Epidemic model

Hiroyuki Matsuda
Download the excel file from
ecorisk.ynu.ac.jp/matsuda/2020/SIR_model_by_HM.zip

See also
米山隆一シミュレーションから浮かぶ二つの可能性。究極の戦術をとる前にするべきことは.論座2020/3/29
https://webronza.asahi.com/politics/articles/2020032900001.html

押谷仁氏　COVID-19への対策の概念　2020/3/29
https://www.jsph.jp/covid/files/gainen.pdf

Keywords　SIR model; RNA virus; explosion (“overshoot”); herd immunity; Cluster; Triage medical; incubation period; medical collapse; false positive; adaptive management
キーワード：感染症力学モデル；RNAウィルス；感染爆発；集団免疫；クラスター；患者分流；潜伏期間；医療崩壊；疑陽性；順応的管理

Imperial College COVID-19 Response Team (2020 March 16 Report 9)

Impact of non-pharmaceutical interventions (NPIs) to reduce COVID-19 mortality and healthcare demand

- Two fundamental strategies are possible:
  - (a) mitigation, which focuses on slowing but not necessarily stopping epidemic spread –reducing peak healthcare demand while protecting those most at risk of severe disease from infection, and
  - (b) suppression, which aims to reverse epidemic growth, reducing case numbers to low levels and maintaining that situation indefinitely.
- Each policy has major challenges. We find that that optimal mitigation policies (combining home isolation of suspect cases, home quarantine of those living in the same household as suspect cases, and social distancing of the elderly and others at most risk of severe disease) might reduce peak healthcare demand by 2/3 and deaths by half. However, the resulting mitigated epidemic would still likely result in hundreds of thousands of deaths and health systems (most notably intensive care units) being overwhelmed many times over. For countries able to achieve it, this leaves suppression as the preferred policy option.

https://www.imperial.ac.uk/mrc-global-infectious-disease-analysis/covid-19/

Herd immunity 集団免疫

- Herd immunity is the indirect protection from a contagious infectious disease that happens when a population is immune either through vaccination or immunity developed through previous infection.
- This means that even people who aren’t vaccinated, or in whom the vaccine doesn’t trigger immunity, are protected because people around them who are immune can act as buffers between them and an infected person.
- Once herd immunity has been established for a while, and the ability of the disease to spread is hindered, the disease can eventually be eliminated.

https://www.gavi.org/vaccineswork/what-herd-immunity

SARSの場合

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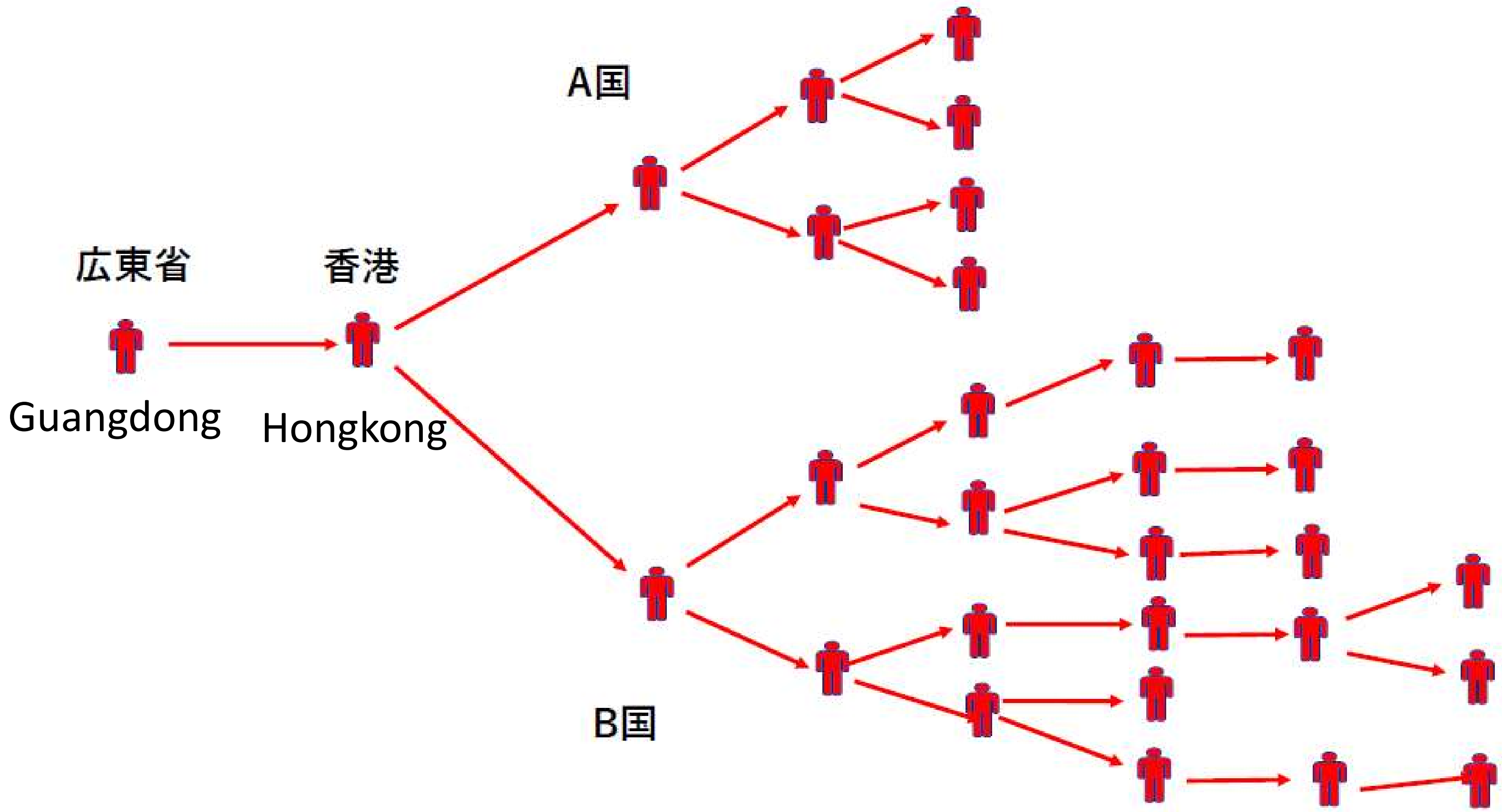
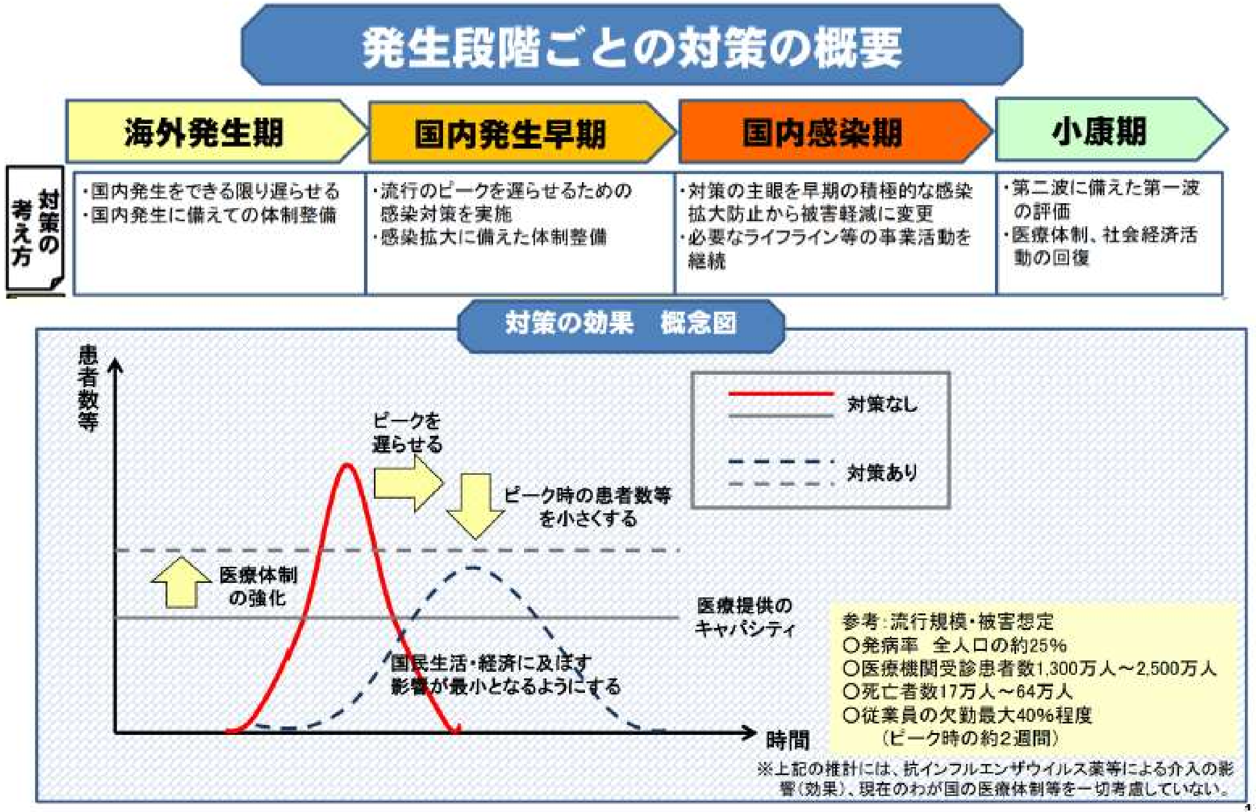


