Modeling COVID-19 Optimal Testing Strategies in Retirement Homes: An Optimization-based Probabilistic Approach

Mansoor Davoodi, *Ana Batista*, *Abhishek Senapati*,

Weronika Schlechte-Welnicz, *Justin Calabrese*

m.davoodi-monfared@hzdr.de

Center for Advanced Systems Understanding (*CASUS*), *Görlitz*, *Germany*

Helmholtz-Zentrum Dresden-Rossendorf e.V. (*HZDR*)

https://www.casus.science/

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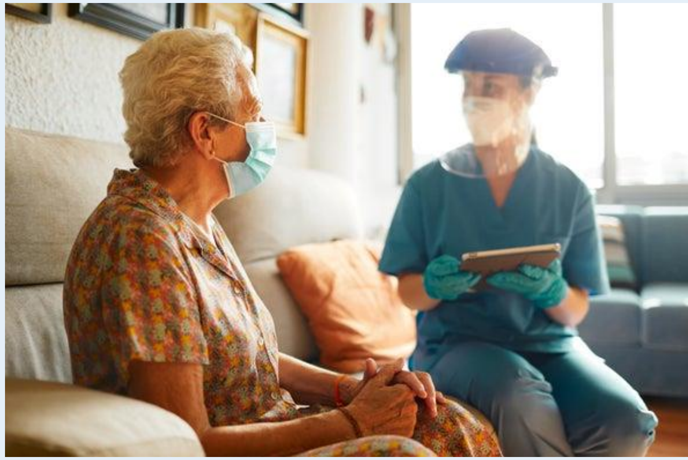
COVID-19 and Retirement Homes

- The Residents are older adults with highly risk of infections and mortality. They are in contact with each other, staff, visitors and doctors.
- Controlling the spreading of the pandemic by isolating the residents is a challenge. Once the infection arrives at the facility, it spread so fast [1].
- According to the European Centre for Disease Prevention (ECDC), by May 2020, 37-66% of all COVID-19 related deaths in several EU countries were found in such homes [2]. In the US, over 30% of COVID-19 deaths were associated with nursing homes institutions [3].

https://www.aic.sg/care-services/nursing-home

https://account.bradenton.com/paywall/subscriberonly?resume=242117241&intcid=ab_archive

Testing Process in Retirement Homes



Suppose an RH with m residents and n staff.

The residents are tested regularly by staff, who cleans and prepares the testing workspace for each group (or batch) of resident. Let P_{time} denote such preparation cost (time), and k be the number of groups.

Each resident has his/her testing cost, T_{time}. So,

$$Testing\ cost = k \times P_{time} + m \times T_{time}$$

https://www.healthline.com/health-news/

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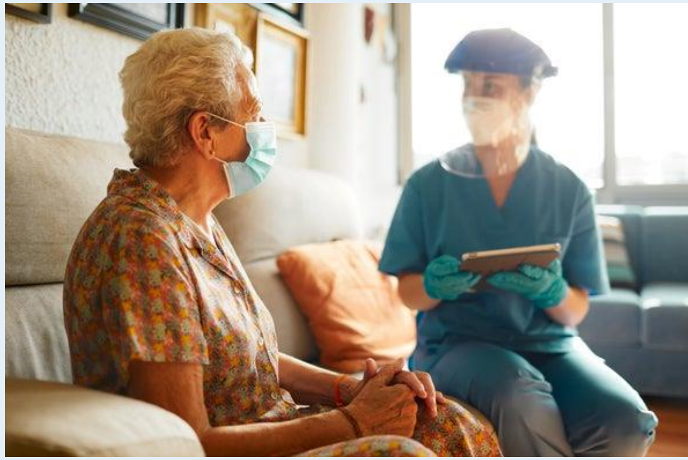

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$$Testing\ cost = k \times P_{time} + m \times T_{time} \leq \quad n \times \tau$$

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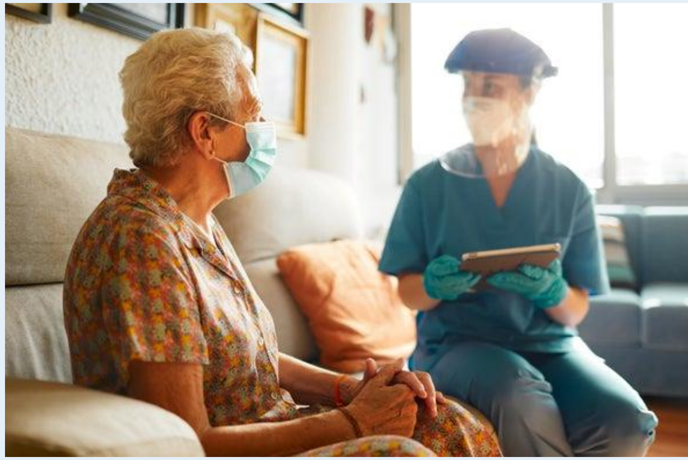

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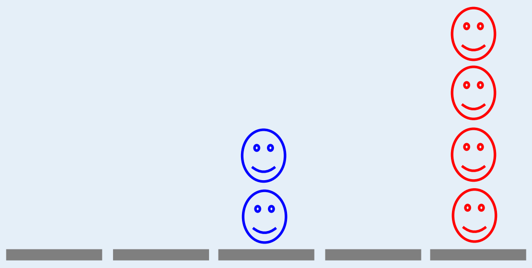
p: Maximum portion (percent) of staff's time which can be allocated to the testing process

