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# Systems Approach to Localize Tipping Points for the Emergency Services

COVID-19

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# Content and Agenda

1. Introduction, Situation, Problem
2. Model and Methodology
3. Assumptions and Parameter
4. Baseline Scenario and General Effects
5. Scenarios: Modulated Parameters
6. Conclusion and Outlook

# 1. Introduction, Situation, Problem

CORONAVIRUS

**Laredo hospitals 'at capacity'; mayor says 'things are critical' after 10 more COVID-19 deaths**

[1] https://www.myhighplains.com/news/laredo-hospitals-at-capacity-mayor-says-things-are-critical-after-10-more-covid-19-deaths/

**Just 15% of Alabama ICU beds are available and officials are concerned**

[2] https://www.al.com/news/2020/08/just-15-of-alabama-icu-beds-are-available-and-officials-are-concerned.html

**56 Florida hospital ICUs have hit capacity**

[3] https://www.cnn.com/2020/07/07/health/us-coronavirus-tuesday/index.html

CALIFORNIA

**'We're just overwhelmed': The view from inside hospitals as coronavirus surge hits**

[4] https://www.healthleadersmedia.com/covid-19/were-just-overwhelmed-view-inside-ca-hospitals-coronavirus-surge-hits

CORONAVIRUS NEW YORK CITY

**Coronavirus News: NYC hospitals nearing capacity with COVID-19 patients**

[5] https://abc7ny.com/nyc-hospitals-javits-center-coronavirus-news/6080435/

**Dominican Republic hospitals hit capacity for COVID-19 patients**

[6] https://www.miamiherald.com/news/nation-world/world/americas/article244728677.html

# 1. Introduction, Situation, Problem

*Virus's Toll on N.Y. Police: 1 in 6 Officers Is Out Sick*

[7] https://www.nytimes.com/2020/04/03/nyregion/coronavirus-nypd.html

U.S. | NEW YORK | CRIME

**New York Police Fight Coronavirus in Department as 1 in 5 Go Out Sick**

Protocols and routines shift; department distributes thousands of masks, gloves and wipes

[8] https://www.wsj.com/articles/new-york-police-fight-coronavirus-in-department-as-1-in-5-go-out-sick-11586366632

**12 NYPD members die from coronavirus; 20% of uniformed officers sick**

[9] https://fox8.com/news/coronavirus/12-nypd-members-die-from-coronavirus-20-of-uniformed-officers-sick/

HEALTH AND SCIENCE

**More than 1,000 New York City police officers have the coronavirus as 911 calls hit records**

[10] https://www.cnbc.com/2020/04/01/more-than-1000-new-york-city-police-officers-are-infected-with-coronavirus.html

# 1. Introduction, Situation, Problem

COVID causes a multitude of stressors for systems and services

▼

Possibility of Collapse and or System Transition

=

Provides predictive power ⇦ **Tipping Point**

**How to find/define?**

⇨ Research Gap

**Quantifiable and Objective Assessment of Tipping Points**

# 1. Introduction, Situation, Problem

## Complexity

**Complexity**

*A large number of interacting components, whose emergent "global'' behavior is more than can be explained or predicted from understanding the sum of the behavior of the individual components.*

<u>Dynamic</u>

<u>Short Term</u>

Behavior unpredictable due to non-linearities

<u>Long Term</u>

Evolvement over time and adaptation to environment

<u>Structural</u>

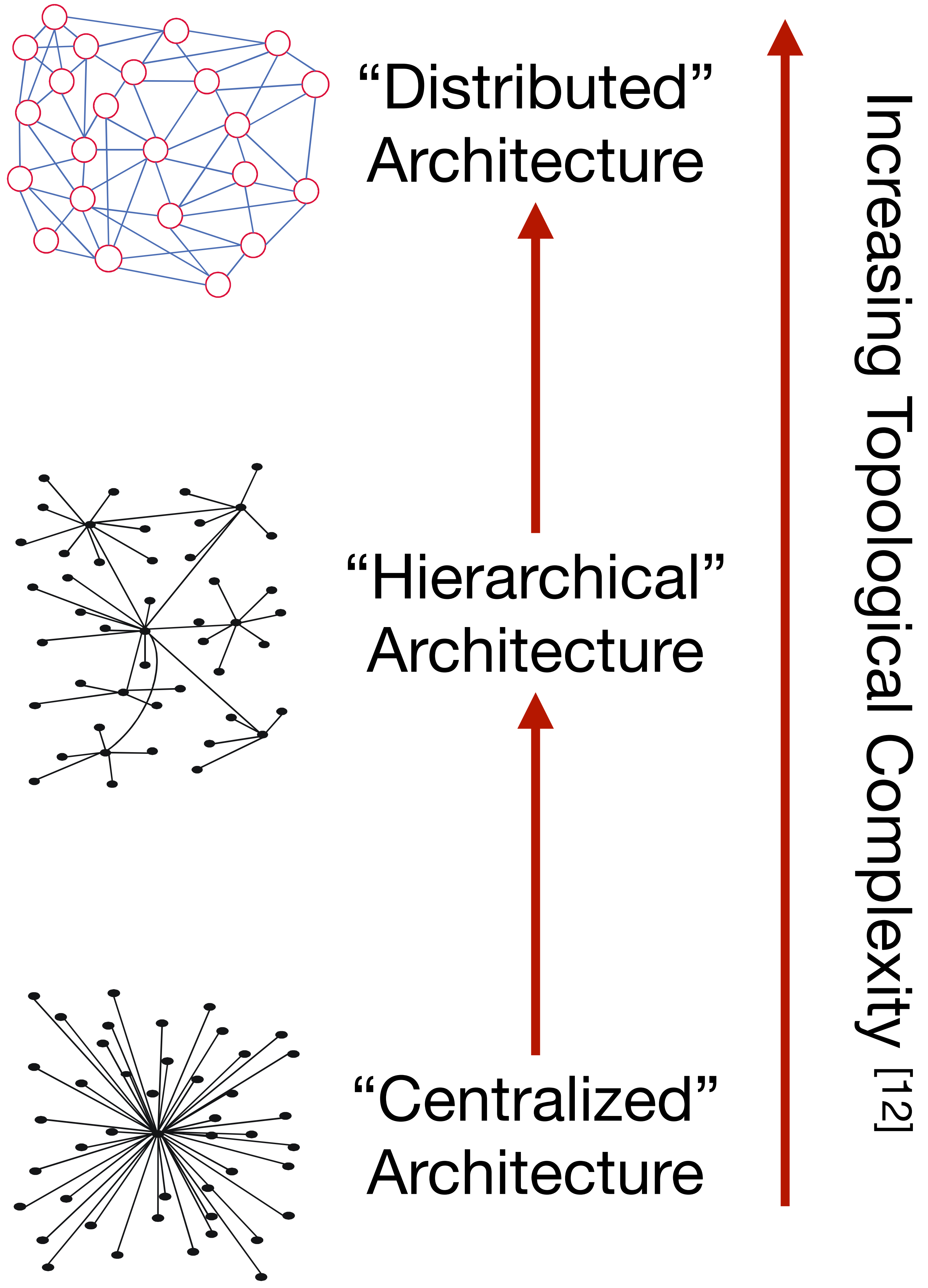
- Size
- Connectivity
- Topology

# 1. Introduction, Situation, Problem

## Complexity

<u>Attributes of Complex Systems</u>

- Potential for unexpected behavior
- Non-linear interactions
- Circular causality and feedback loops
- Potential logical paradoxes and strange loops
- Small changes may lead to emergence unpredictable behavior [11]
- Often associated with increased fragility and vulnerability
- Distinguished from complicated systems by emergence and self-organization




[11] P. Erdi, Complexity Explained, Springer Science & Business Media, 2007.
[12] K. Sinha, "Structural Complexity and its Implications for Design of Cyber-Physical Systems," Doctor of Philosophy, Engineering Systems Division, Massachusetts Institute of Technology, 2014.

# 1. Introduction, Situation, Problem

## Tipping Point

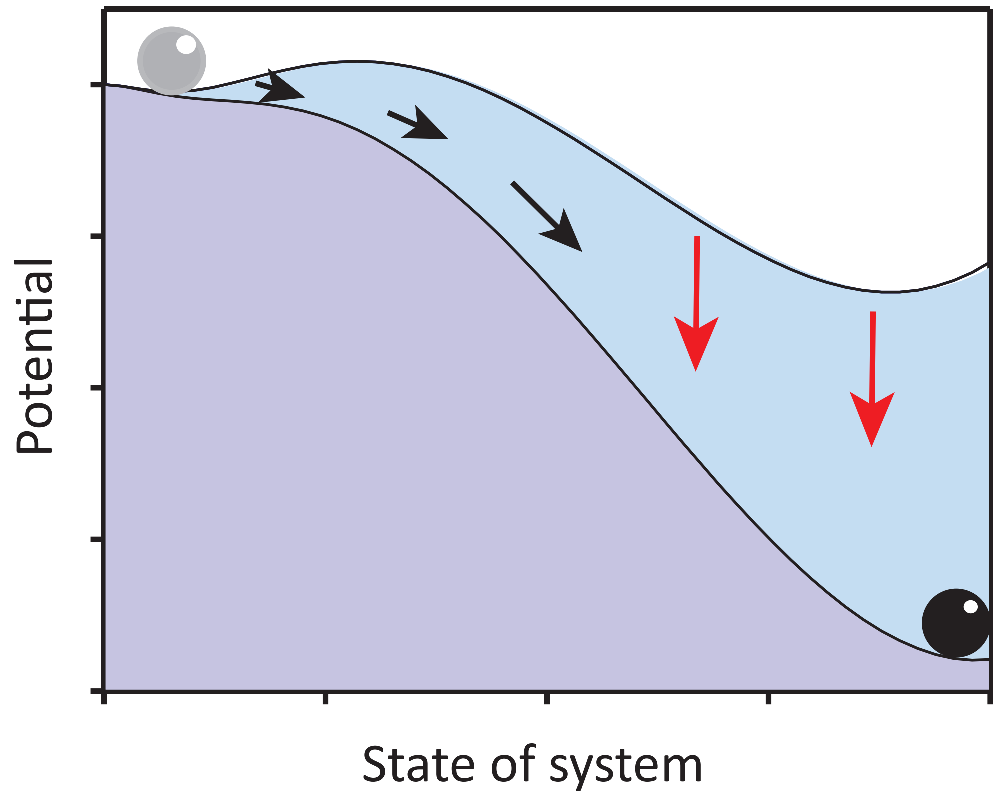
*Definition:*

When small changes to a system lead to a runaway process that causes major transitions. [13]