- ほとんどの感染者が重症化するSARSの場合、ほとんどすべての感染連鎖を広東省までたどることができた。
- そのためすべての感染連鎖を断ち切ることが可能だった。

In the case of SARS (severely infected in most cases), almost all transmission chains could be traced to Guangdong.
That's why it was possible to break the entire chain of infection.

新型インフルエンザ対策の基本的考え方



新型インフルエンザ等対策
政府行動計画の概要

- 新型インフルエンザであればすでに積極的拡大防止策から被害軽減に変更すべき時期。
- このウイルスでは被害軽減という考え方は成り立たたず、諦めた時に大規模感染が始まる。

If it is a influenza, it is time to change from aggressive prevention [suppression] measures to damage reduction [mitigation].
For the COVID-19, the concept of mitigation does not hold, and when it gives up, a massive outbreak begins.

中国の戦略

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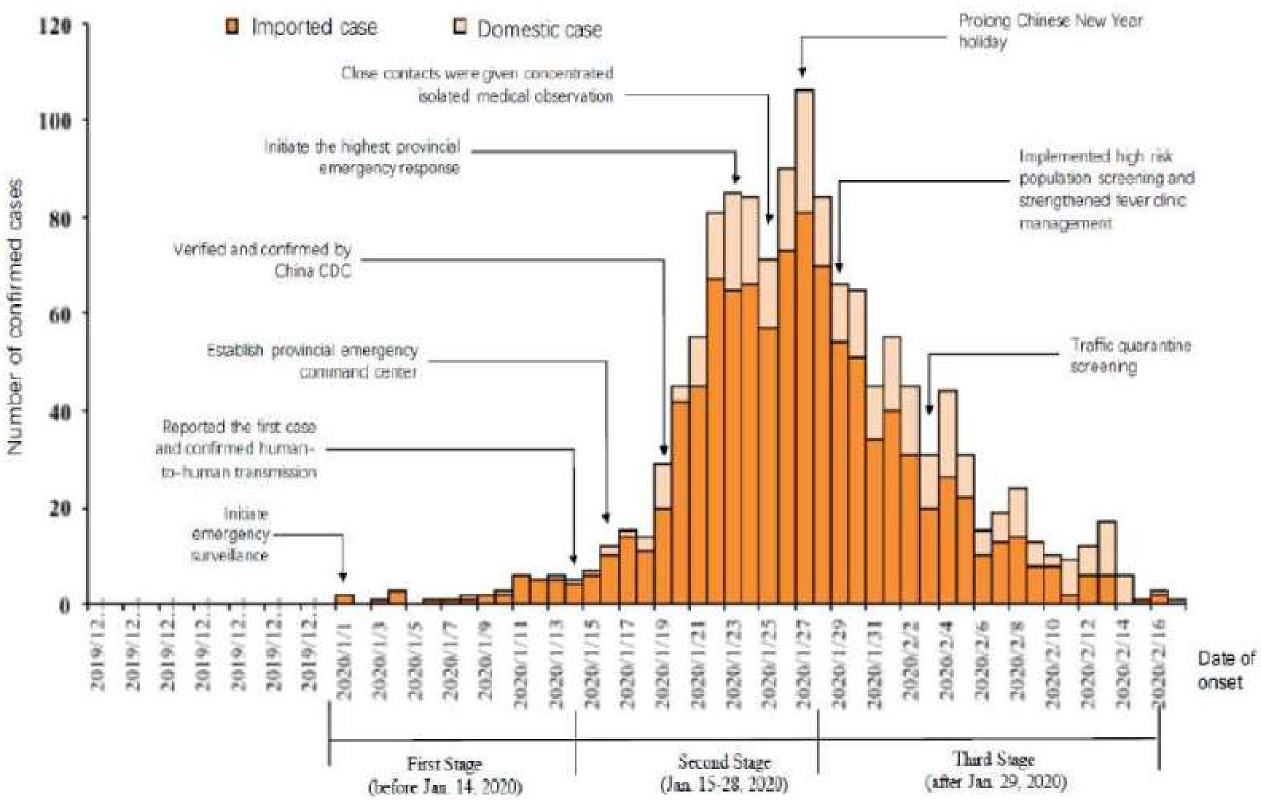