Testing Strategy

A testing Strategy is (k, τ, G, D) where



k: Number of groups

$(k = 2, \tau = 5, G = \{2,4\}, D = \{3,5\})$

τ: The test interval

$G = \{g_1, g_2, \ldots, g_k\}$ a partitioning of the people

$\mathrm{D} = \{d_1, d_2, \ldots, d_k\}$ testing day for each group

Two models for RH testing strategy (Model 1)

Minimize Expected Detection Time of (k, τ, G, D)

s.t.:

$$k \times P_{time} + m \times T_{time} \leq p \times n \times \tau$$

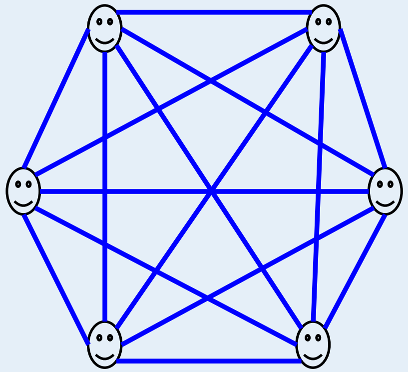
$$\sum_{i=1}^{k} |g_i| = m$$

$$\tau \leq Max_{\tau}$$

$$|g_i| \leq Max_g, \quad \forall i = 1, 2, \ldots, k$$

The First Question

If we can test a set of 6 people under one of the following testing strategies



- Two groups, every 4 days
- Three groups, every 5 days

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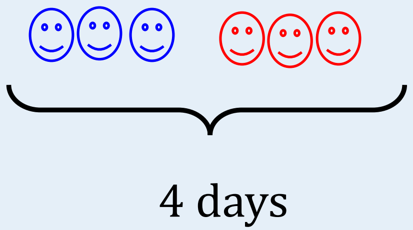

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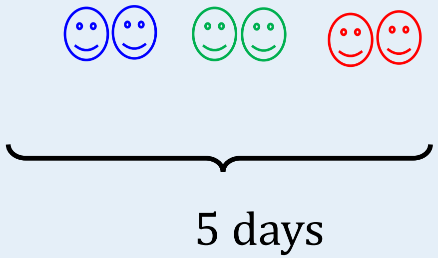

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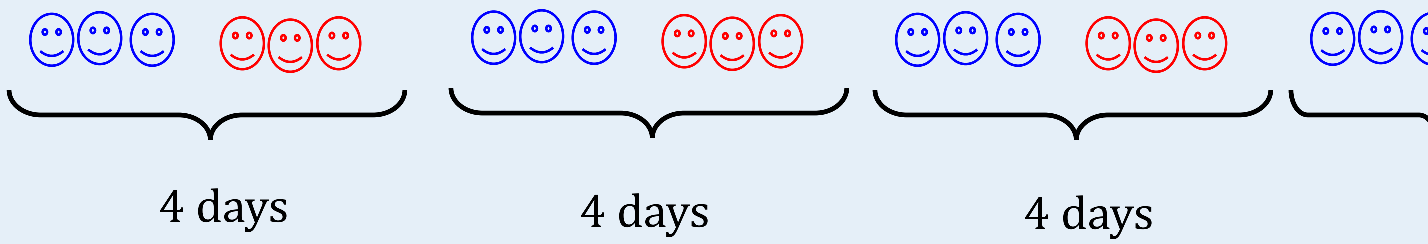

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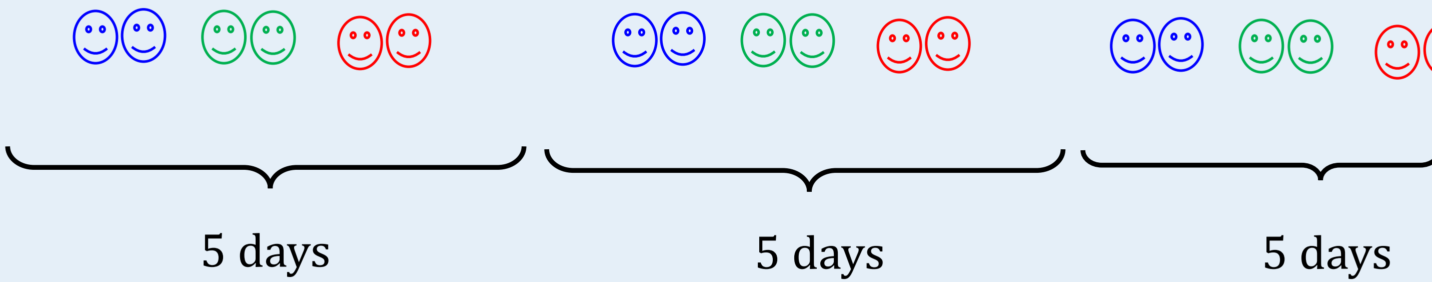

