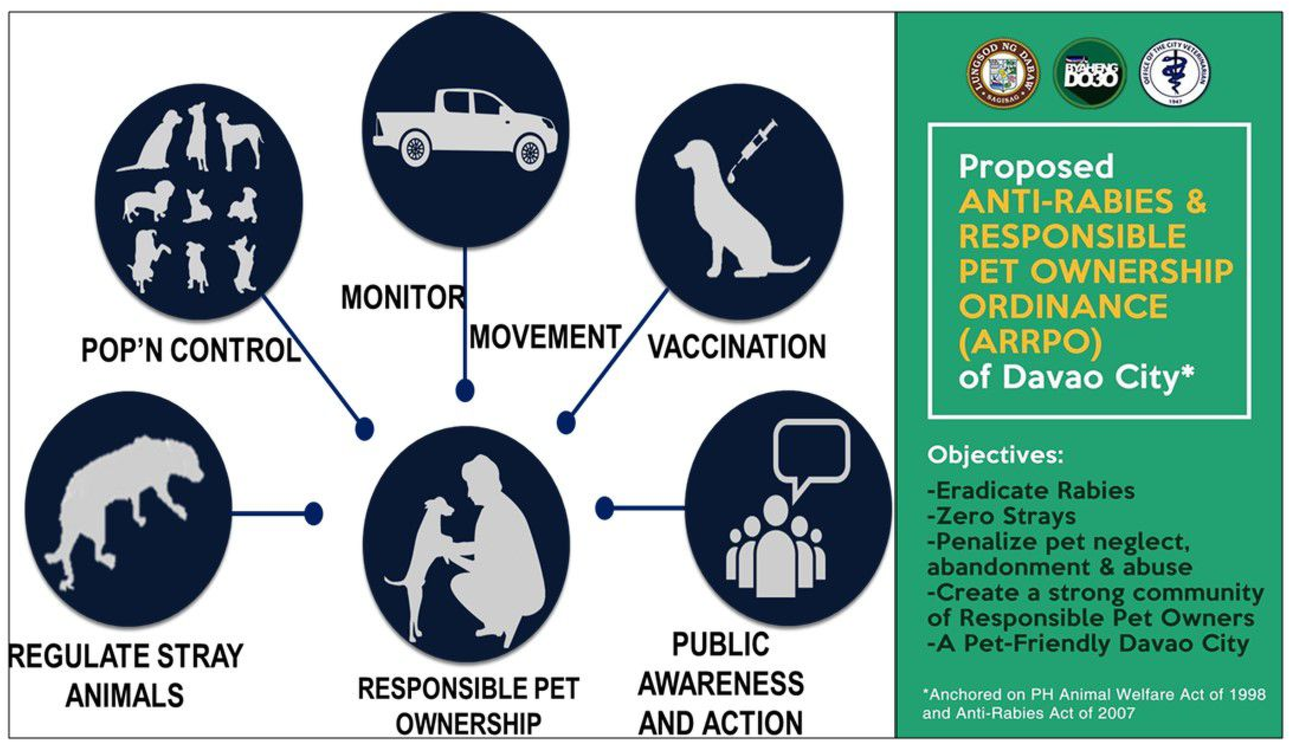

Fig. 2. Left: The facets of responsible pet ownership. Right: The proposed ARRPO of Davao City and its Adopt-a-Dog program.

LHS-PRCC METHODOLOGY APPLIED TO A RABIES EPIDEMIC MODEL

Model Formulation

An SEIR (Susceptible-Exposed-Infectious-Recovered) epidemiological model was formulated based on the rabies model [1] and [2] with slight modification on parameter definitions and basic assumptions. The interactions of the dynamic variables along with the parameters are described in the schematic diagram shown in Fig. 3.