Report of the WHO-China Joint Mission on Coronavirus Disease 2019 (COVID-19)

- 中国では、武漢の都市封鎖・外出を厳格に制限・人が集まることを制限することでウイルスをほぼ完全に制御

In China, the virus is almost completely controlled by strictly restricting the blockade and outing of Wuhan and restricting people gathering

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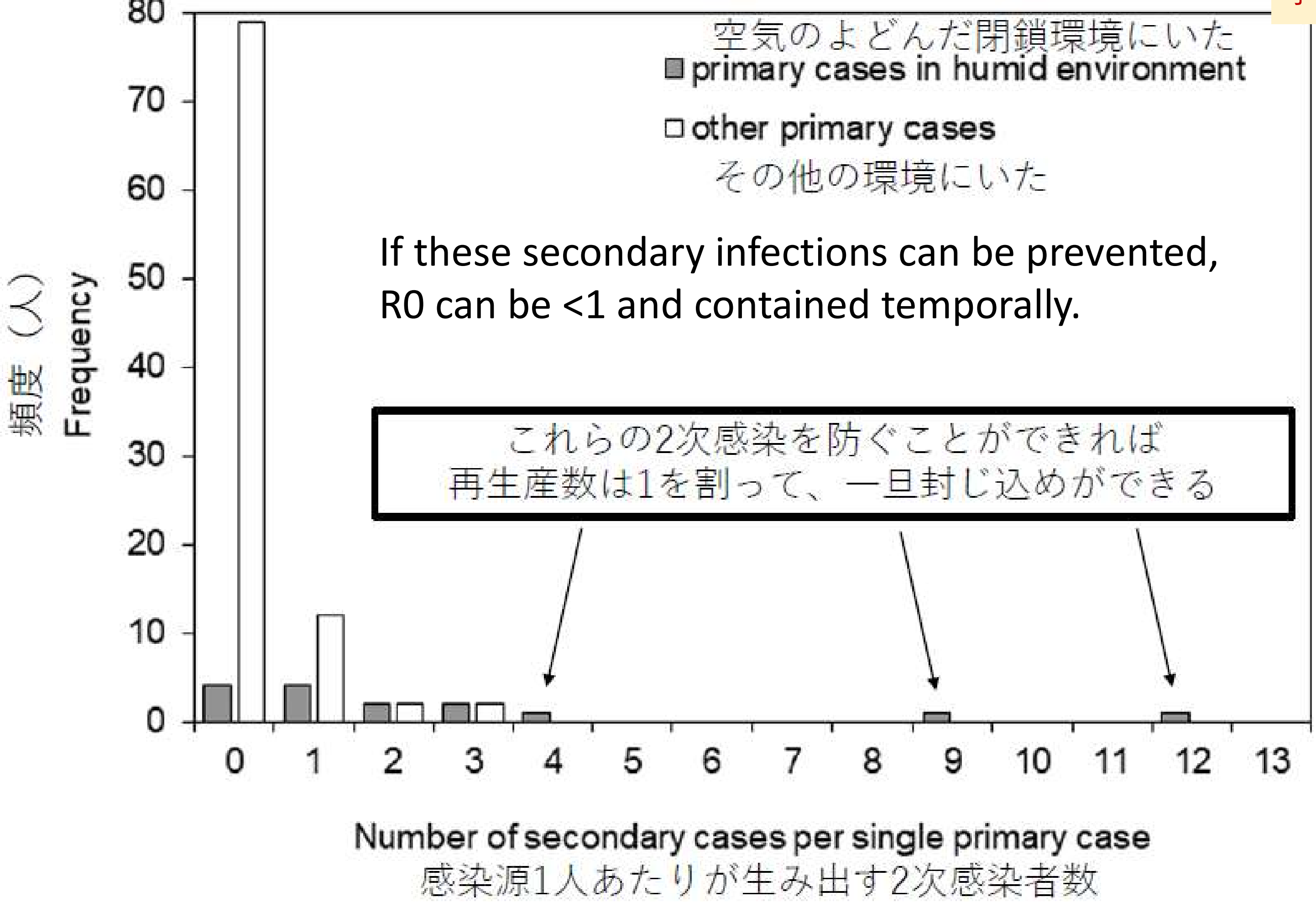
1人の感染者が生み出す2次感染者数の頻度（n=110）



- 北大西浦教授のグループの解析から多くの感染者はだれにも感染させていないことがわかっていた。

Many infected people have not transmitted anyone. Only a small number of infected people (super spreader) transmitted many people.

Nishiura et al.: https://www.medrxiv.org/content/10.1101/2020.02.28.20029272v1.full.pdf

Basic strategy against new coronavirus in Japan

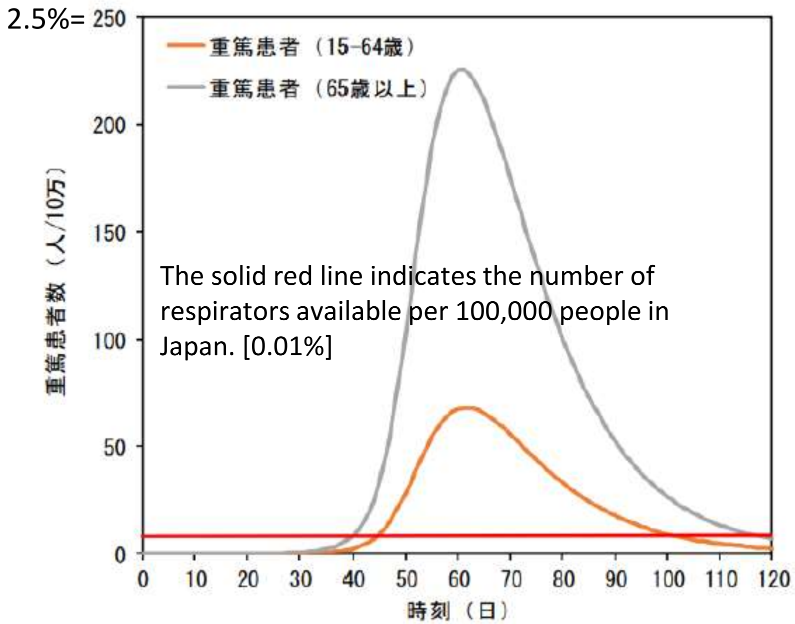
Maximize the effect of suppressing the spread of infection while minimizing the impact on social and economic functions.
The primary goal should slow the spread of the infection and reduce the incidence and deaths of the most severely ill.
February 24, 2020 Expert Council on New Coronavirus Infection Control
The solid red line indicates the number of respirators available per 100,000 people in Japan.