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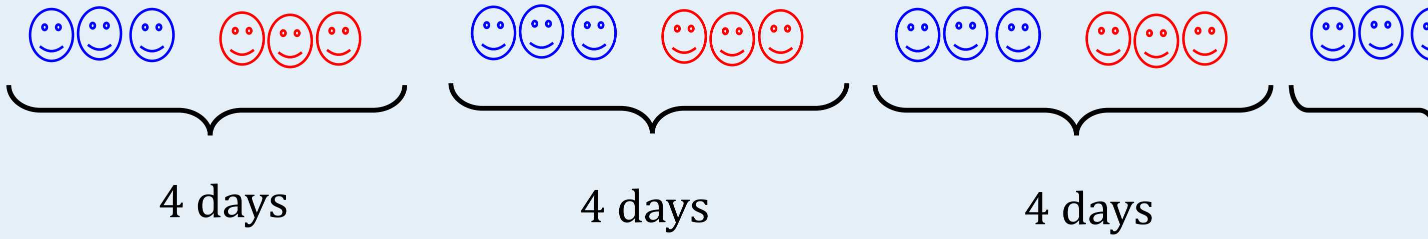
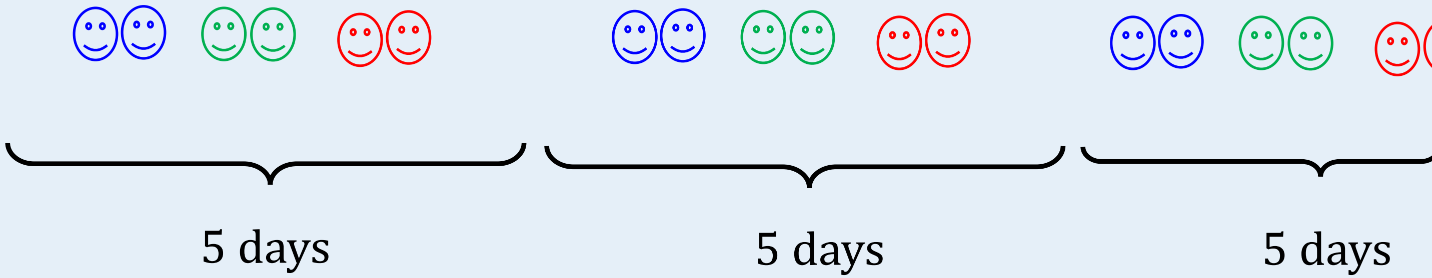


Objective: *Minimizing Detection Time*

Expected

- Three groups, every 5 days



The Second Question

How do partition the people, and on which days do the tests?

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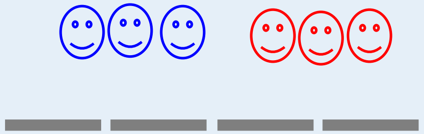

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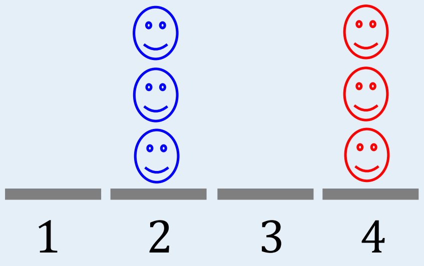

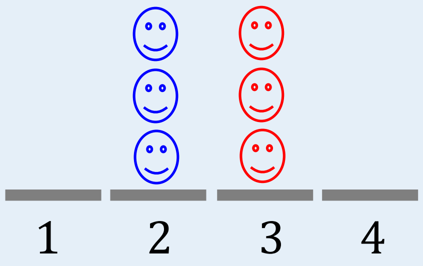

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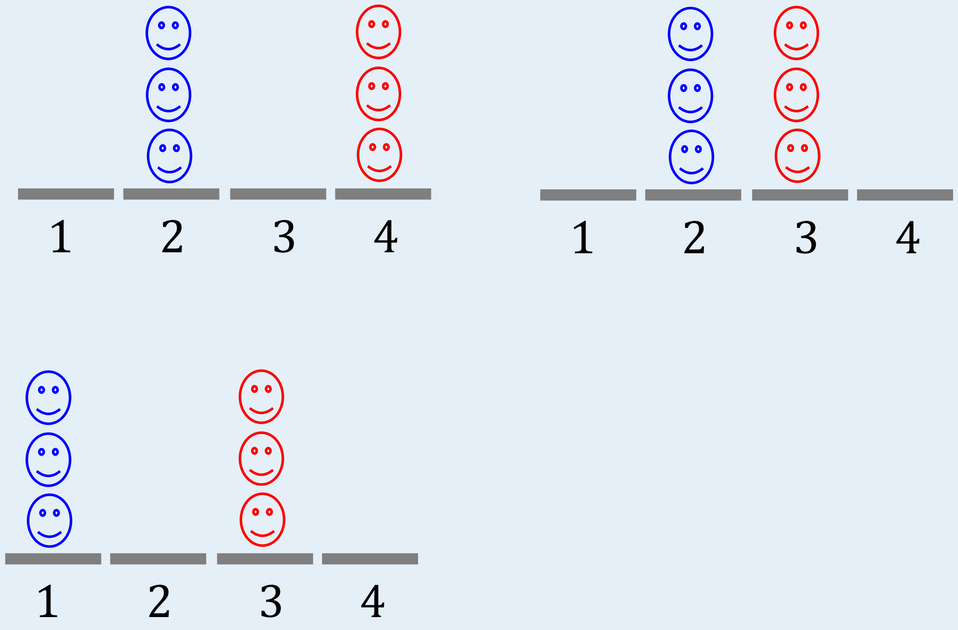