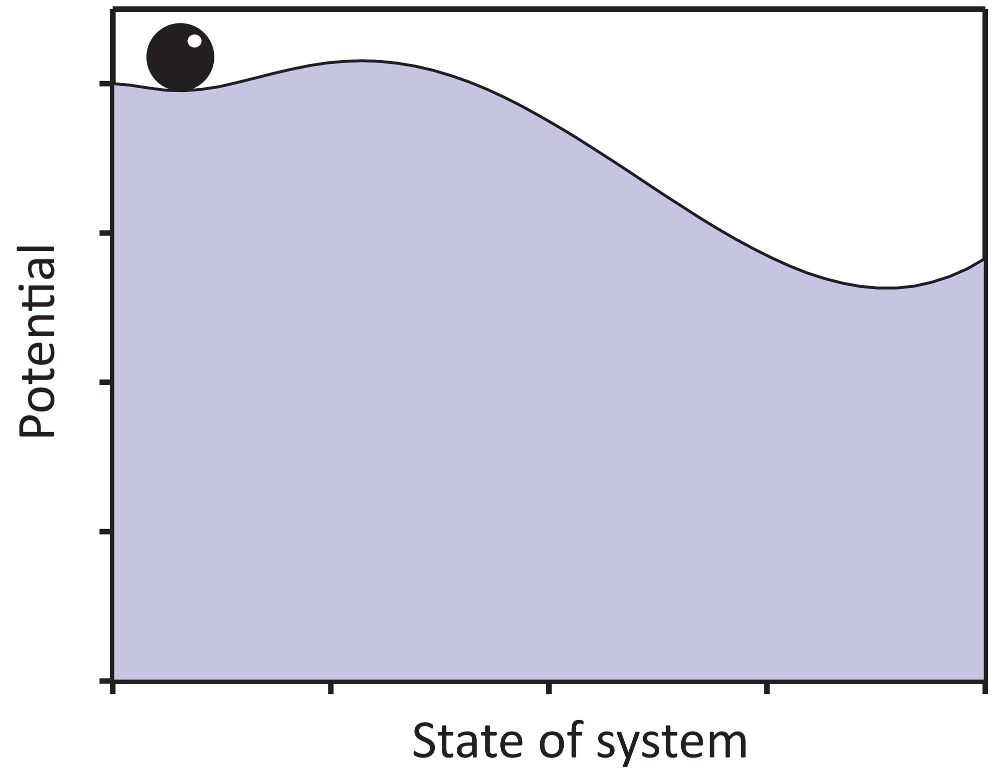
*Types of Tipping Points*

Tipping Point due to change in conditions ⇨ shift in underlying structure

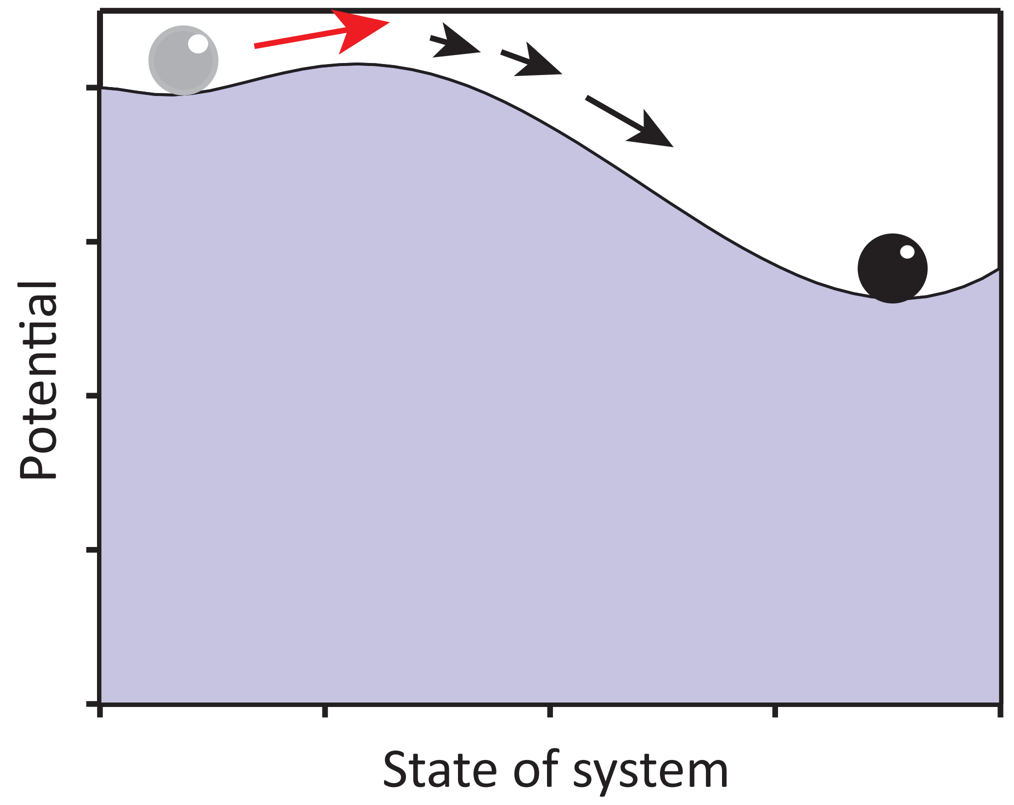
Tipping due to change in state ⇨ shift between steady-states




Original stability landscape




[14]





[13] M. Gladwell, *The Tipping Point*, 1st ed. New York, NY: Little, Brown and Company, 2000.
[14] E. H. van Nes et al., "What Do You Mean, 'Tipping Point'?," Trends in Ecology & Evolution, vol. 31, no. 12, pp. 902-904, 2016, doi: 10.1016/j.tree.2016.09.011.

# 2. Model and Methodology

- Simulation approach to dynamically model disease spread
- **Spread of the disease NOT based on reproduction factor**

  **⇨ contact rate**
- **Focus on emergency services**
- Introduced performance and capacity of emergency services
- Simulation of behavior and implications for the emergency services
- Variable performance/capacity due to prolonged stressors

**⇨ Dynamic Model**

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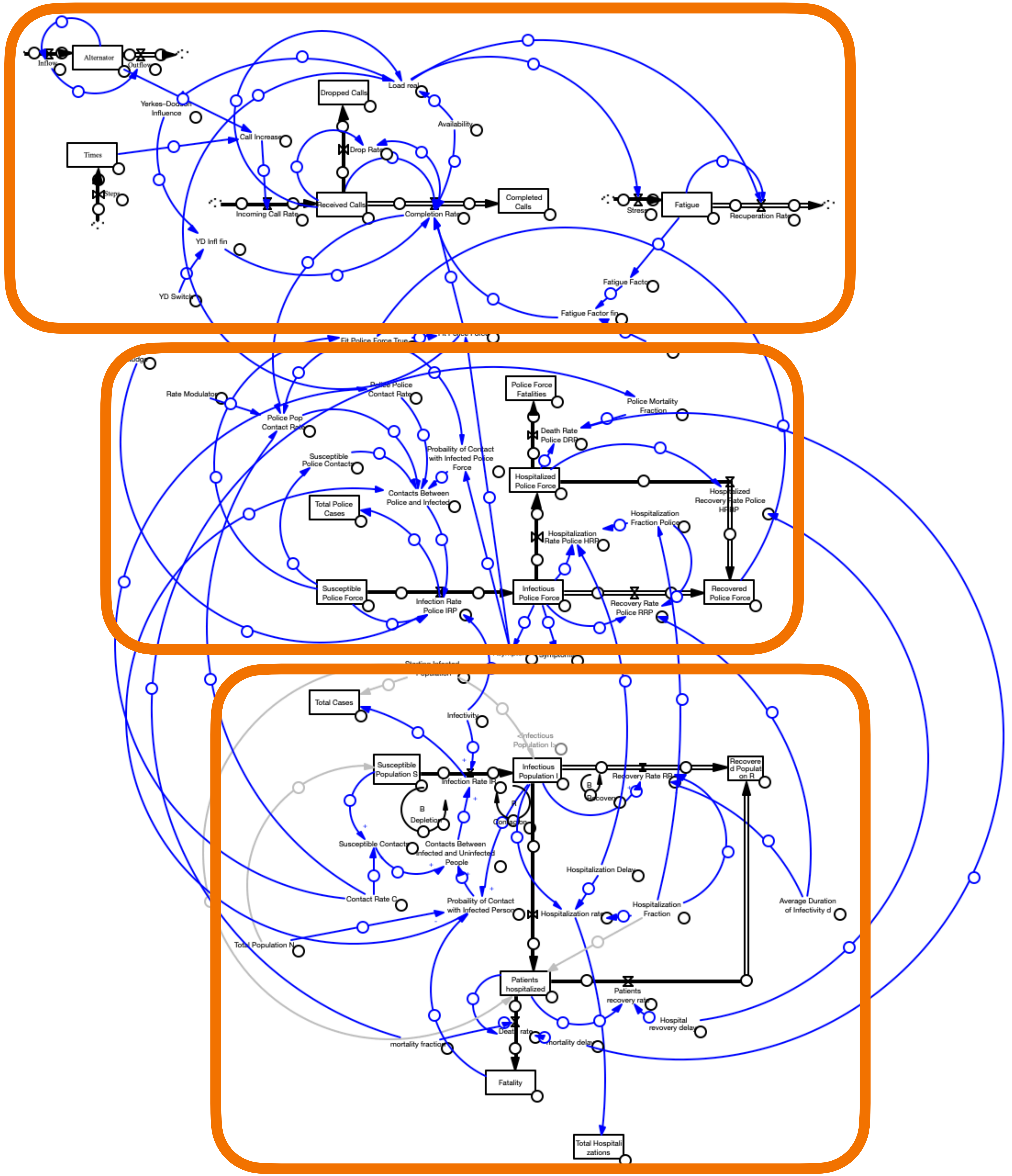
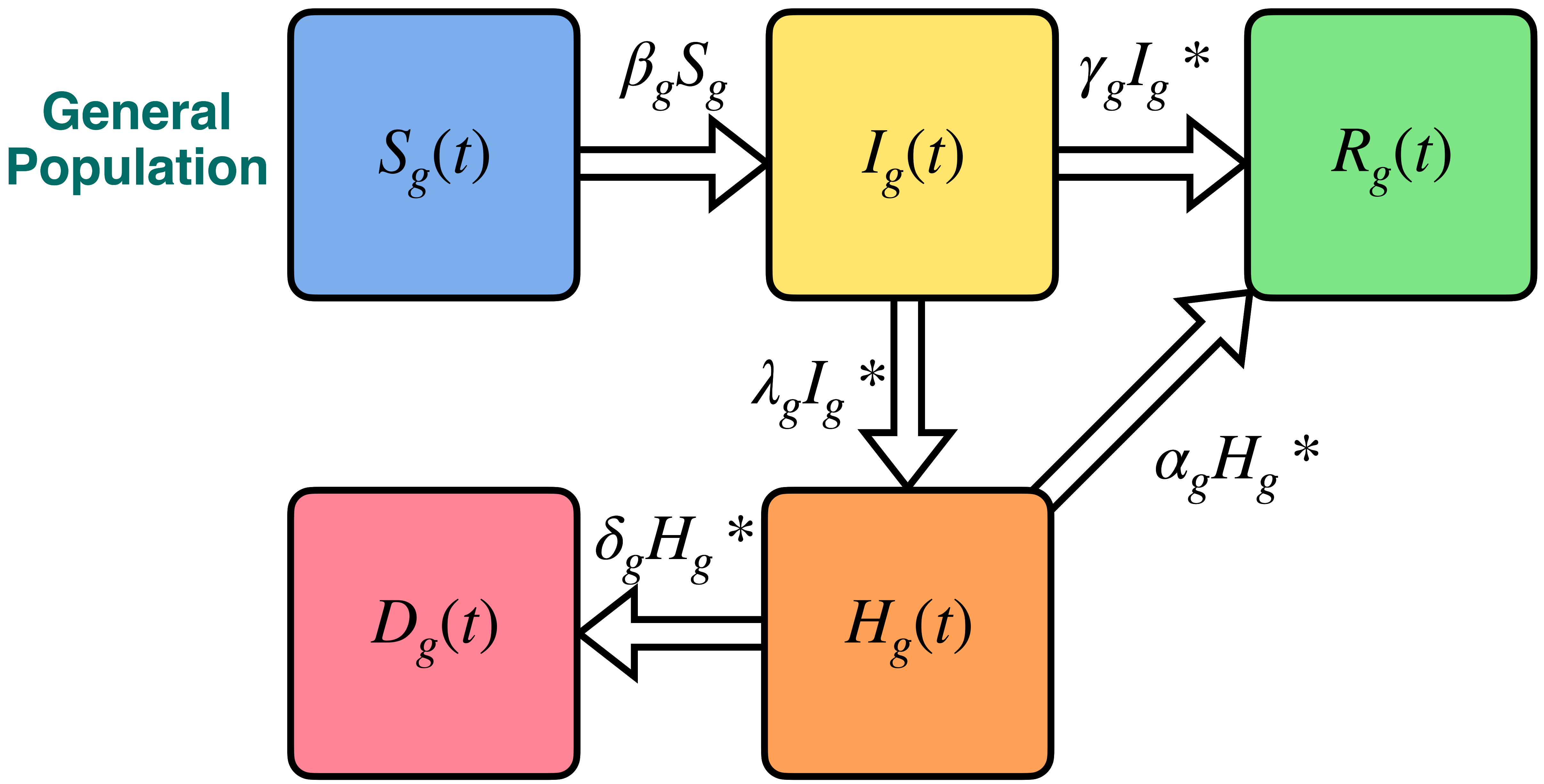