日本の新型コロナウイルス対策の目的

社会・経済機能への影響を最小限としながら、感染拡大の抑制効果を最大限にする

これからとるべき対策の最大の目標は、感染の拡大のスピードを抑制し、可能な限り重症者の発生と死亡数を減らすことです

2020年2月24日　新型コロナウイルス感染症対策専門家会議



赤実線は日本国内の 10 万人あたりの使用可能な人工呼吸器台数を示す。

新型コロナウイルス感染症対策専門家会議
「新型コロナウイルス感染症対策の状況分析・提言」（2020 年 3 月 19 日）

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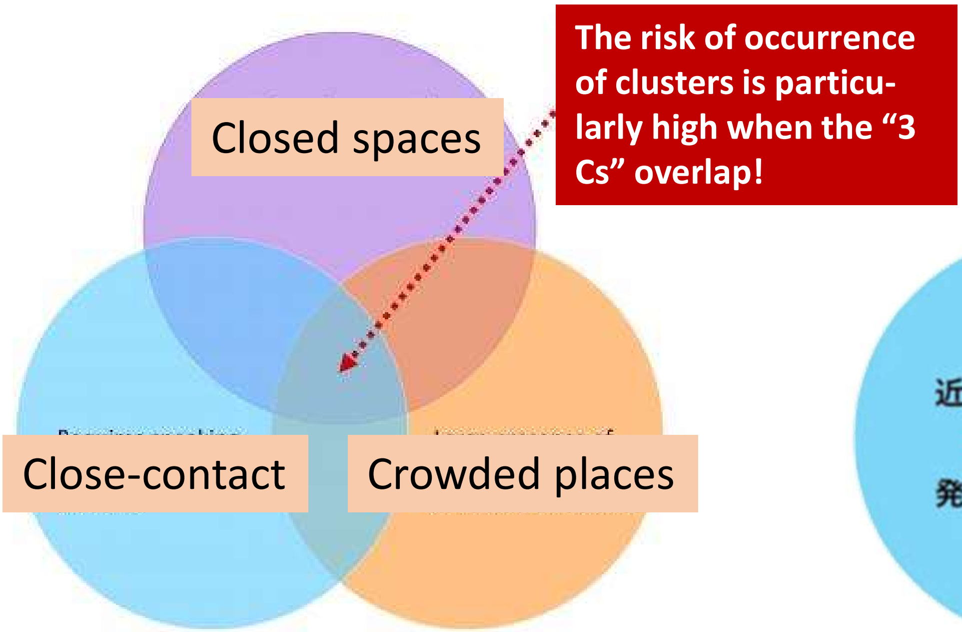
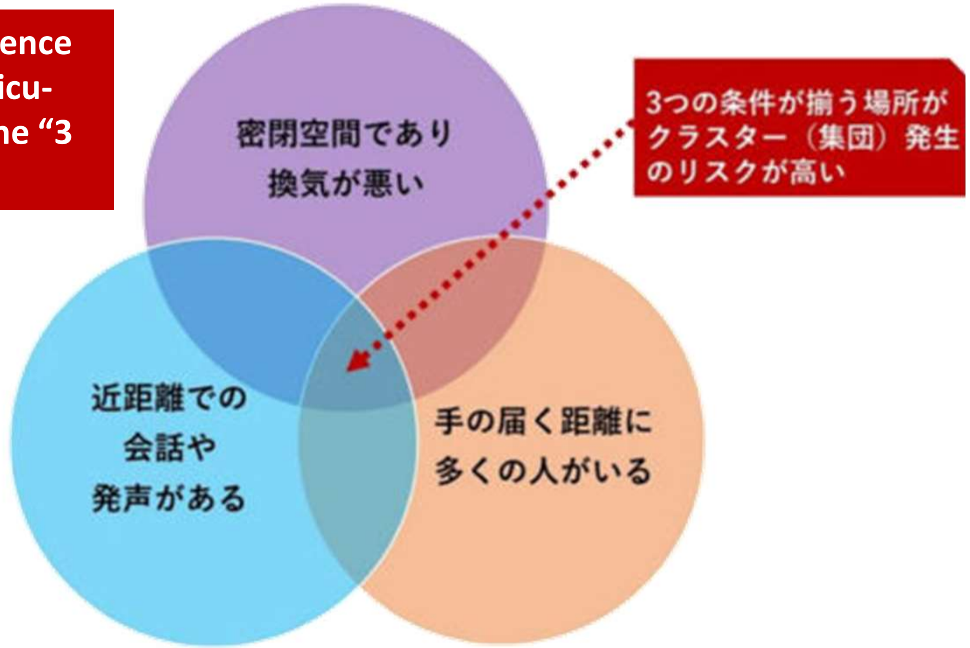
日本の対策の３本柱
Three pillars of measures in Japan

- クラスター（集団）の早期発見・早期対応
- 患者の早期診断・重症者への集中治療の充実と医療提供体制の確保
- 市民の行動変容
- Early detection and early response of clusters (groups)
- Enhance intensive care for patients with early diagnosis and illness and secure medical provision system
- Civil behavior change

Avoid the three Cs





Key Summary from the COVID-19 Countermeasures Experts Meeting

https://www.pref.oita.jp/soshiki/10140/coronavirus2019-english.html

クラスター対策の基本となっている考え方
Adaptive management for clustering countermeasures

- 地域の流行状況に応じた対策
- すべての地域で実施すべき対策
  - 1）3要素＋αの環境をできるだけ避ける
  - 2）クラスター対策
- 地域内の感染拡大の兆候が見られた地域
  - 1）3要素＋αの環境をできるだけ避けるためにより実効性を伴う対策
  - 2）より積極的な行動変容の呼びかけ（外出の自粛など）
  - 3）クラスター対策の主体は医療機関・高齢者施設などにシフト
- さらに感染拡大が続く場合、もしくは医療体制が維持できないと考えられた場合
  - 1）特措法による緊急事態宣言
  - 2）外出の自粛要請・施設の使用制限などのより積極的対策