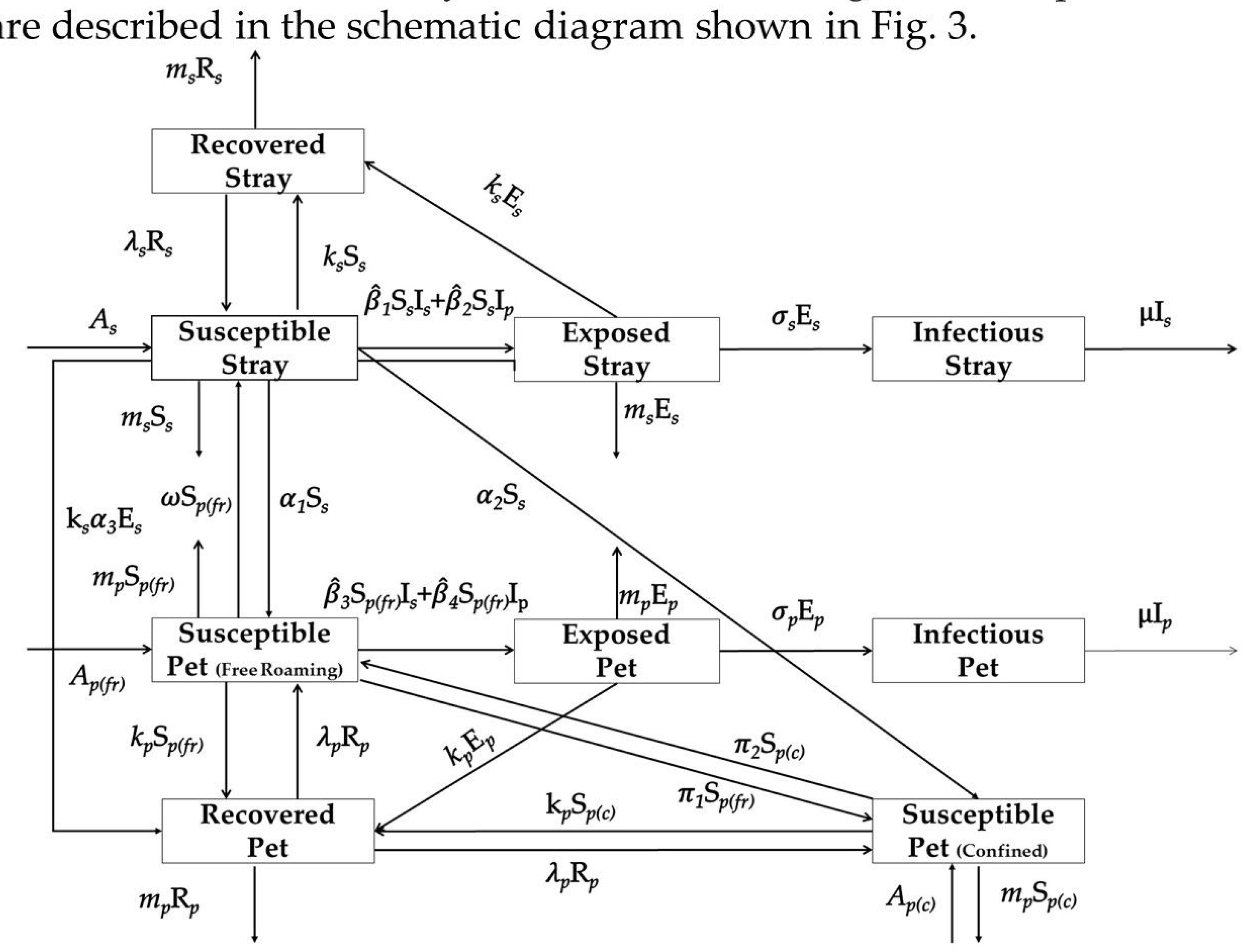

Fig. 3. SEIR-based model for the rabies transmission among pet and stray dogs.

Model Parameters

A – annual crop of dogs
m – natural mortality rate of dogs
λ – rate of loss of vaccine immunity
k – vaccination rate
$1/\sigma$ – incubation period
μ – mortality rate of rabid dog
α_i – rate of adoption for
i = 1 (stray to free-roaming pet dogs), 2 (stray to confined pet dogs), & 3 (exposed stray dogs with compulsory vaccination)
π_i – pet ownership status
for i = 1 (intensified pet ownership, i.e., free-roaming to confined status) & 2 (relieved pet ownership, i.e., confined to free-roaming status)
ω – pet dog loss rate (free-roaming pet dogs to stray)
β_i – direct transmission rate of rabies for i = 1 (I_s to S_s), 2 ($I_{p(fr)}$ to S_s), 3 (I_s to $S_{p(fr)}$), and 4 ($I_{p(fr)}$ to $S_{p(fr)}$).
The subscripts s, p, $p(fr)$, and $p(c)$ refer to stray, pet, free-roaming pet, and confined pet, respectively.

Model Equations

The model is a system of nine ordinary differential equations:

$$\frac{dS_s}{dt} = A_s + \lambda_s R_s + \omega S_{p(fr)} - k_s S_s - \beta_0 S_s I_s - \alpha_2 S_s - \alpha_1 S_s - m_s S_s,$$

$$\frac{dE_s}{dt} = \hat{\beta}_1 S_s I_s + \hat{\beta}_2 S_s I_p - k_s E_s - \sigma_s E_s - m_s E_s - k_s \alpha_3 E_s,$$

$$\frac{dI_s}{dt} = \sigma_s E_s - \mu I_s,$$

$$\frac{dR_s}{dt} = k_s S_s + k_s E_s - \lambda_s R_s - m_s R_s,$$

$$\frac{dS_{p(fr)}}{dt} = A_{p(fr)} + \alpha_1 S_s + \pi_2 S_{p(c)} + \lambda_p R_p - m_p S_{p(fr)} - \omega S_{p(fr)} - \left(\beta_3 S_{p(fr)} I_s + \beta_2 S_{p(fr)} I_p\right) - \pi_1 S_{p(fr)} - k_p S_{p(fr)},$$