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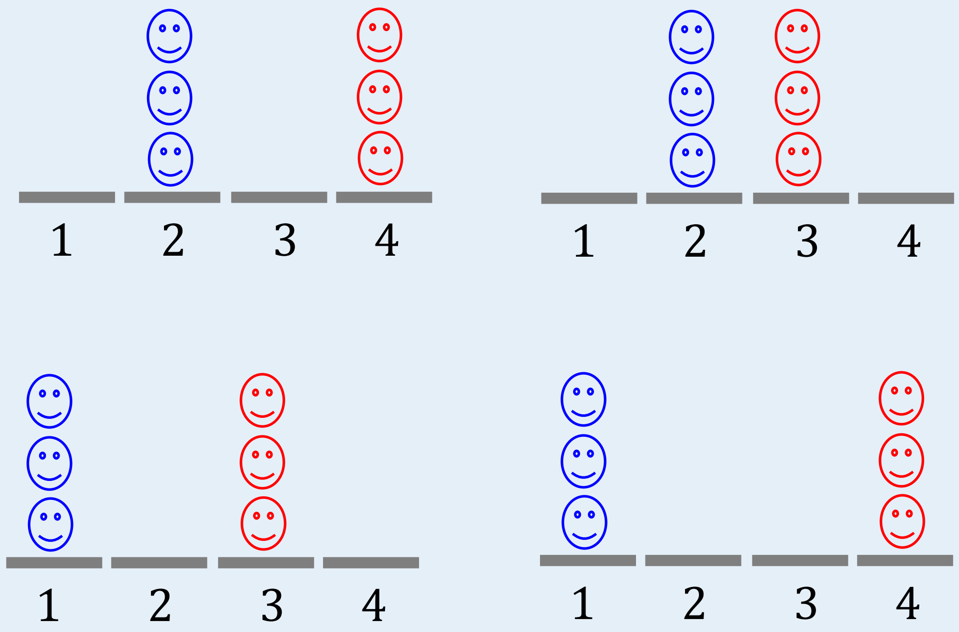

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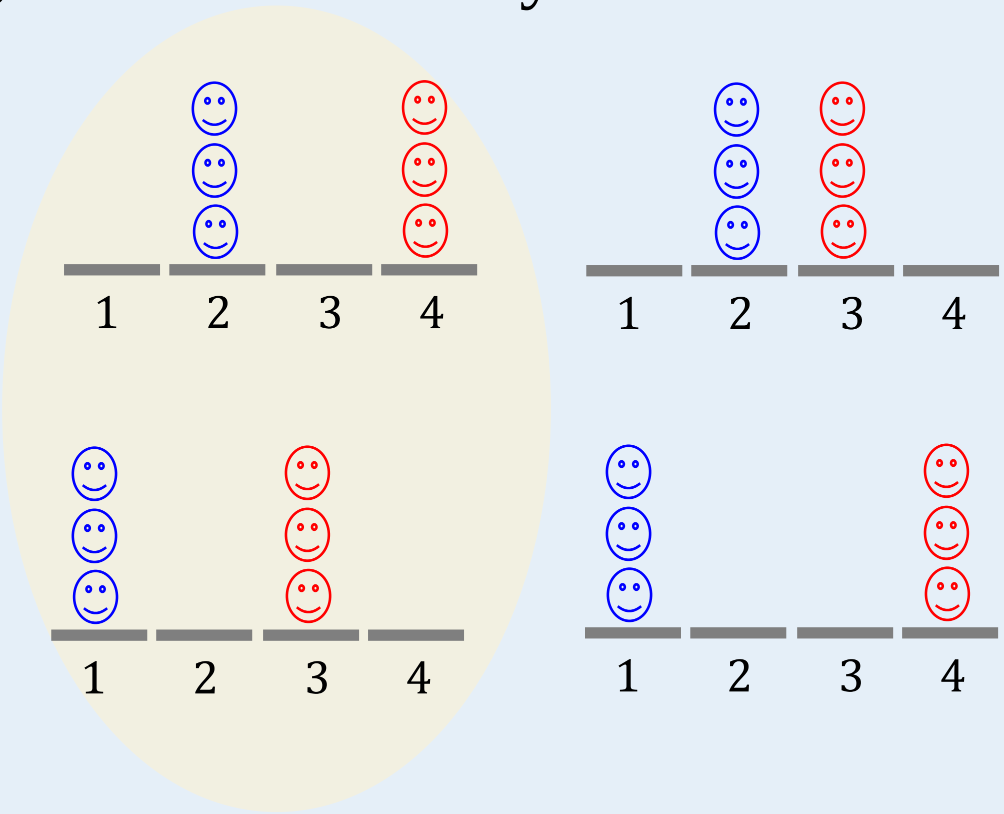