Alternator
Inflow
Outflow
Yerkes-Dodson Influence
Times
Steps
Dropped Calls
Load real
Availability
Call Increase
Drop Rate
Incoming Call Rate
Received Calls
Completion Rate
Completed Calls
Stress
Fatigue
Recuperation Rate
YD Infl fin
YD Switch
Fatigue Factor
Fatigue Factor fin
Fit Police Force True
Rate Modulator
Police Police Contact Rate
Police Pop Contact Rate
Police Force Fatalities
Police Mortality Fraction
Death Rate Police DRP
Probaility of Contact with Infected Police Force
Susceptible Police Contacts
Contacts Between Police and Infected
Hospitalized Police Force
Hospitalized Recovery Rate Police HRRP
Total Police Cases
Hospitalization Fraction Police
Hospitalization Rate Police HRP
Susceptible Police Force
Infection Rate Police IRP
Infectious Police Force
Recovery Rate Police RRP
Recovered Police Force
Total Cases
Infectivity
Susceptible Population S
Infection Rate IR
Infectious Population I
Recovery Rate RR
Recovered Population R
Depletion
Contagion
Susceptible Contacts
Contacts Between Infected and Uninfected People
Hospitalization Delay
Hospitalization rate
Hospitalization Fraction
Average Duration of Infectivity d
Contact Rate C
Probability of Contact with Infected Person
Total Population N
Patients hospitalized
Patients recovery rate
Hospital revovery delay
Death rate
mortality delay
mortality fraction
Fatality
Total Hospitalizations

# 2. Model and Methodology

## Pandemic Progress Flowchart




*Equations For Both Sub-System*
*(x substitutes g and p):*

(I) Susceptible General Population:

$\dot{S}_x = -\beta_x S_x$ with $S_x(0) = S_{xo} \geq 0$

(II) Infectious General Population:

$\dot{I}_z = \beta_z S_x - \gamma_x I_x - \lambda_x I_x$ with $I_x(0) = I_{xo} \geq 0$

(III) Removed General Population (delayed):

$\dot{R}_x = \gamma_x I_x + \alpha_x H_x$ with $R_x(0) = R_{xo} \geq 0$

(IV) Hospitalized General Population (delayed):

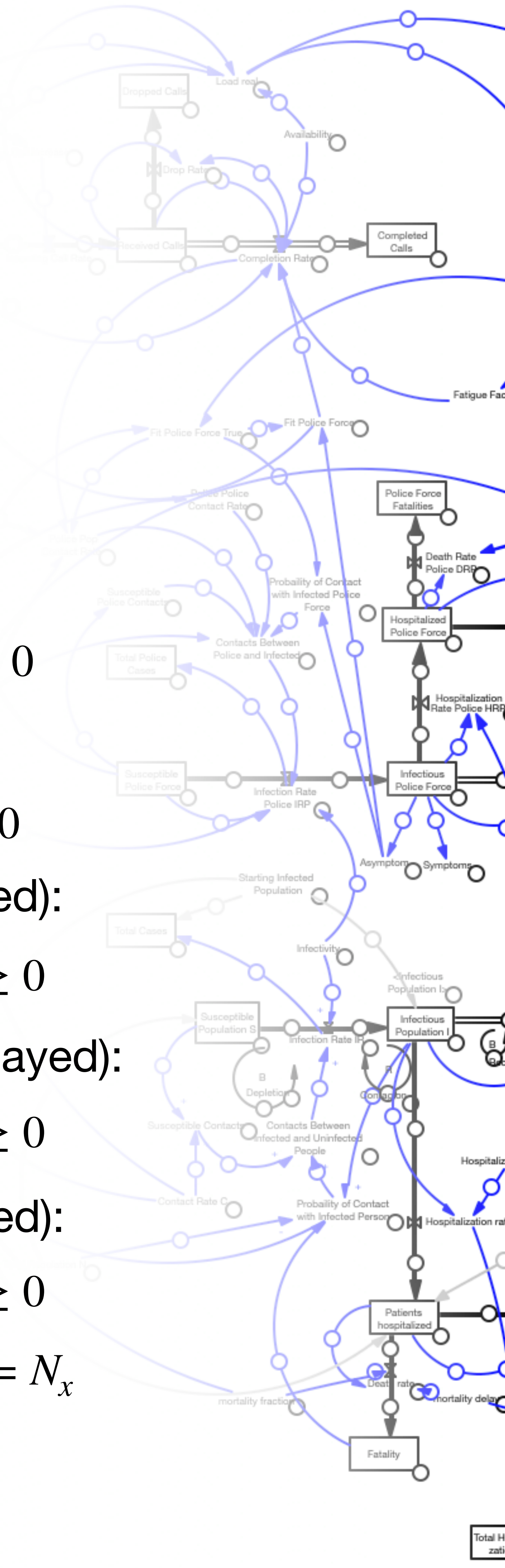
$\dot{H}_x = \lambda_x I_x - \delta_x H_x - \alpha_x H_x$ with $R_x(0) = R_{xo} \geq 0$

(V) Deceased General Population (delayed):

$\dot{D}_x = \delta_x H_x$ with $R_x(0) = R_{xo} \geq 0$

so that $S_x(t) + I_x(t) + R_x(t) + H_x(t) + D_x(t) = N_x$

and $\dot{S}_x + \dot{I}_x + \dot{R}_x + \dot{H}_x + \dot{D}_x = 0$



# 2. Model and Methodology

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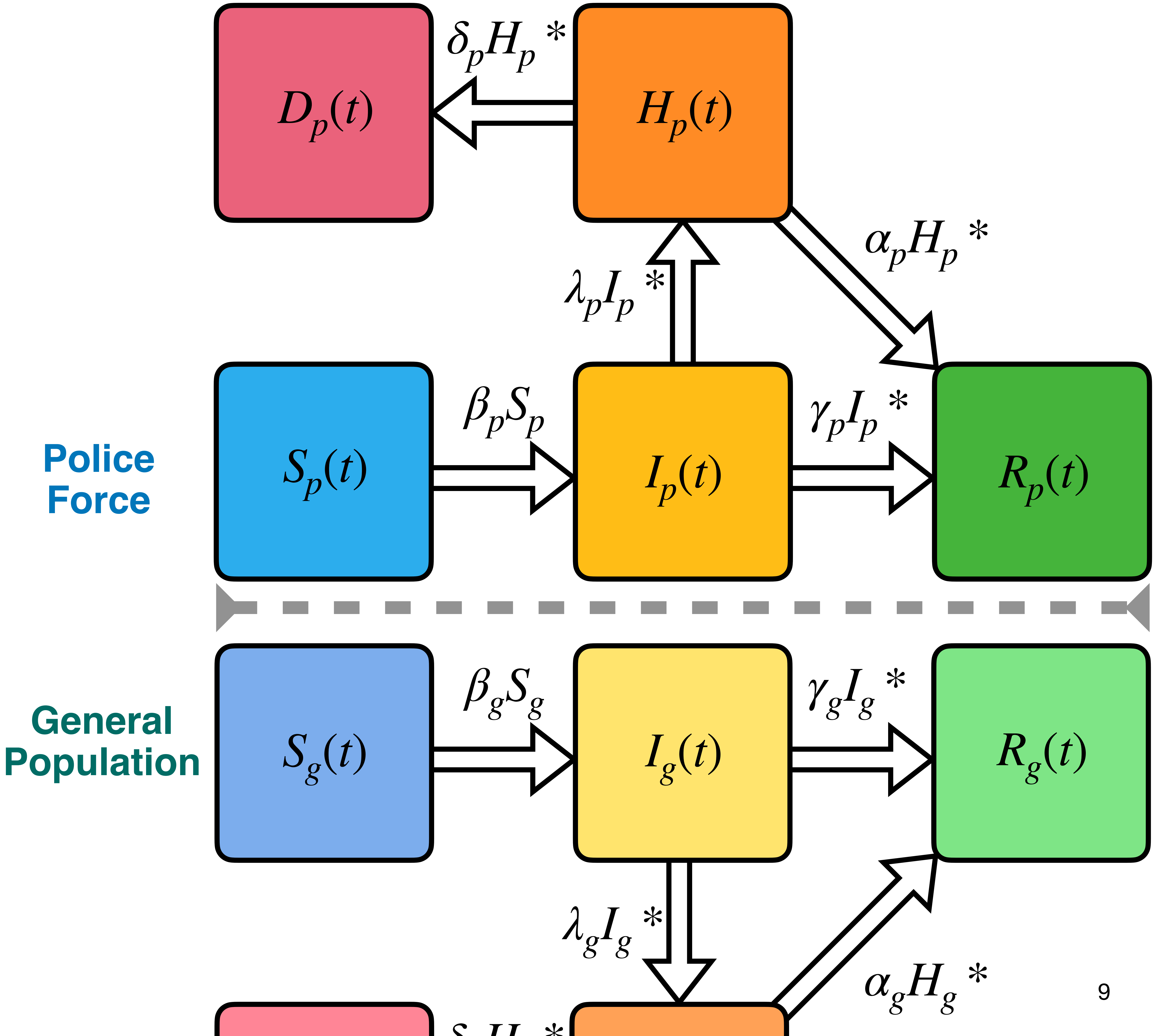