$$\frac{dS_{p(c)}}{dt} = A_{p(c)} + \lambda_p R_p + \pi_1 S_{p(fr)} + \alpha_2 S_s - k_p S_{p(c)} - \pi_2 S_{p(c)} - m_p S_{p(c)},$$

$$\frac{dE_p}{dt} = \beta_3 S_{p(fr)} I_s + \beta_4 S_{p(fr)} I_p - m_p E_p - \sigma_p E_p - k_p E_p,$$

$$\frac{dI_p}{dt} = \sigma_p E_p - \mu I_p,$$

$$\frac{dR_p}{dt} = k_s \alpha_3 E_s + k_p S_{p(fr)} + k_p E_p + k_p S_{p(c)} - 2\lambda_p R_p - m_p R_p.$$

Outcome Measure

The basic reproduction number $\Re_0$, which is the ave. number of secondary infections caused by one infected individual in a completely susceptible population, is the outcome measure in this analysis. The basic reproduction is defined by

$$\Re_0 \approx \frac{1}{2}\left(\frac{\beta_1 S_s^0 \sigma_s \left(k_p + m_p + \sigma_p\right) + \beta_4 S_{p(fr)}^0 \sigma_p \left(k_s + m_s + \sigma_s + \alpha_3 k_s\right)}{\left(k_p + m_p + \sigma_p\right)\left(k_s + m_s + \sigma_s + \alpha_3 k_s\right)\mu}\right),$$

where S_s^0 and $S_{p(fr)}^0$ are the disease-free equilibria (i.e., $E_s^0 = E_p^0 = 0$). $\Re_0$ is the maximum eigenvalue of $-\boldsymbol{T}\boldsymbol{\Sigma}^{-1}$ where $\boldsymbol{T}$ and $\boldsymbol{\Sigma}$ are the transmission and transition matrices, respectively [3].

LHS-PRCC Procedure

LHS-PRCC is useful in knowing the parameters in a model to which the outcome measure is most sensitive [4] or to which parameters impact the R0 significantly [5].

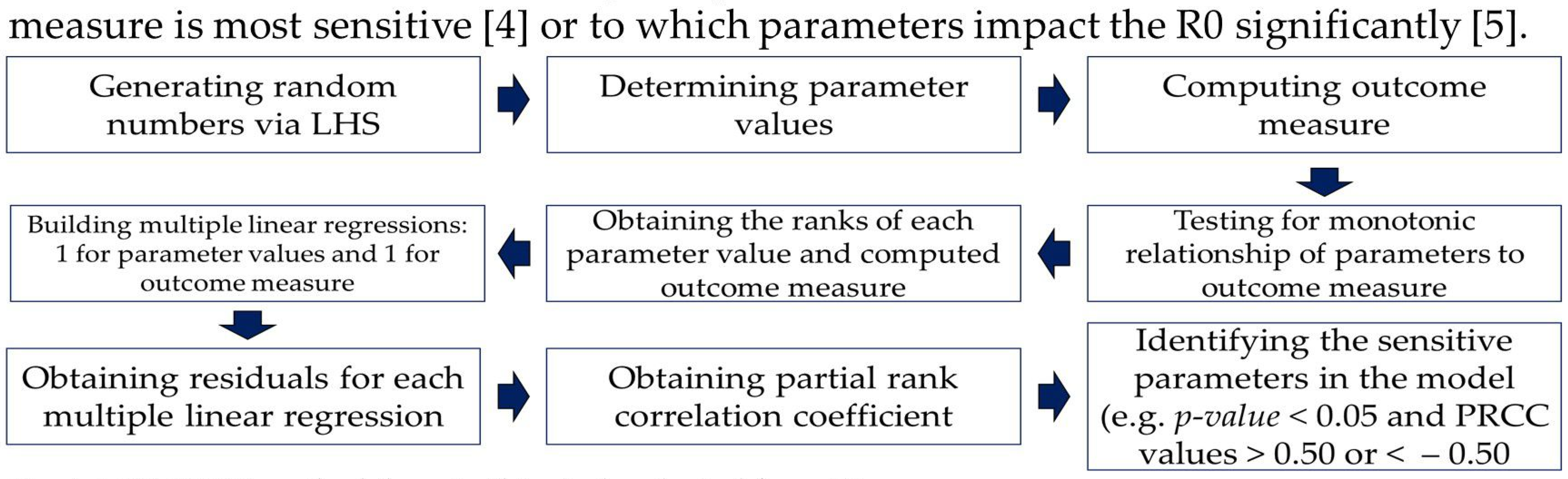

Fig. 4. LHS-PRCC methodology in this study adapted from [4].