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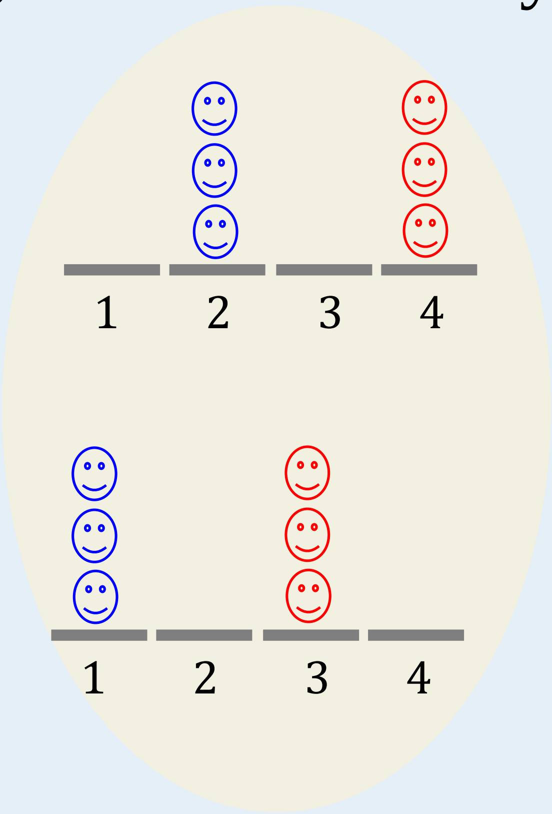

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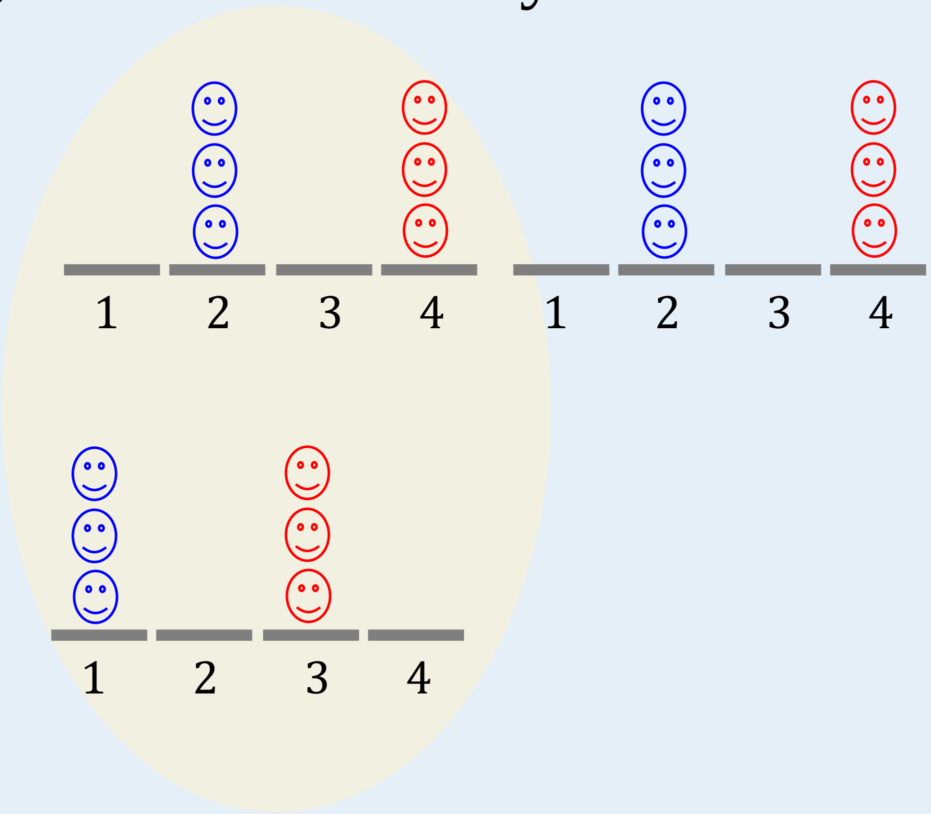

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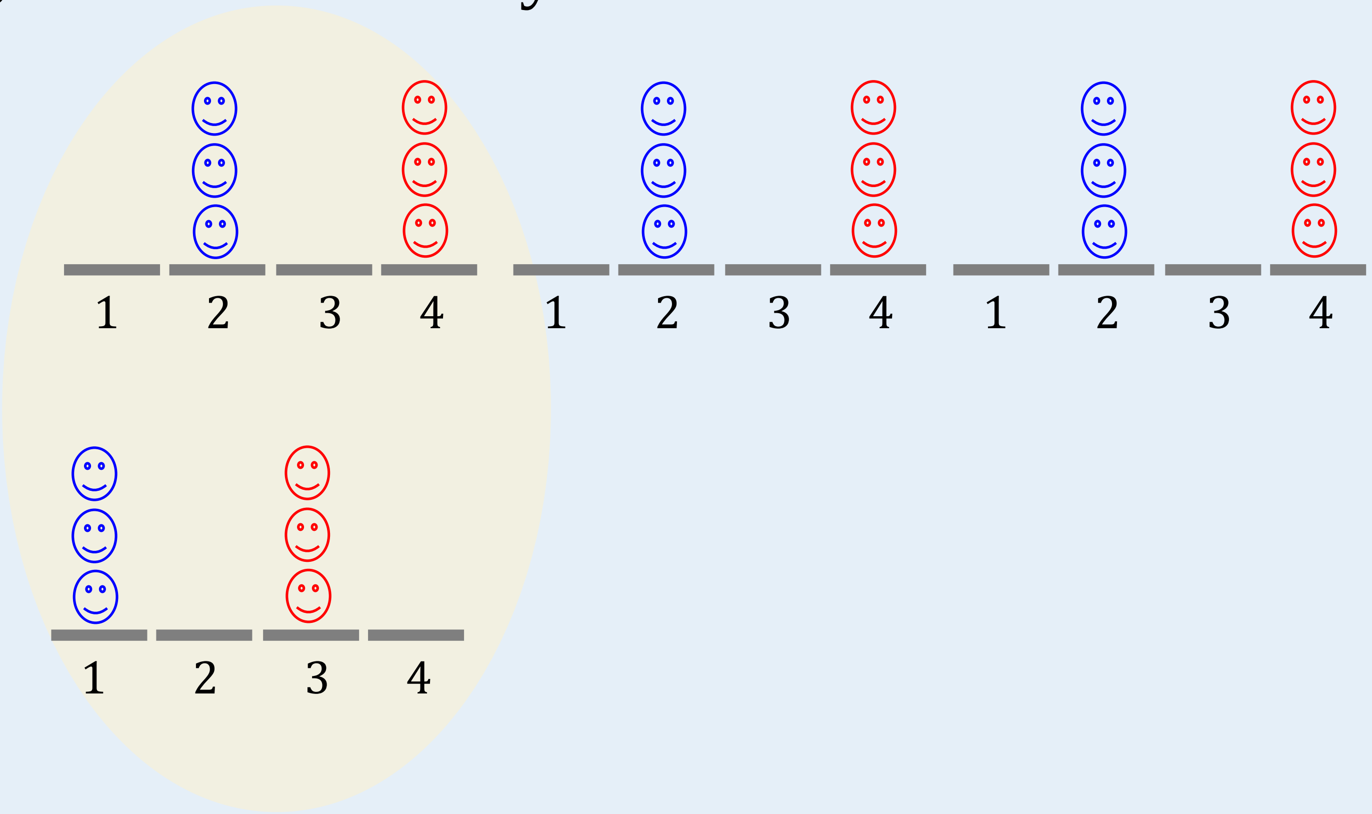