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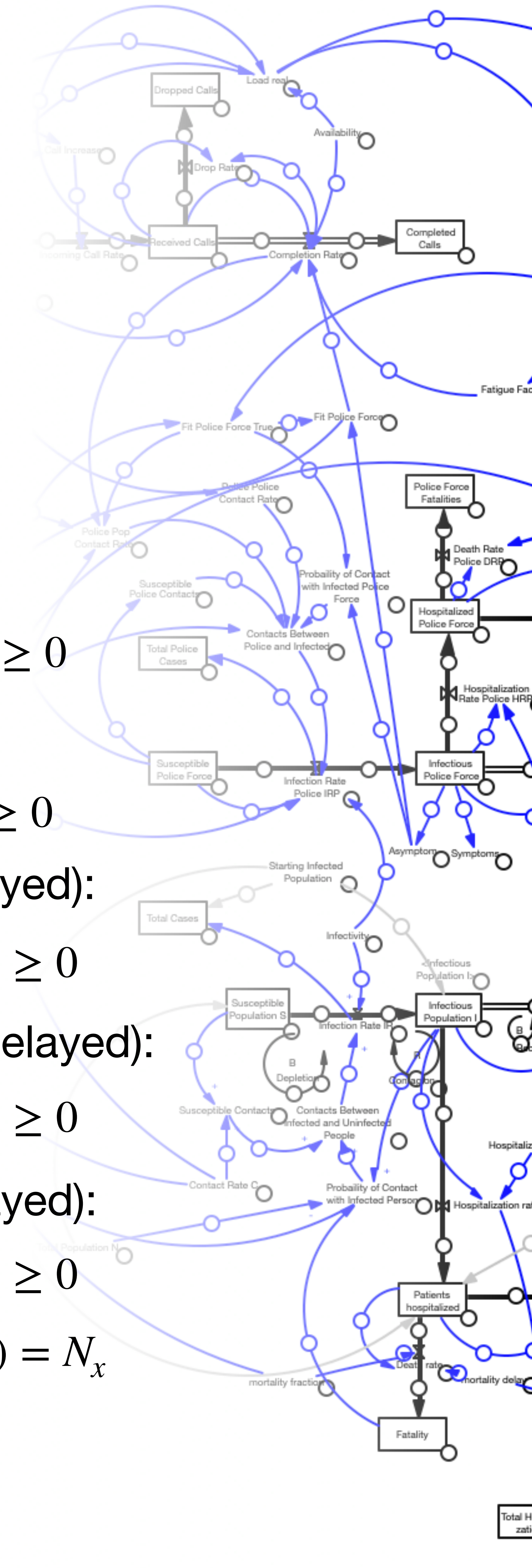
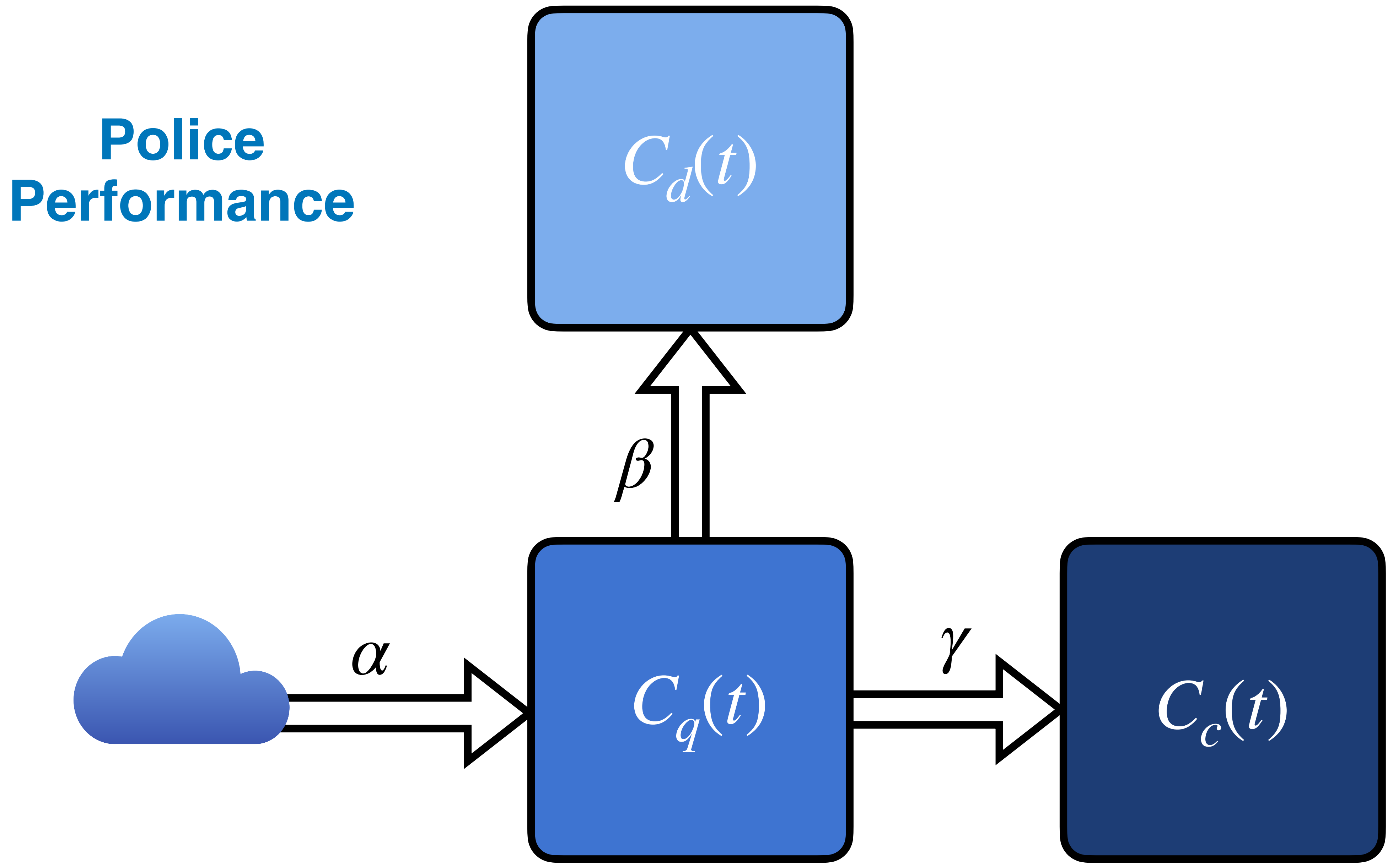


# 2. Model and Methodology

## Police Performance Flowchart




(I) Incoming Call Rate

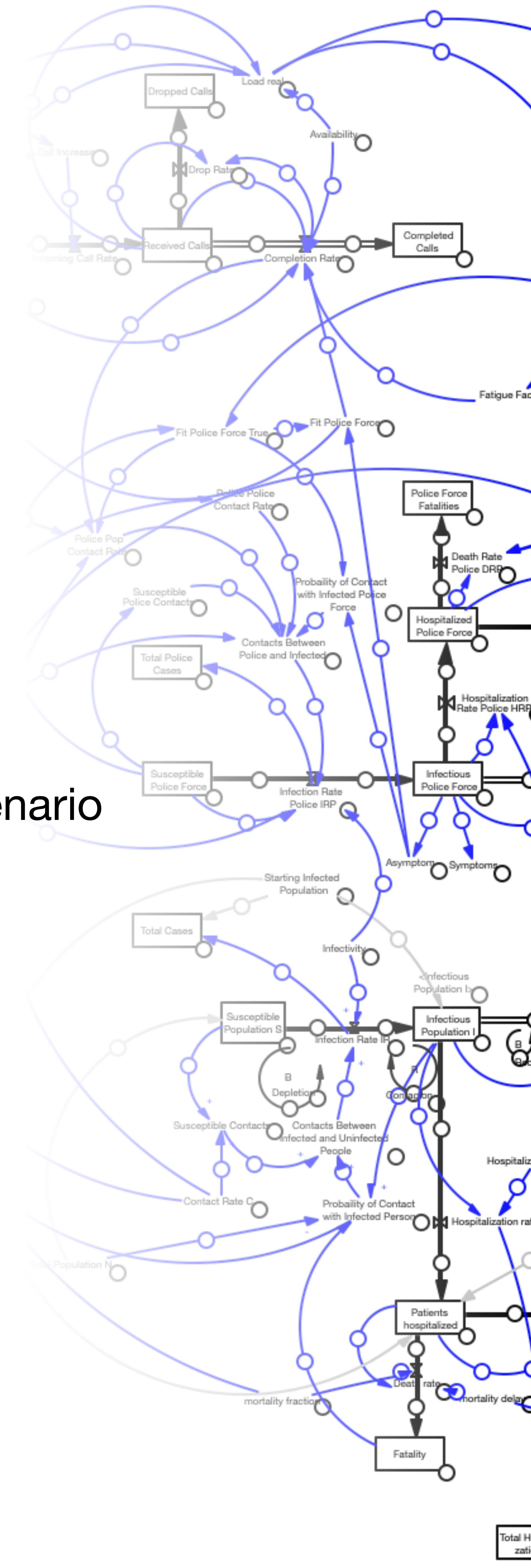
$\alpha$ Constant or variable dependent on scenario