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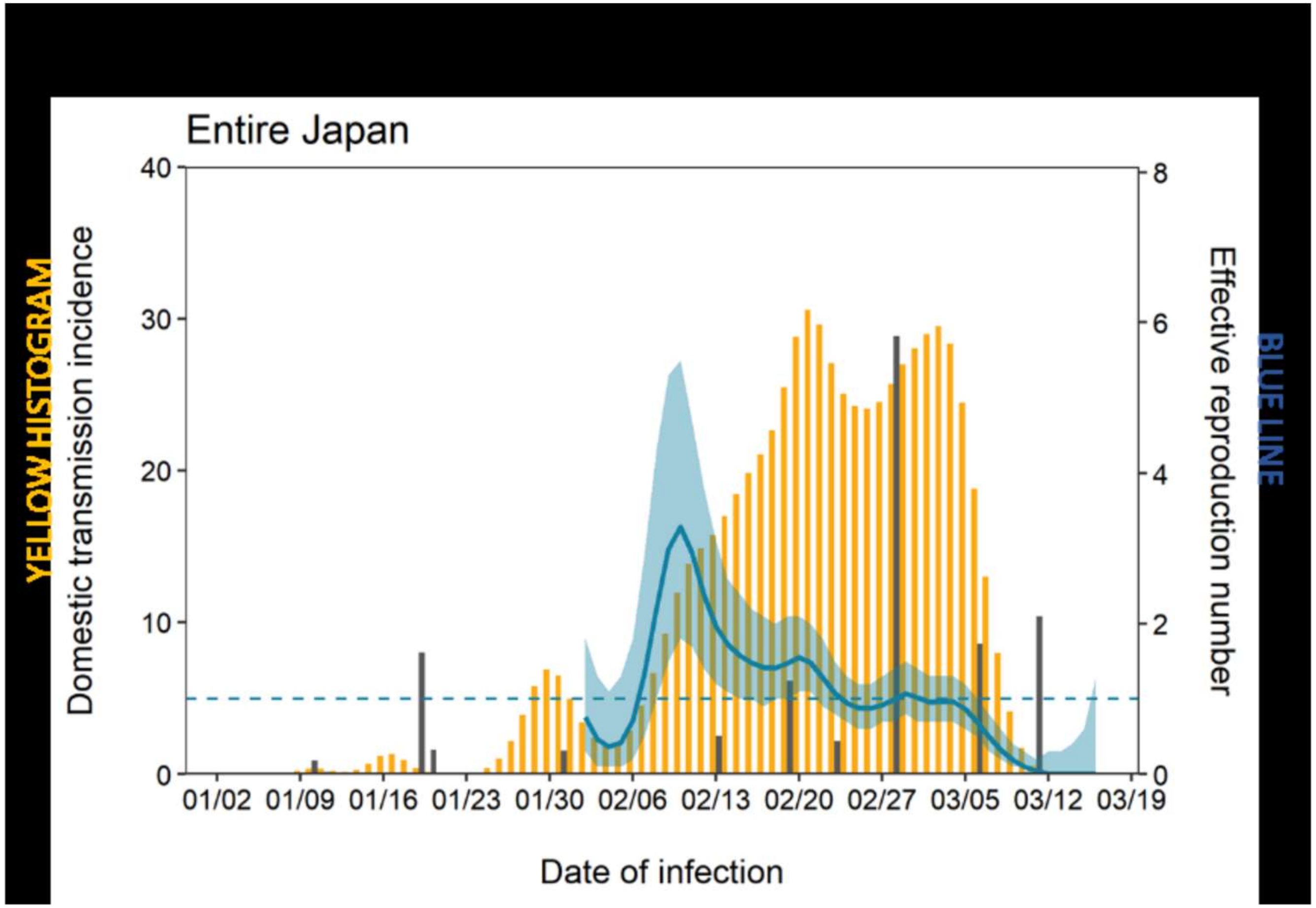

日本の第1波は保健所・自治体・地方衛生研究所・感染症研究所・検疫所・クラスター対策班の若手研究者などの努力でなんとか乗り切ってきた

The first wave in Japan has managed to survive with the efforts of health researchers, municipalities, local health research institutes, infectious disease research institutes, quarantine stations, and young researchers in the cluster response team.

日本での流行状況

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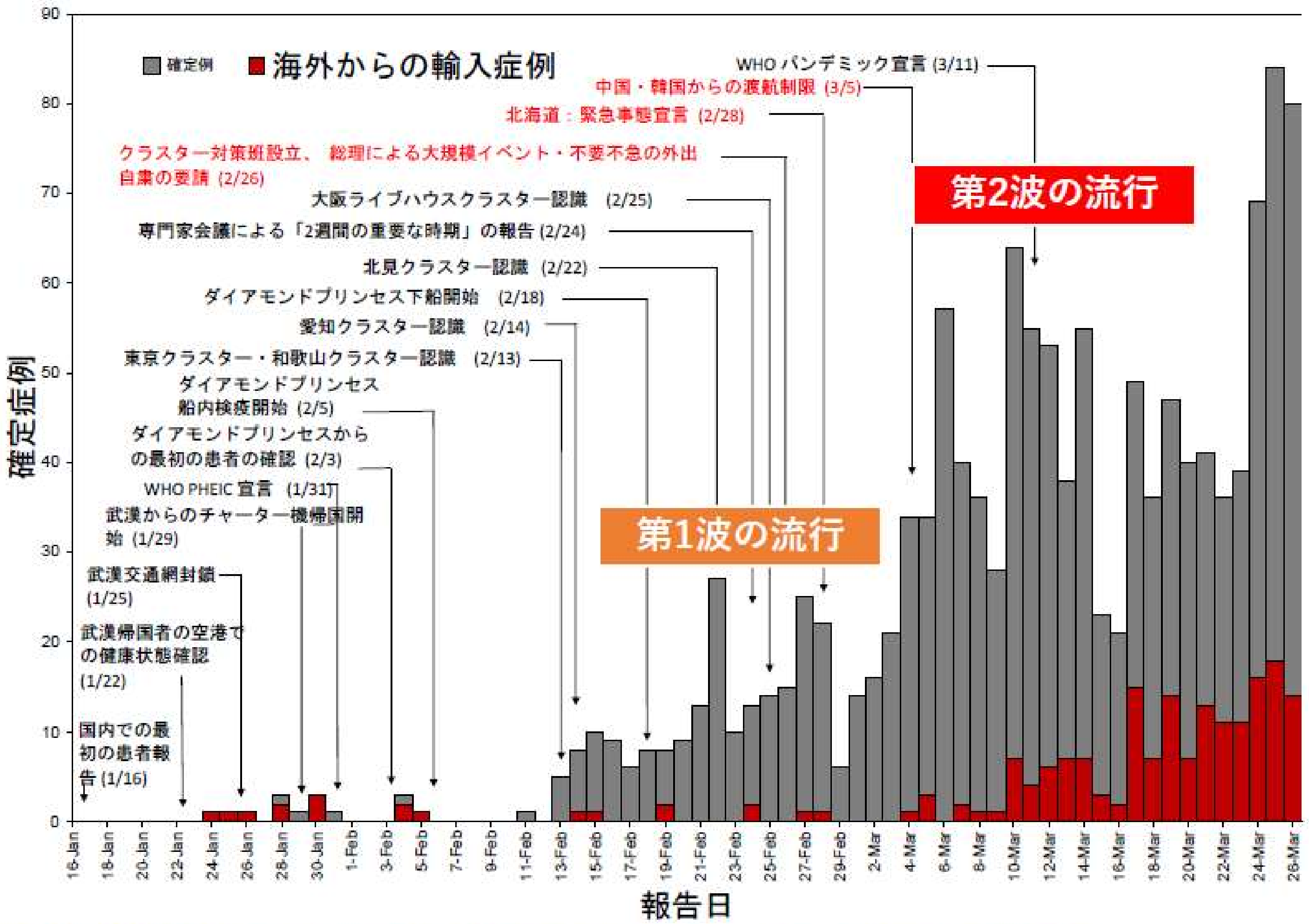