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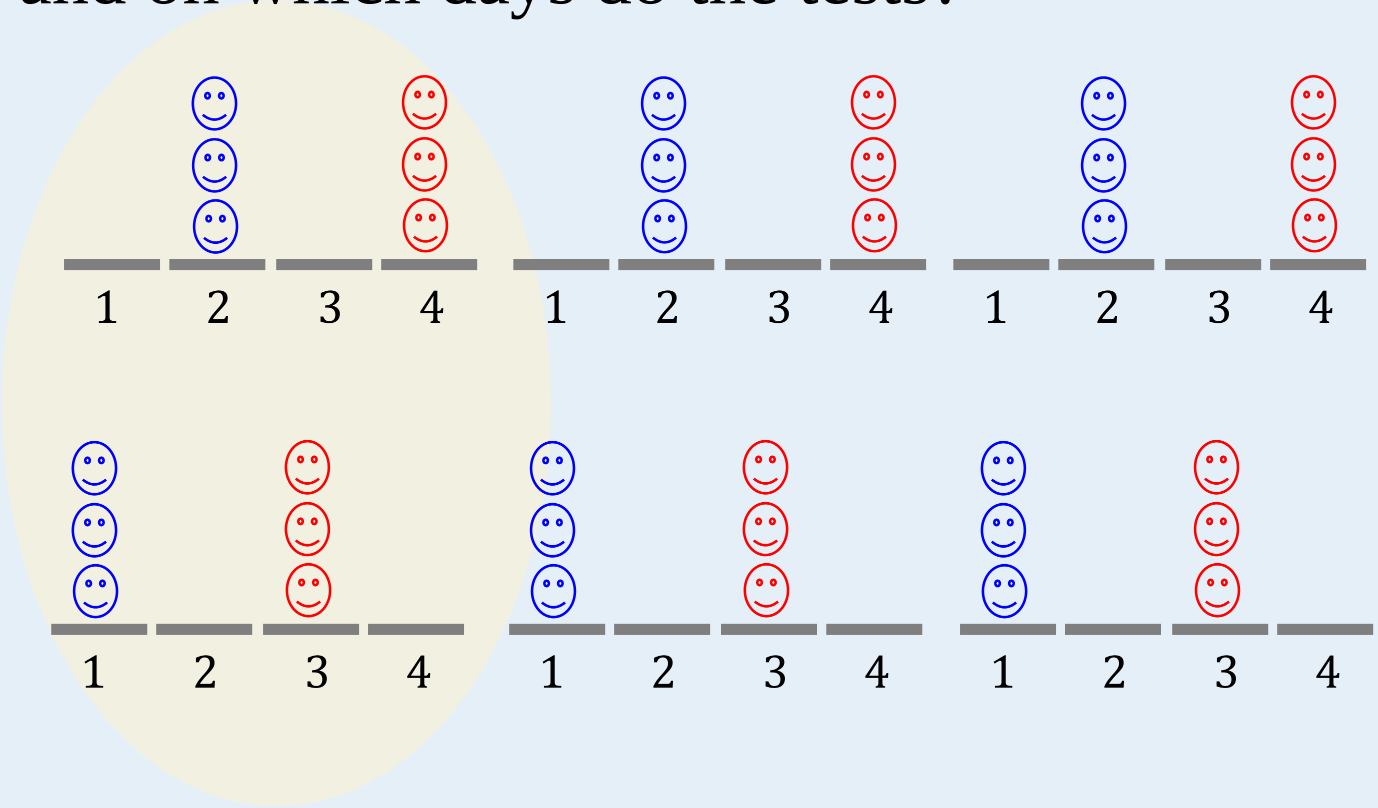