RESULTS

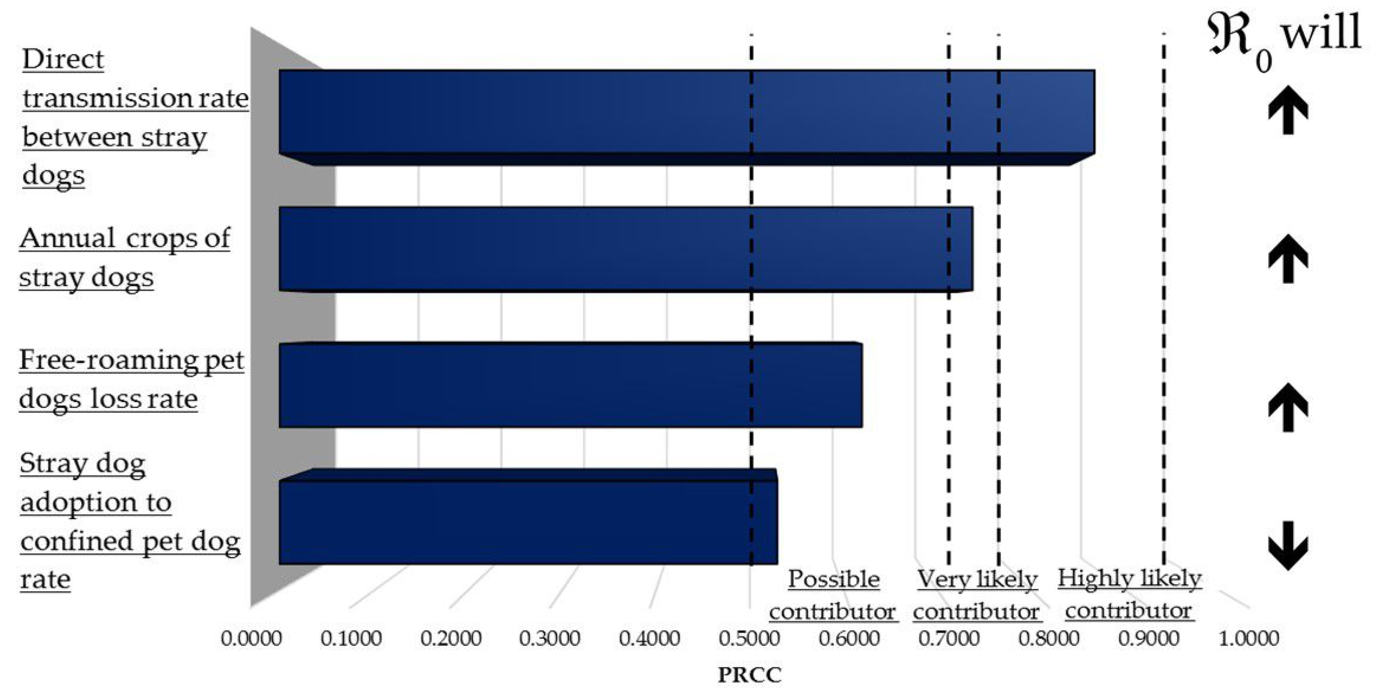

Fig. 5. LHS-PRCC results. The ranges for the relative contribution of each sensitive parameter to R0 is based from [4].

POLICY INSIGHTS

Dog Impounding

to control dog population and transmission rate.

Micro-chipping

to facilitate dog tracking and prevent from losing dogs.

No-to-Dog-Abandonment

raise awareness on RPO aside from clinical veterinary needs (e.g. implications of dog population).

Pet Adoption

to lessen the stray dog population. However, when adopting, **dogs should not freely roam** (e.g. only inside the house/adoption center or must be leashed when strolling outside).

MAIN REFERENCES

[1] Zhang, J., Jin, Z., Sun, G.Q., Zhou, T. and Ruan, S., 2011. Analysis of rabies in China: transmission dynamics and control. *PLoS one*, 6(7), p.e20891.
[2] Leung, T. and Davis, S.A., 2017. Rabies vaccination targets for stray dog populations. Frontiers in veterinary science, 4, p.52.
[3] Diekmann, O., Heesterbeek, J.A.P. and Roberts, M.G., 2009. The construction of next-generation matrices for compartmental epidemic models. Journal of the Royal Society Interface, 7(47), pp.873-885.
[4] Gomero, Boloye, "Latin Hypercube Sampling and Partial Rank Correlation Coefficient Analysis Applied to an Optimal Control Problem." Master's Thesis, University of Tennessee, 2012.
[5] Wu, J., Dhingra, R., Gambhir, M. and Remais, J.V., 2013. Sensitivity analysis of infectious disease models: methods, advances and their application. Journal of The Royal Society Interface, 10(86), p.20121018.