• 第1波の流行が完全に終息する前に第2波の流行が始まっていたと考えられる。

It is probable that the second wave epidemic had begun before the first wave epidemic had completely ceased.

http://ecorisk.ynu.ac.jp/matsuda/2020/SIRV2.xlsb

SIR model

- $dS/dt = -\beta(1-f)IS/N$
- $dI/dt = \beta(1-f)IS/N - \gamma I$
- $dR/dt = \gamma I$

- S: susceptible 未感染者
- I: infected 感染者
- R: recovered 回復者 including died 死亡者
- Total death = 0.03 R
- f: reduction factor in transmission due to intervention strategies 感染抑止措置による感染率減少係数

Usually, β/N is replaced by λ, i.e., $dS/dt = -\lambda IS$; $dI/dt = \lambda IS - \gamma I$

http://www.election.ne.jp/10840/100494.html

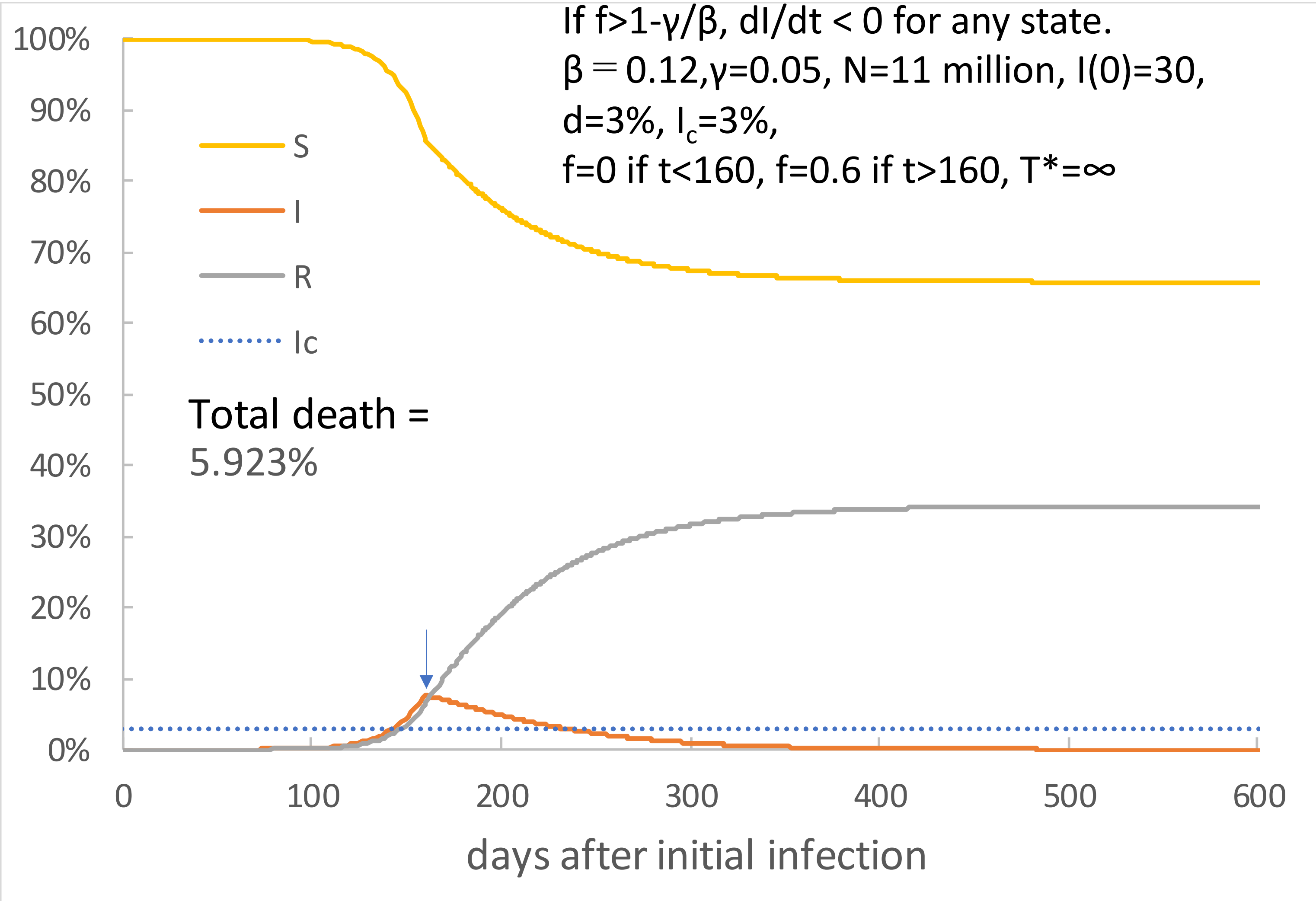
R_0 and S_{th}

- $R_0 = \beta(1\text{-}f)/\gamma$: the basic reproductive number (the expected number of secondary infections produced by an infected person where everyone is susceptible)
- $S_{th} = N/R_0 = \gamma/\beta(1\text{-}f)$. If $S < S_{th}$, dI/dt is negative; i.e., $dI/dt = I[\beta(1\text{-}f)S/N - \gamma]<0$.
- Therefore, $R(t)>N\text{-} S_{th}$, the population get "herd immunity" and new infected people will decrease.
- If f is too large, $S_\infty > S_{th}$ and the outbreak will occur again after the end of intervention ($f=0$)