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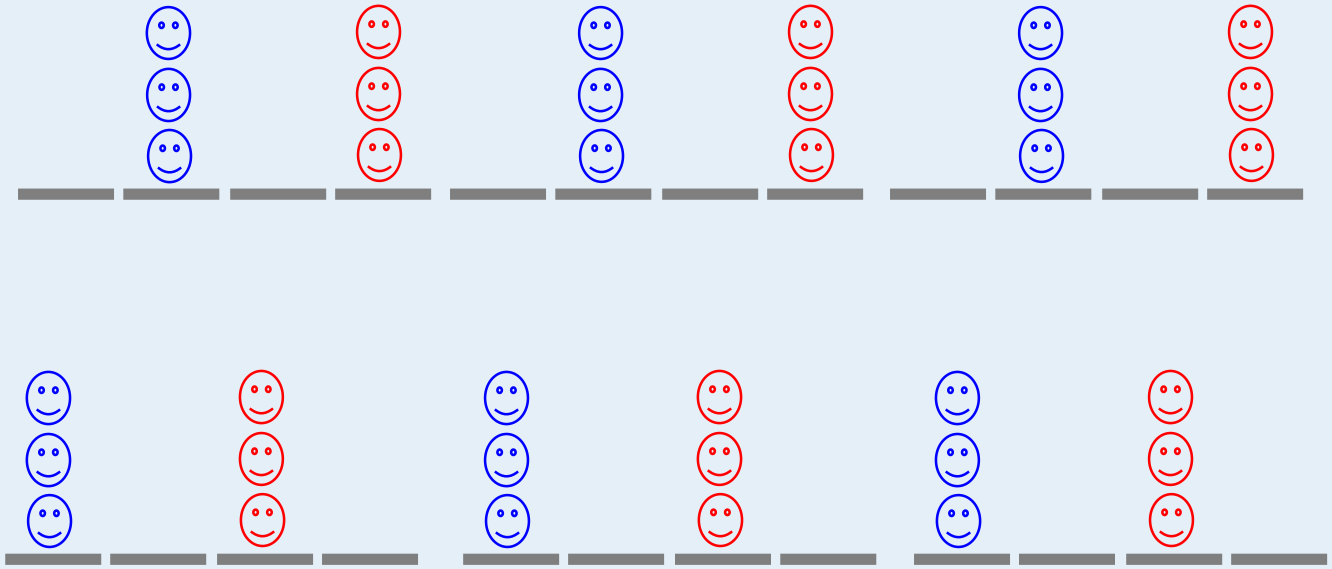

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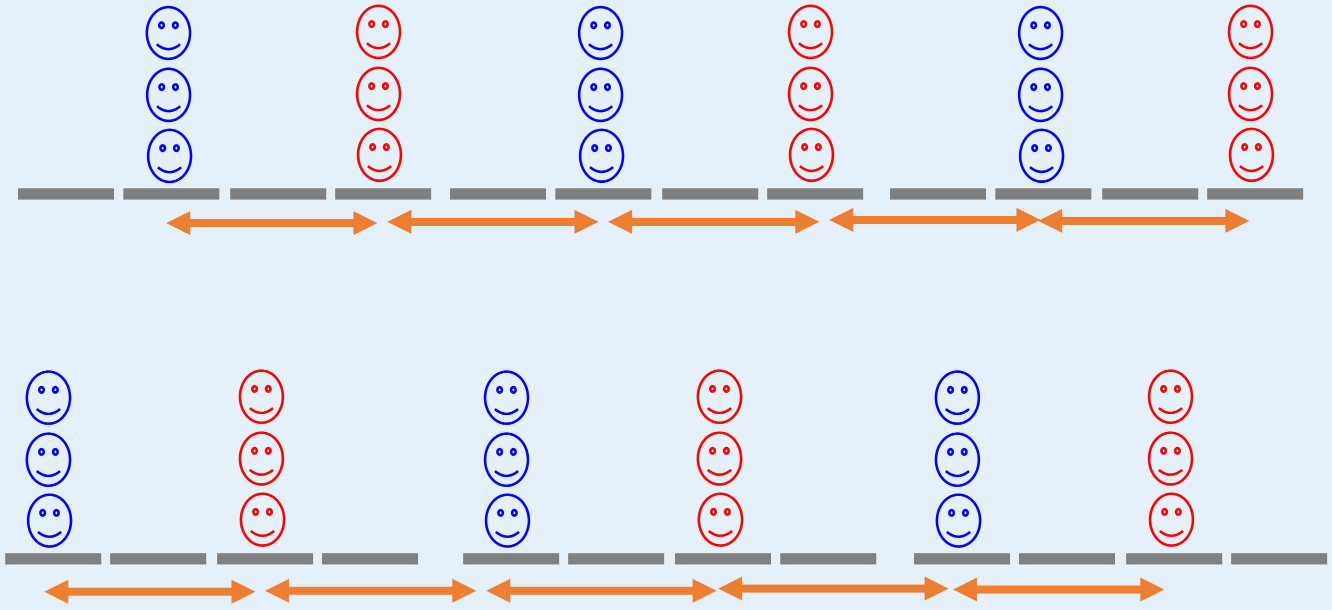