(III) Completion Rate

$\gamma$ Dynamic dependent on capacity

(II) Dropped Call Rate

$\beta$ Percentage of outstanding queue

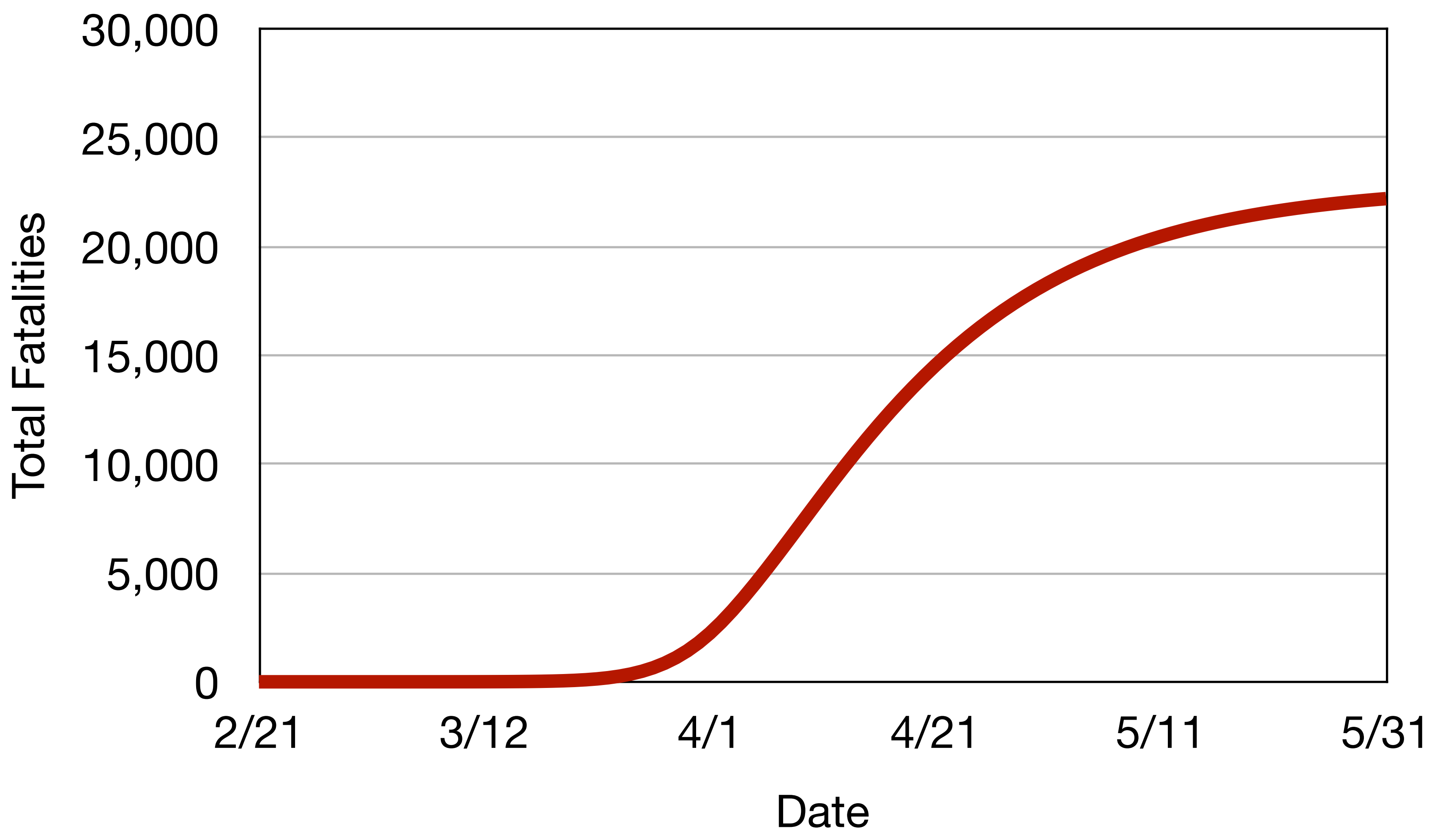


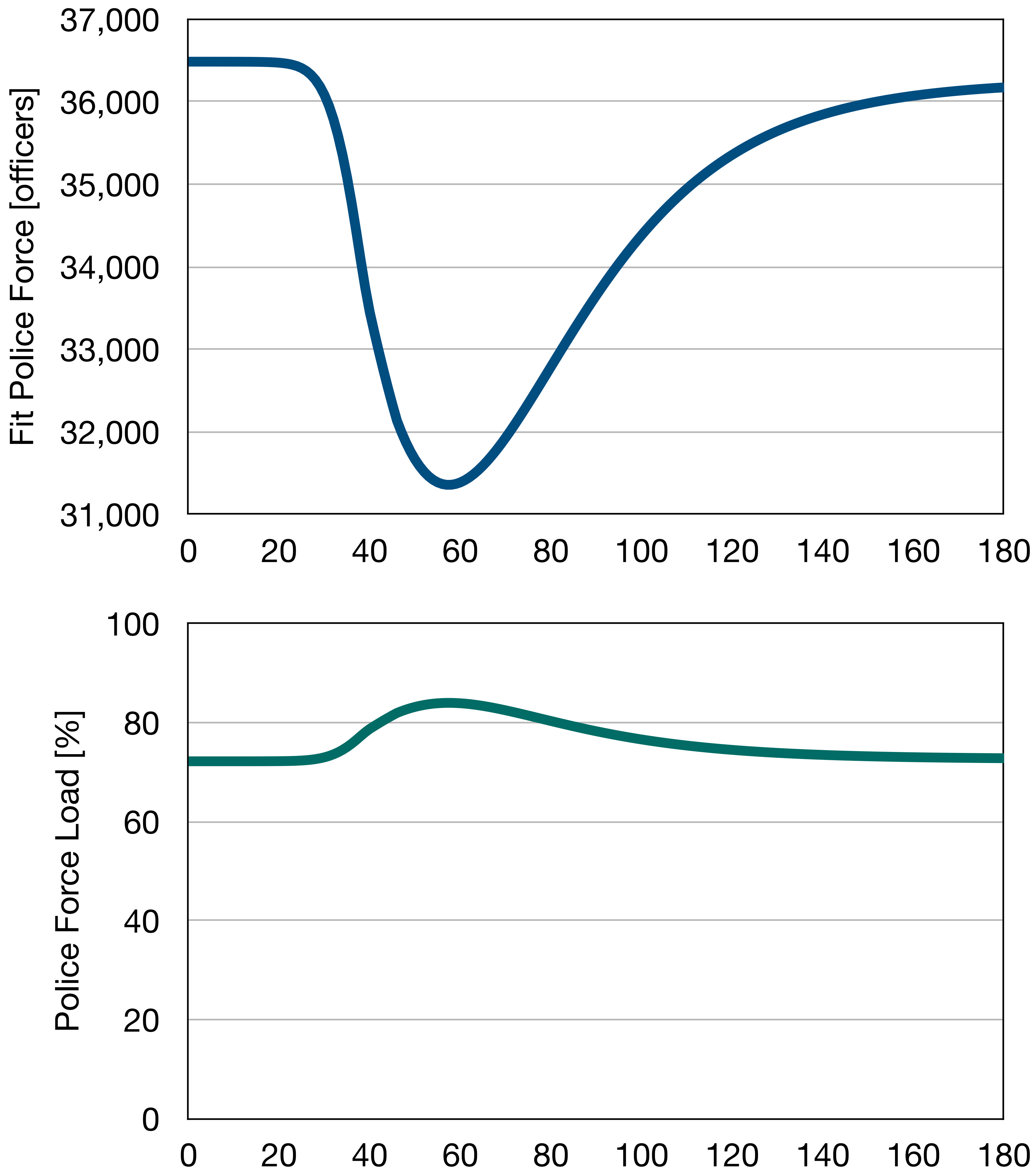
# 3. Assumptions and Parameter

- Simulation Boundaries set to NYC
- Infection Rates based on contact rate derived from Bioterrorism research and official service call data of the NYPD
- Recovery and Hospitalization Rates based on official CDC Dat
- Police Performance derived from official service call data of the NYPD
- Performance Influencing Factors:
  - Fatigue due to prolonged stress - derived from reaction time studies
  - Yerkes-Dodsen Influence for performance under load