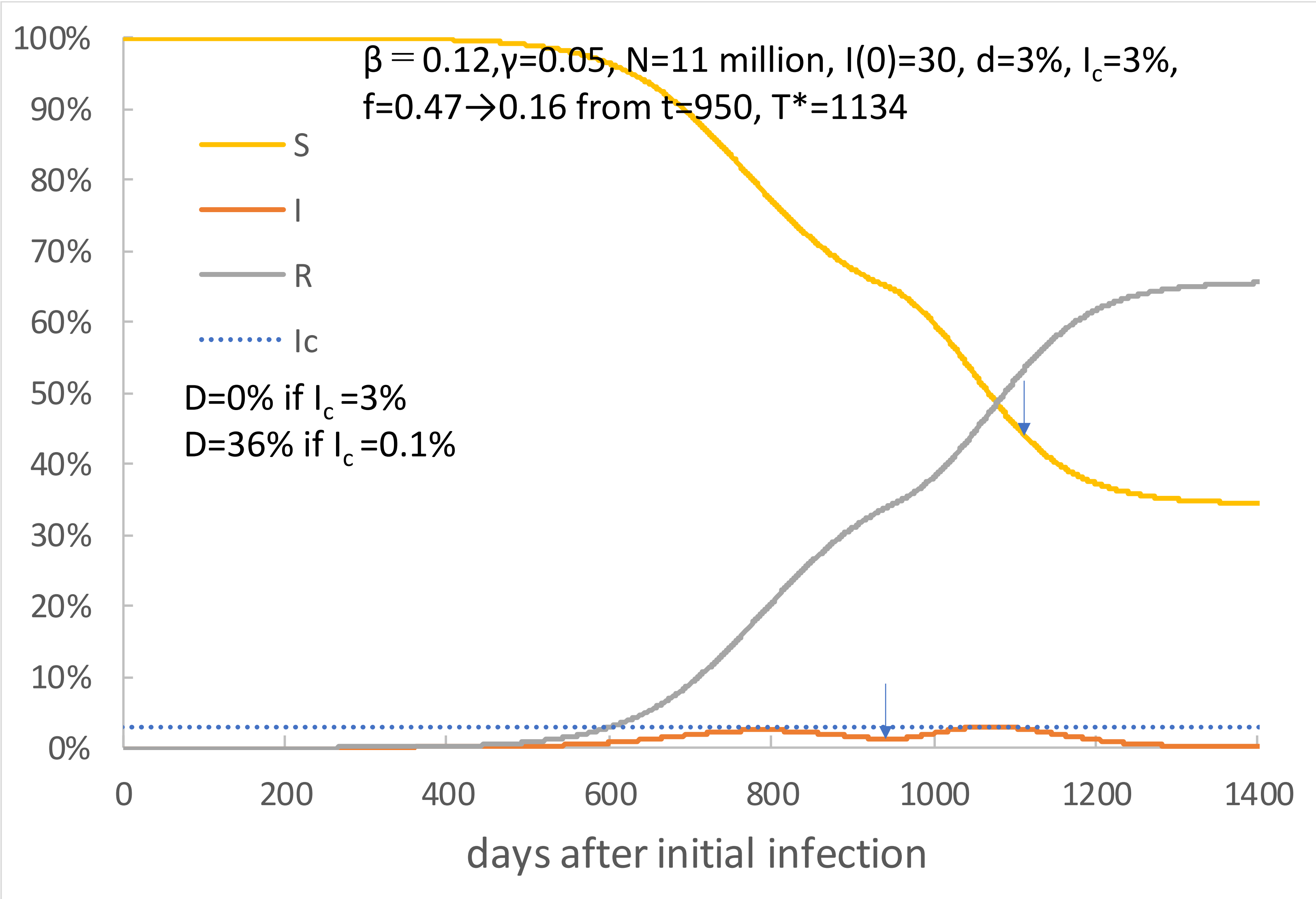
Optimal mitigation strategy to minimize the total death, D.

- I assume: D is defined as $\int d(I-I_c)_+ dt$, is the number of beds available for emergency treatment. d is the mortality rate of infected patient without emergency treatment. (I assume patients with emergency treatment will survive)
- I seek optimal f to minimize D under the constraint that $S_\infty < S_{th}$ (getting the herd immunity when f=0)
- If $S(t_c) < S_{th}$, further intervention is not needed ($f(t)=0$ for $t>T_c$). The total cost is fT_c.
- I assume $R_0=2.4$ ($\beta = 0.12, \gamma=0.05$)