# 4. Baseline Scenario and General Effects

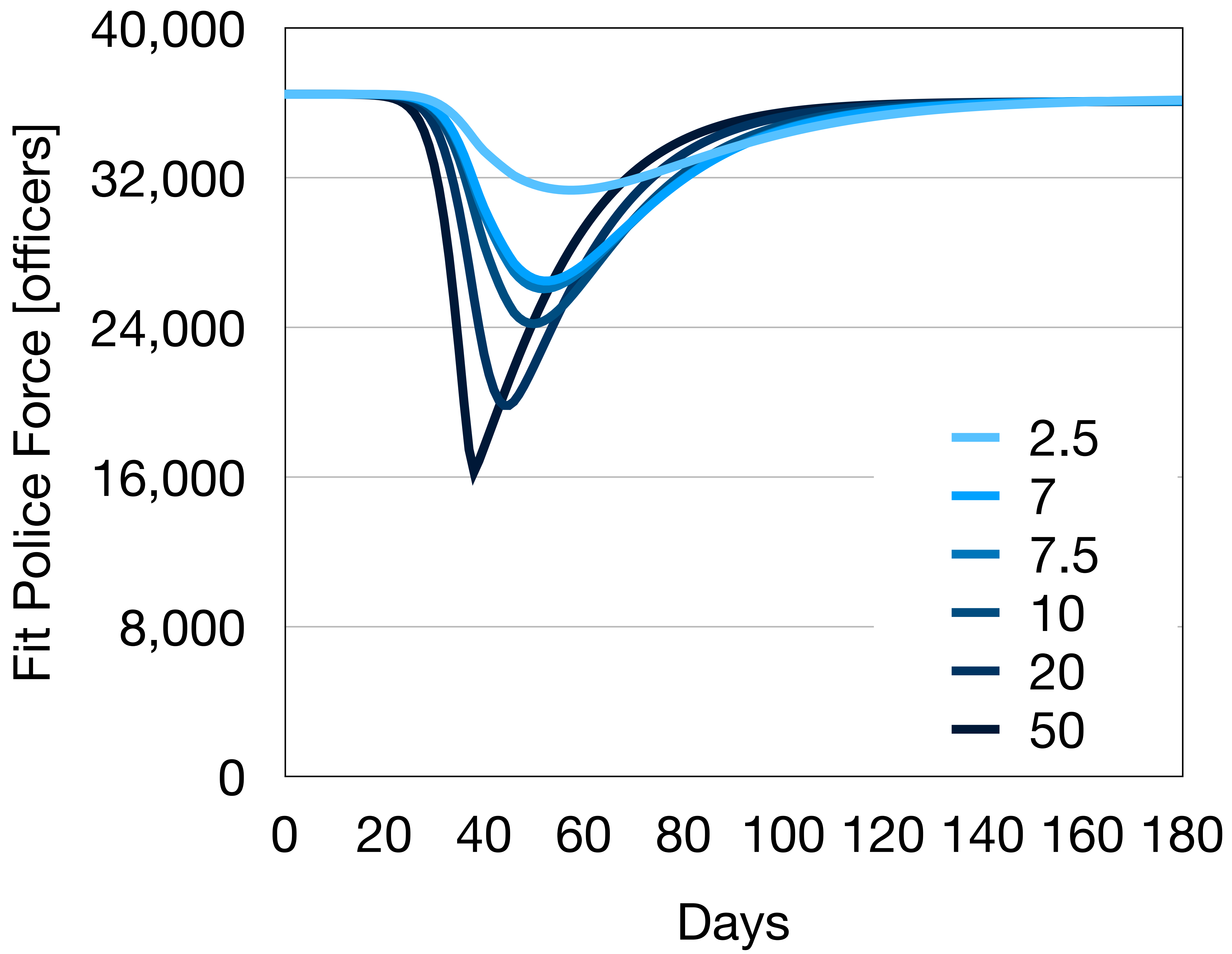
## Verification via Fatalities

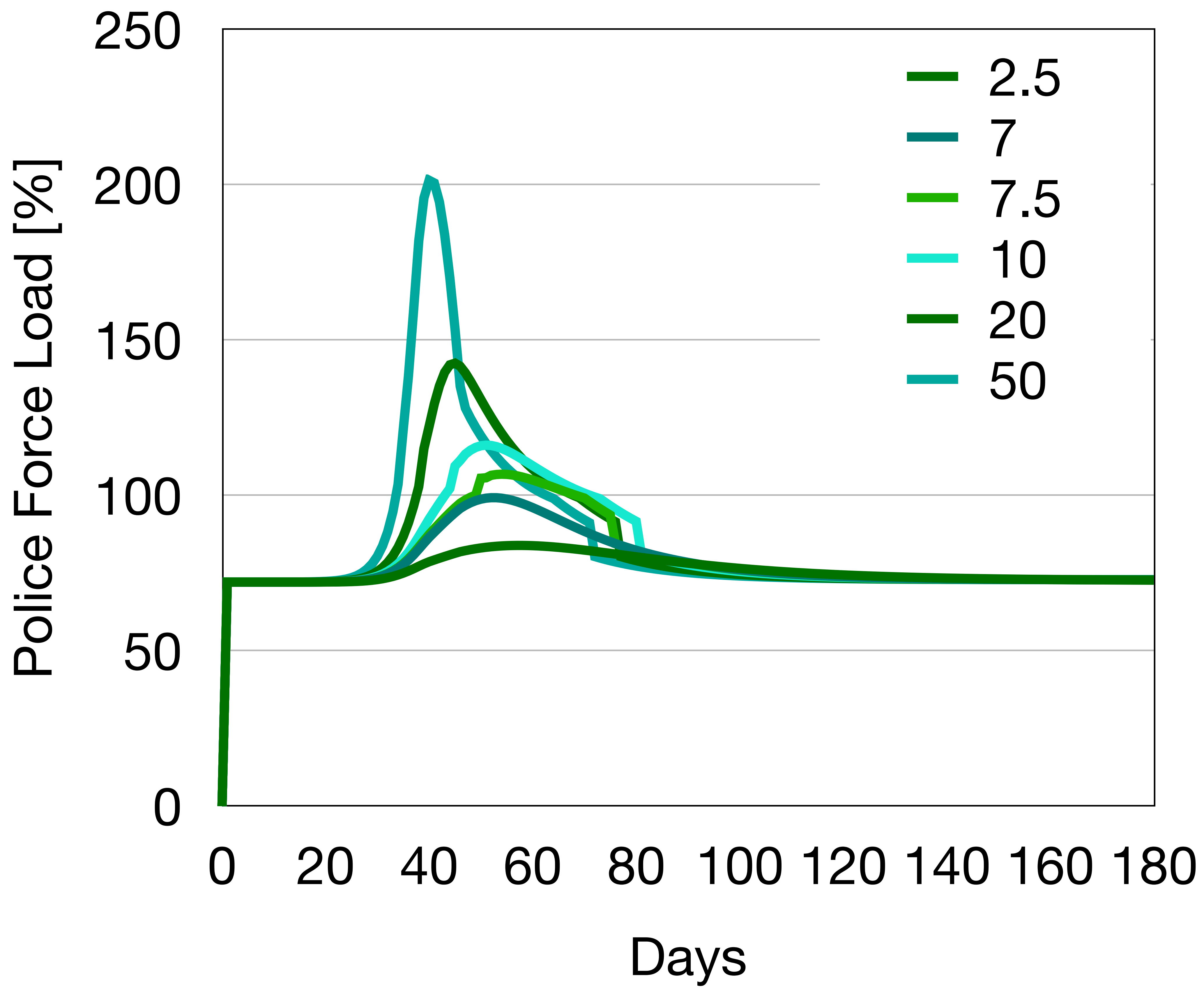


# 5. Scenarios: Modulated Parameters

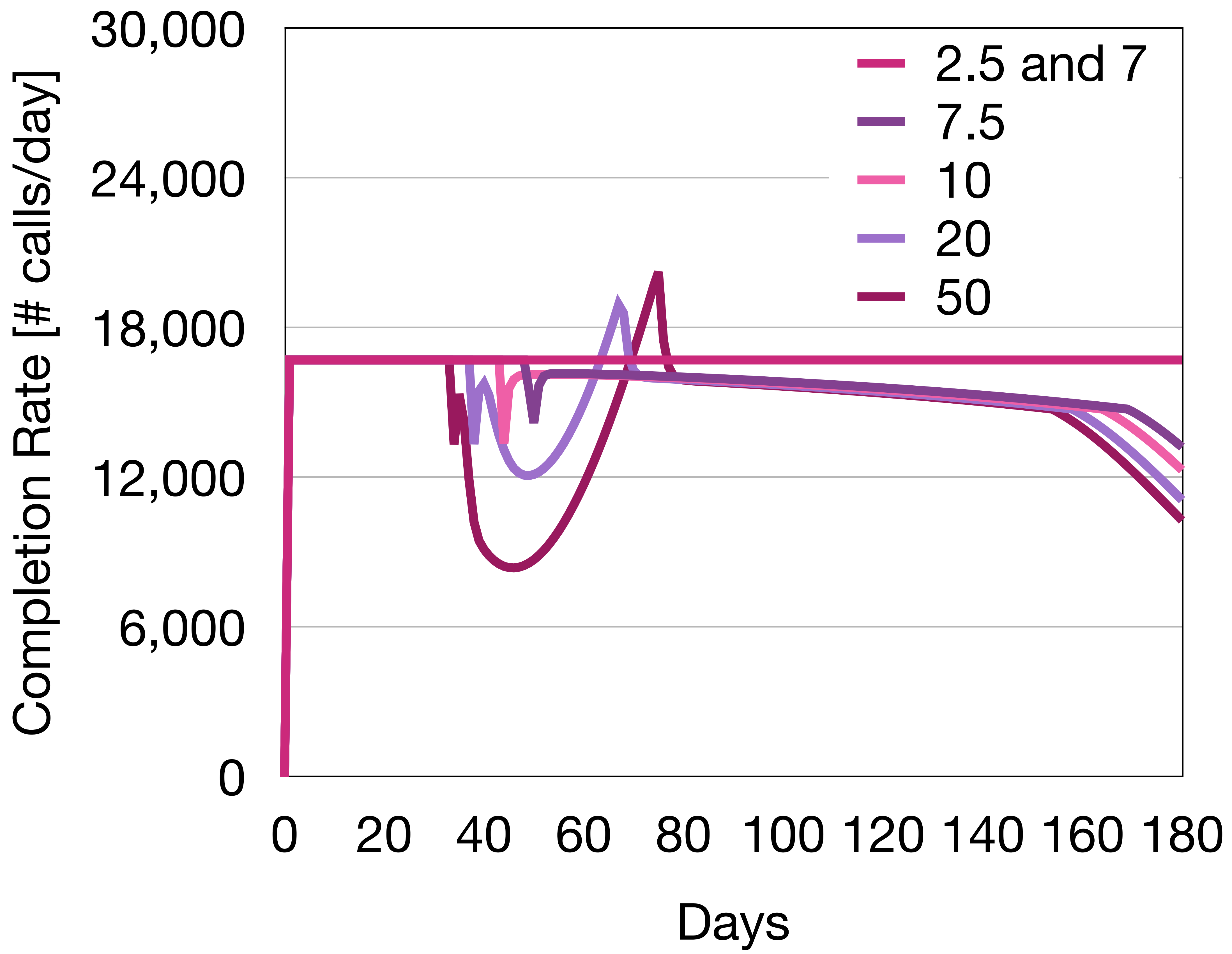
## A - Increased Police Contact Rate

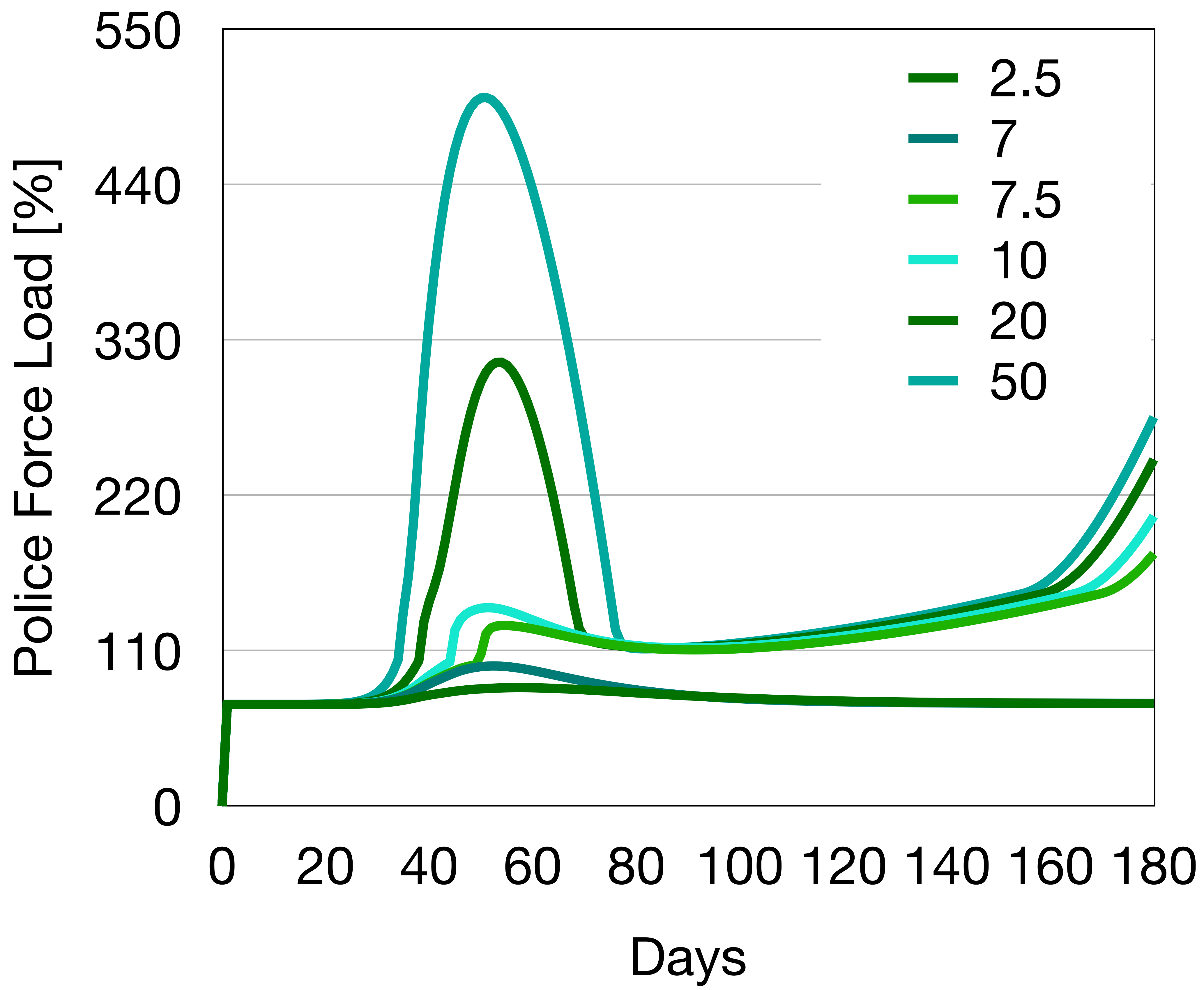


# 5. Scenarios: Modulated Parameters

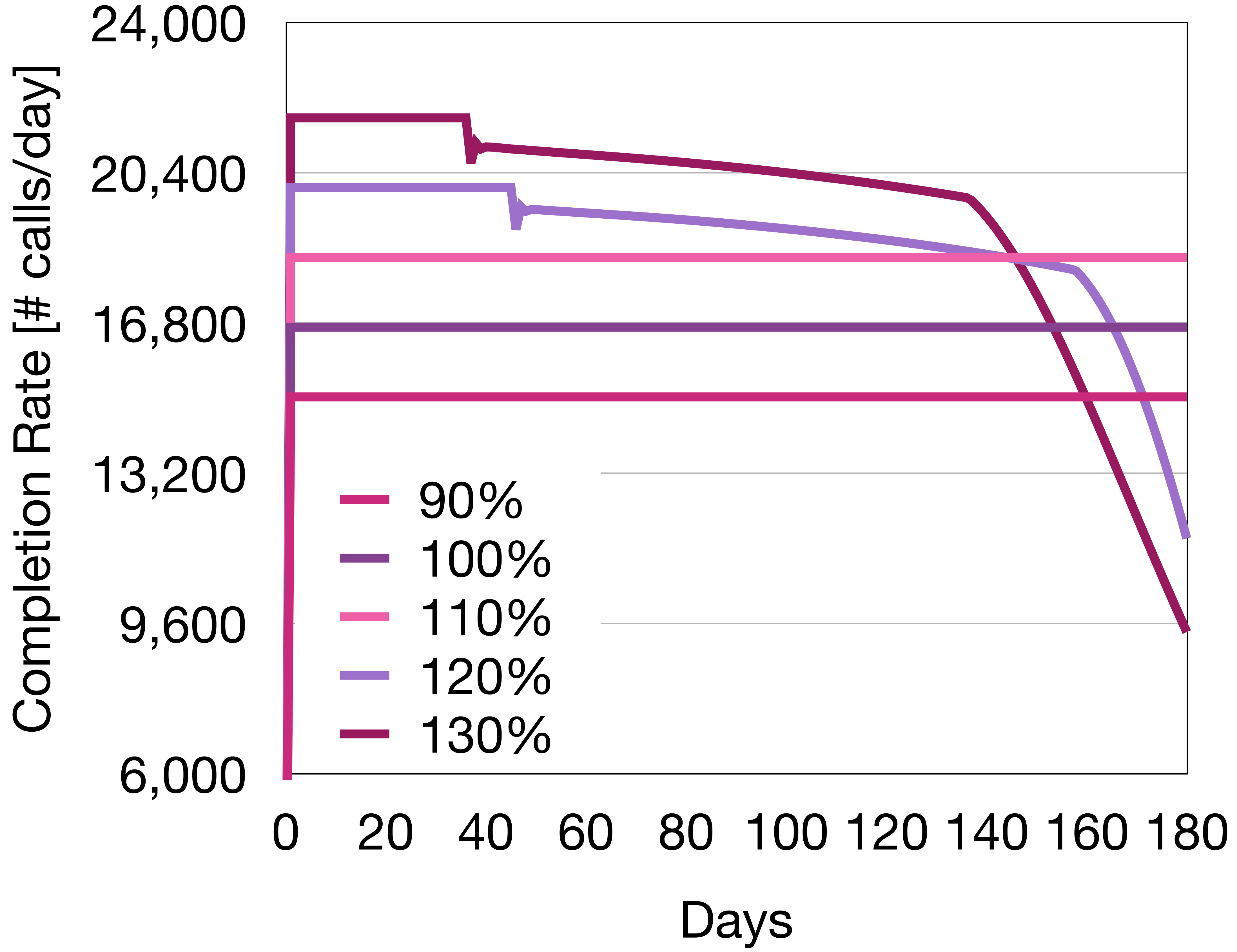
## B - Increased Police Contact Rate and Increased YD-Influence