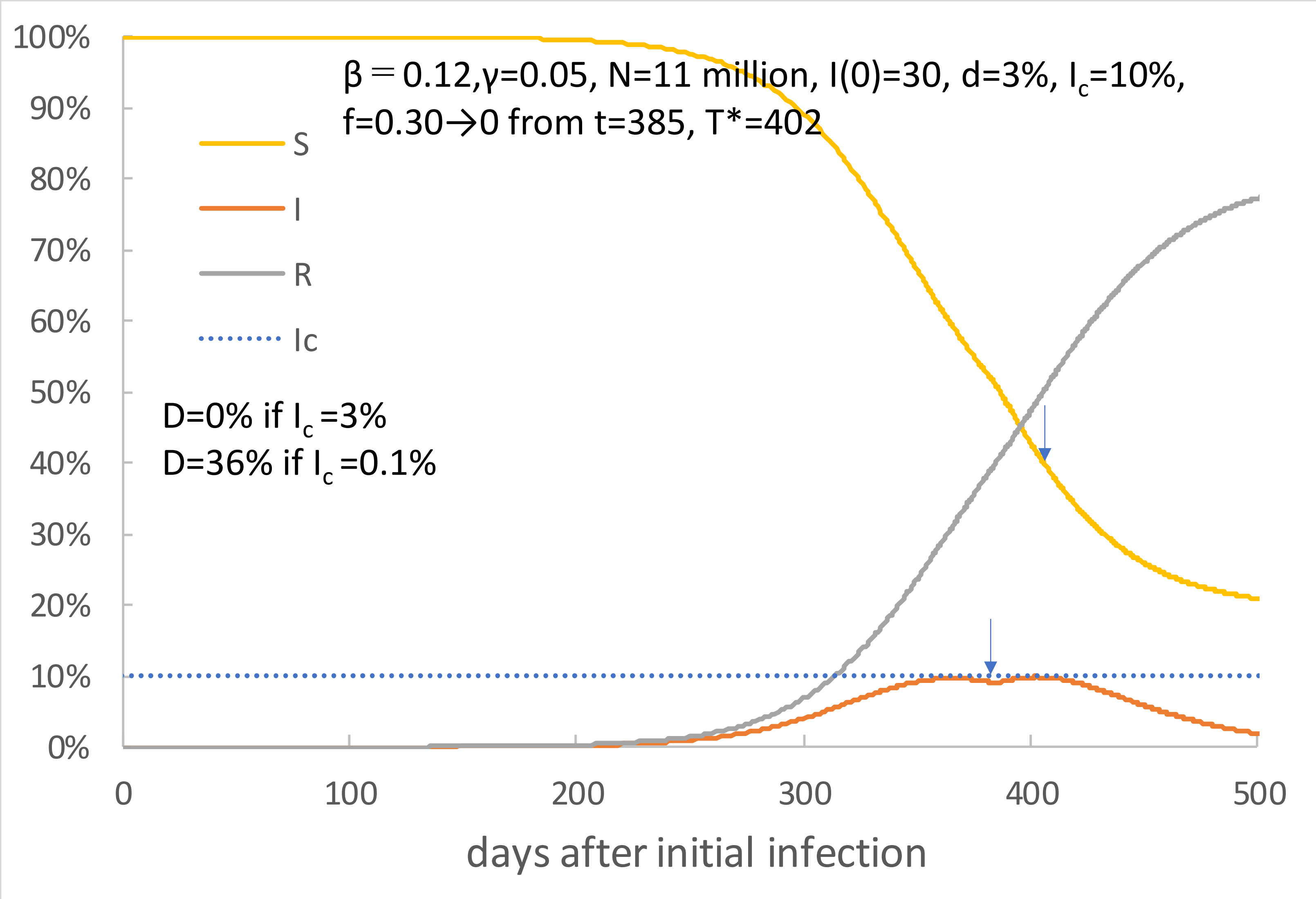
Suppression strategy (f>0.587)



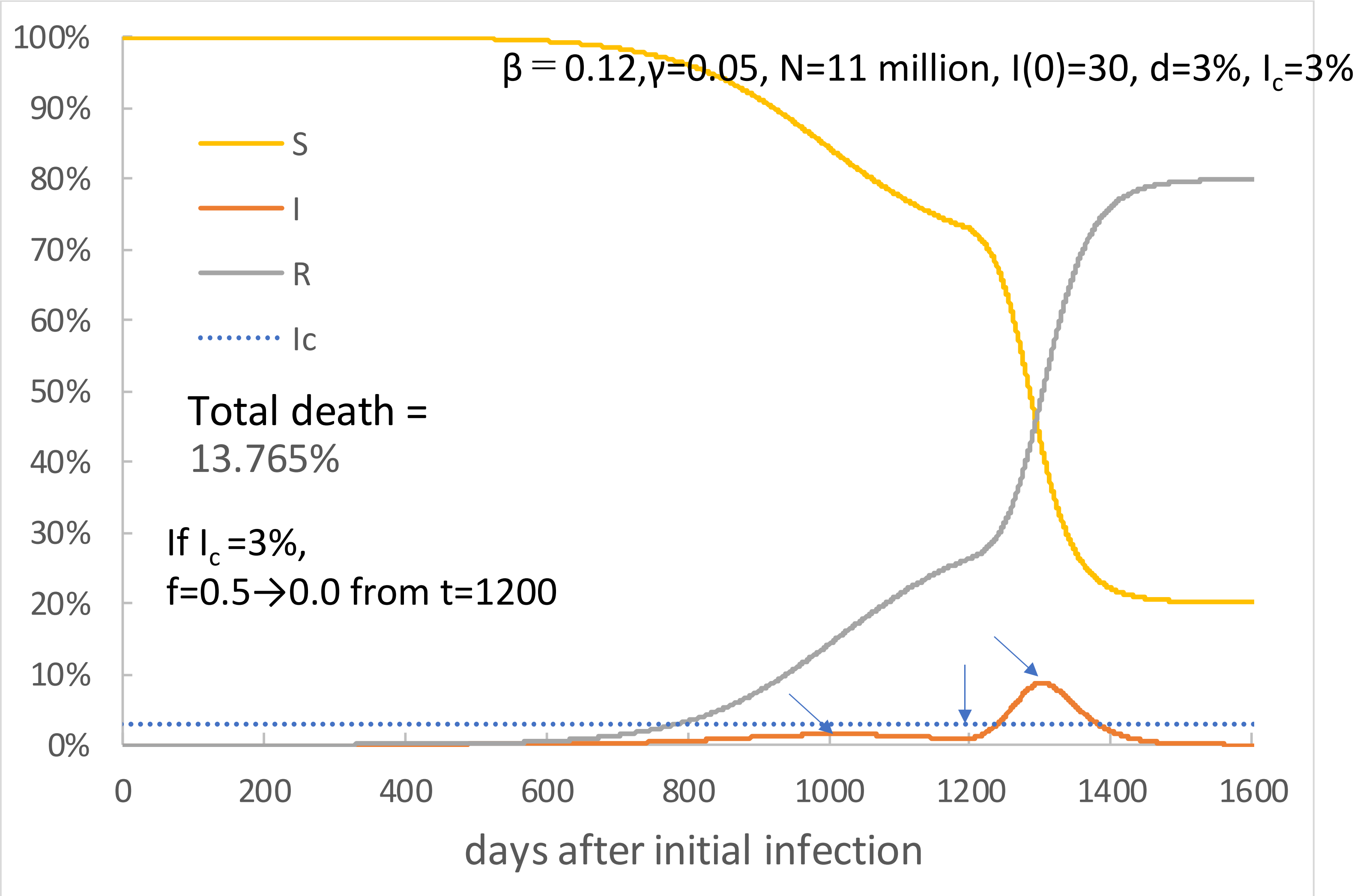
Optimal mitigation strategy if I_c=3%



Optimal mitigation strategy if I_c=10%



If f is too strong, 2^{nd} peak appears



Conclusion

- Suppression strategy needs forever intervention until vaccination is developed or the virus disappear in the world.
- Suppression strategy is possible irrespective of the infection rate ($f>1-\gamma/\beta$)
- Mitigation policy may stop if $S>S_{th,f=0}=\gamma/\beta$
- If the intervention is too strong, a 2nd peak may occur.
- Difference btw f for suppression and f for optimal mitigation is small. Therefore mitigation with a small mortality is probably the best policy.
- The number of beds should be as many as possible if the cost is smaller than the economic damage.