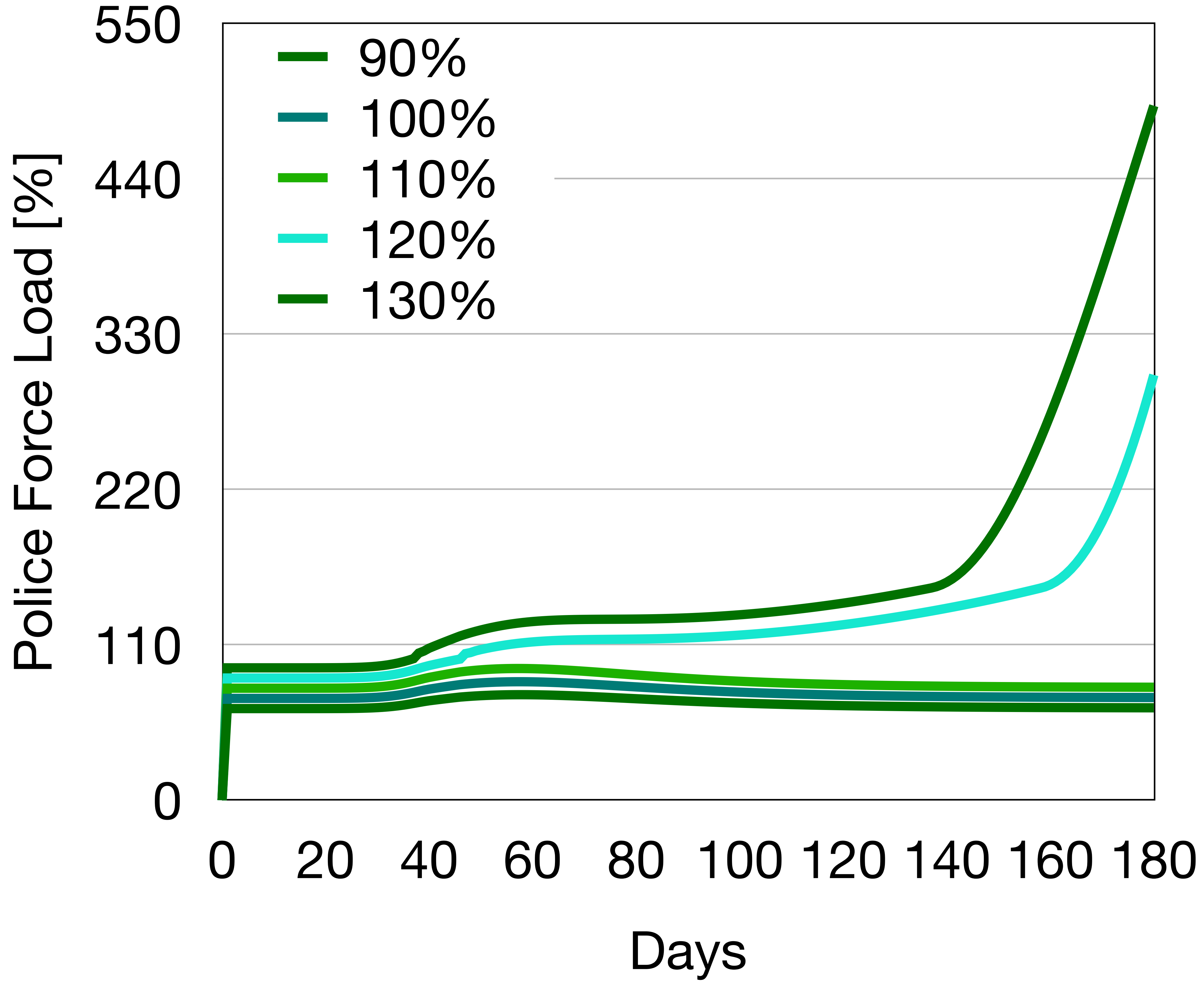


# 5. Scenarios: Modulated Parameters

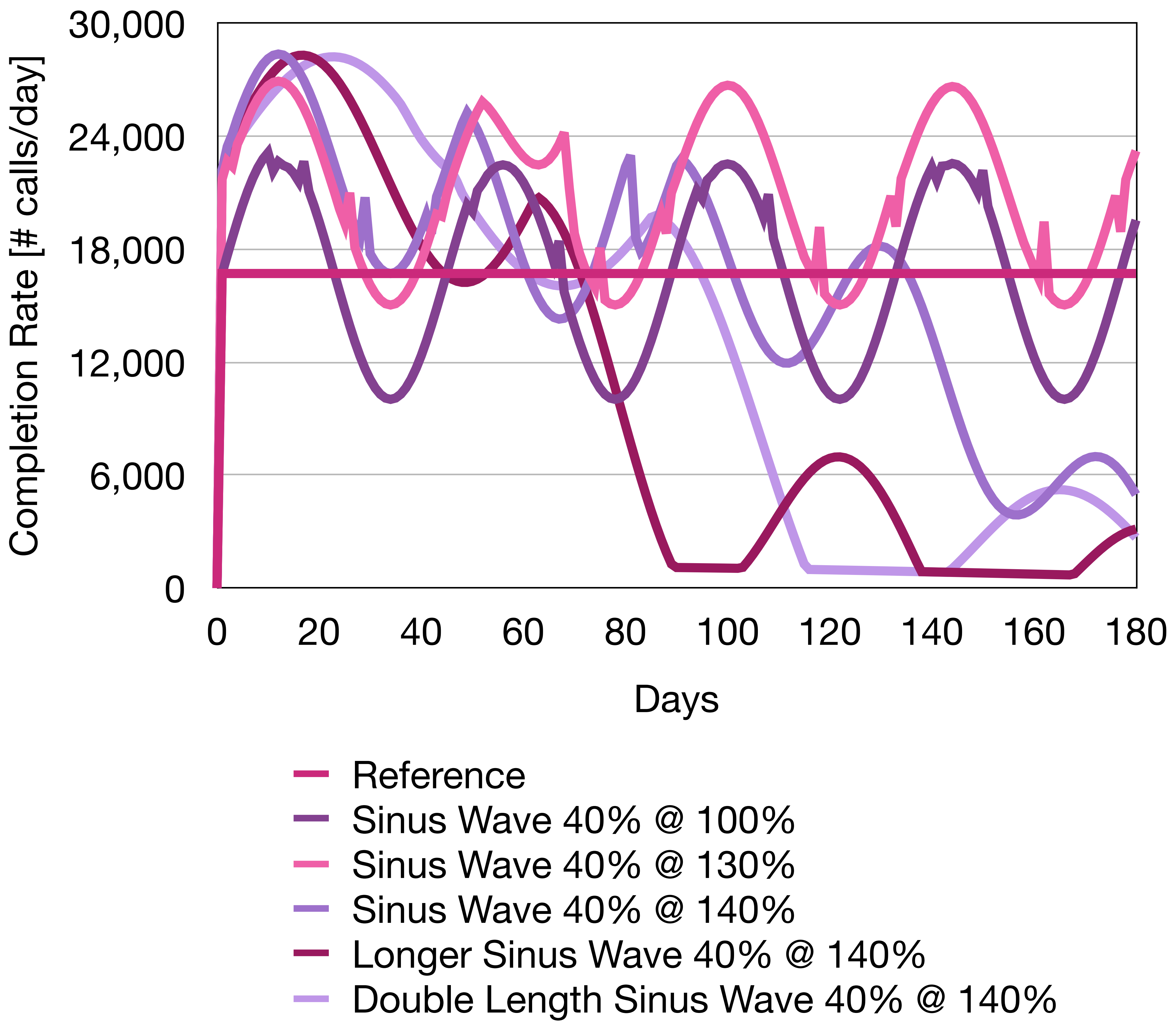
## C - Constantly Increased Call Volume

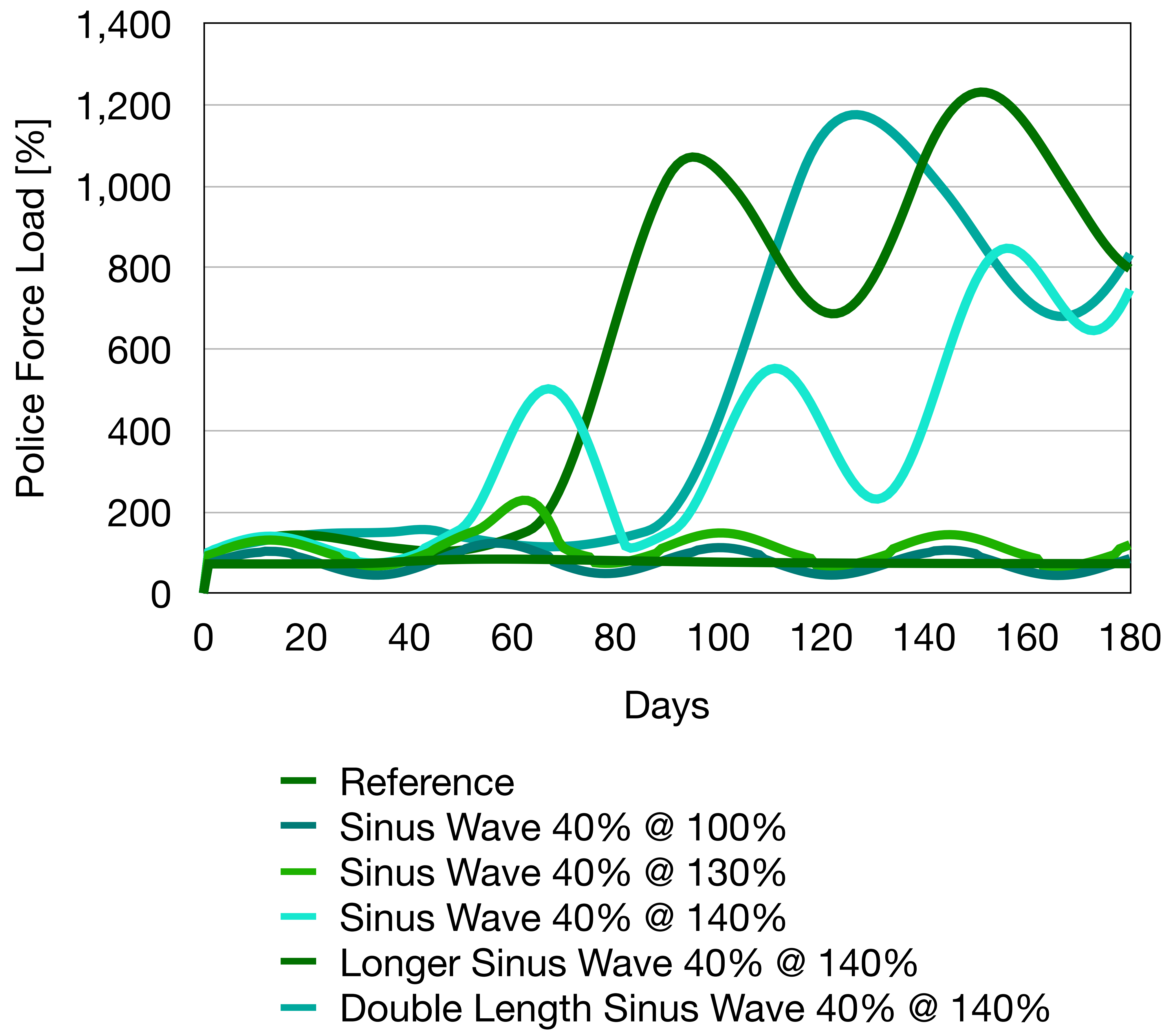


# 5. Scenarios: Modulated Parameters

## D - Varying Call Volume



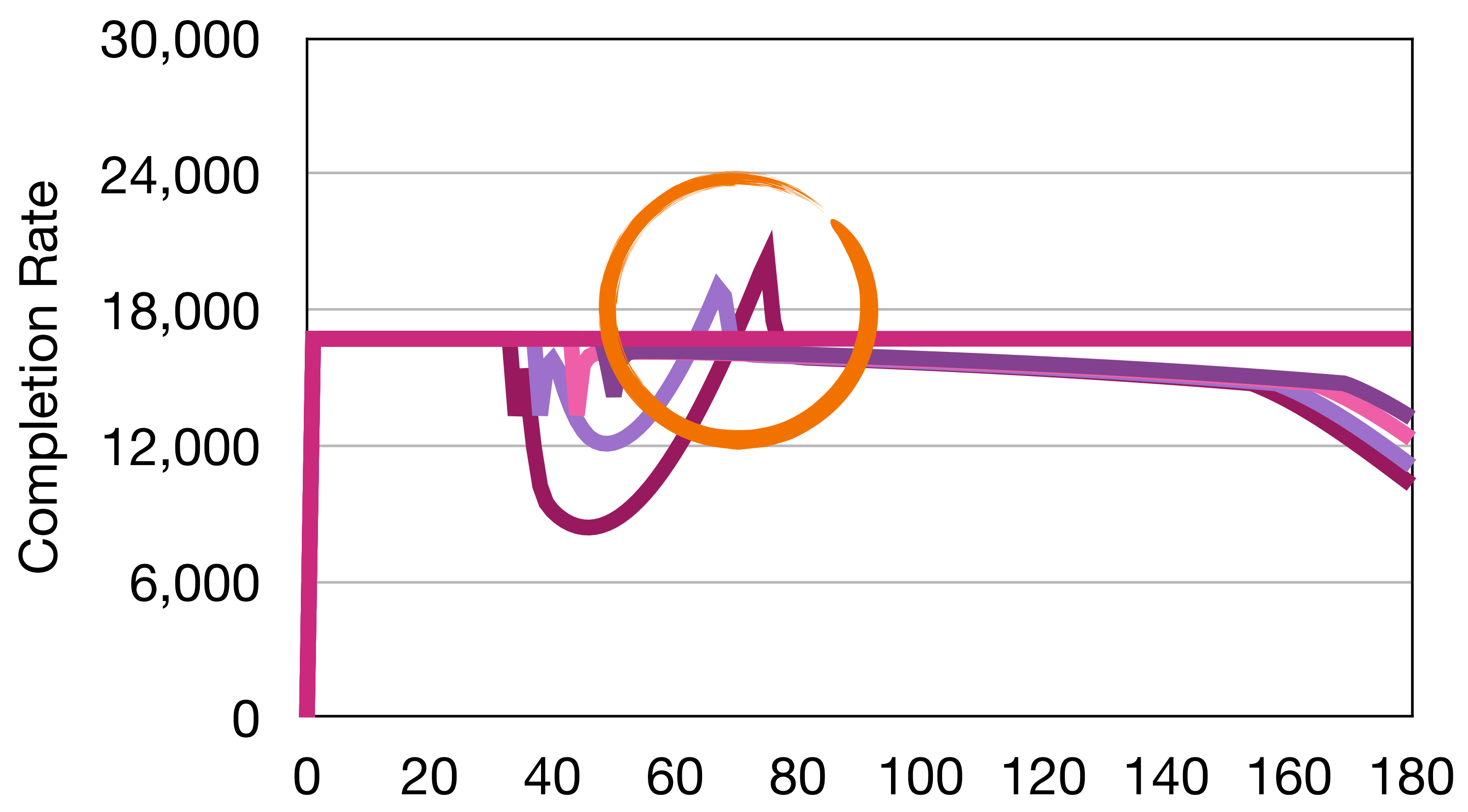



# 6. Conclusion and Outlook

## Results and Insights

- System stable and resilient ⇨ can handle temporary overloads
- Temporarily increased capacity possible

  ⇨ help needed for utilization




- Higher demand can be compensated up to a certain threshold
- Fluctuating Inputs/Influences can help the system, but also accelerate degeneration ⇨ dependance on phase delay

**⇨ Several tipping point behaviors shown**

# 6. Conclusion and Outlook

## Planned Progress and Future Work

- Further evaluate observed and simulated thresholds
- Develop objective mathematical foundation for behavior
- Expand simulation to other emergency services and generalize system
- Assess impact of possible simulation changes, such as:
  - Re-infection due to degeneration of anti-bodies
  - Implications of measures and protective gear