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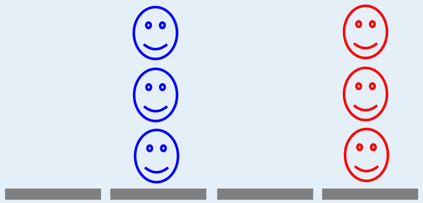

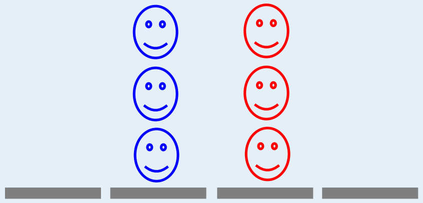

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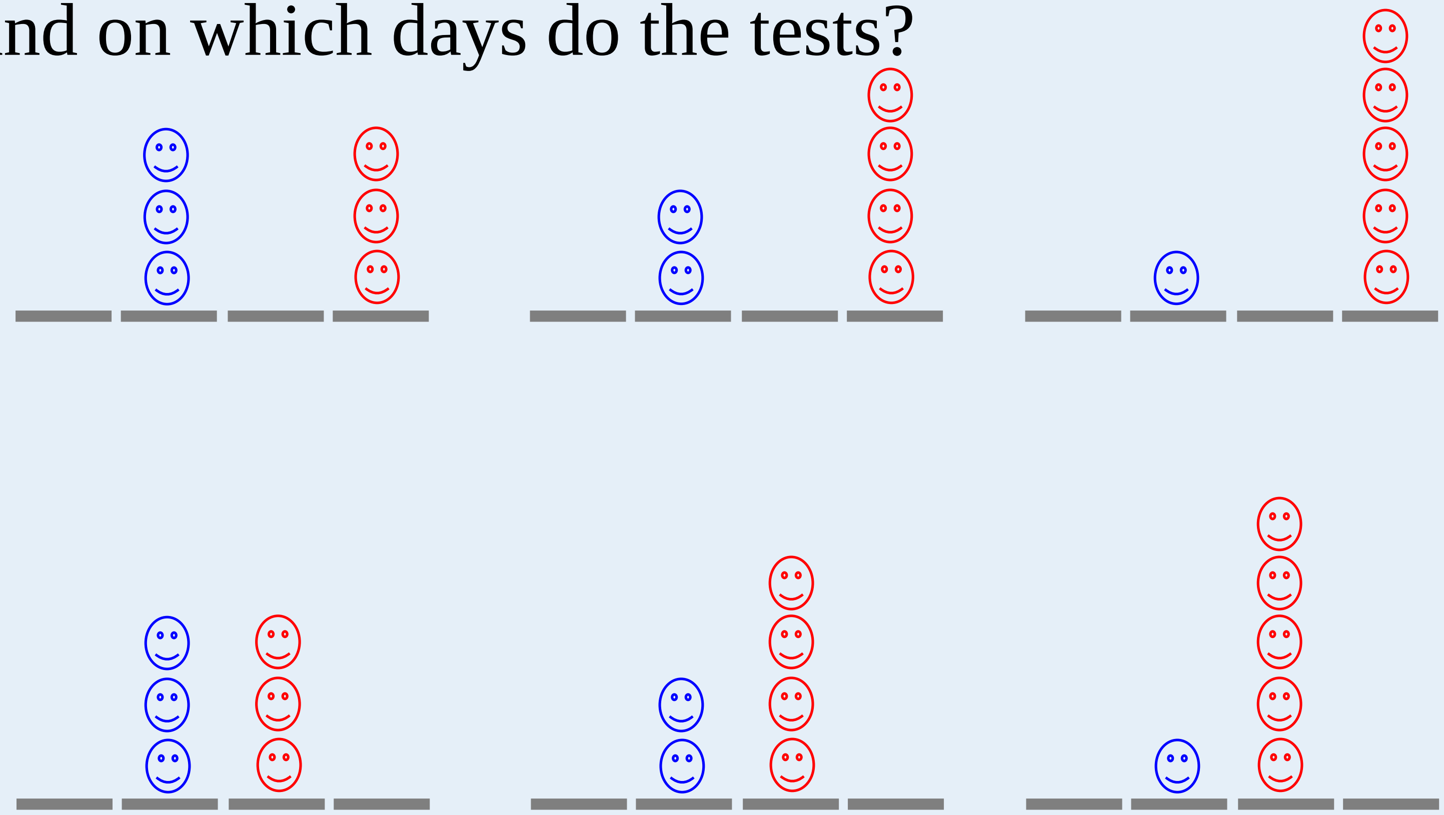

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Which testing strategy results in

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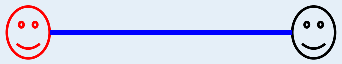

β: The probability of the virus transmits from one infected individual to a susceptible individual per one contact

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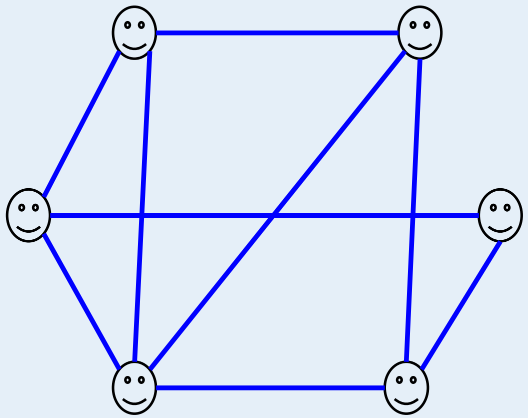
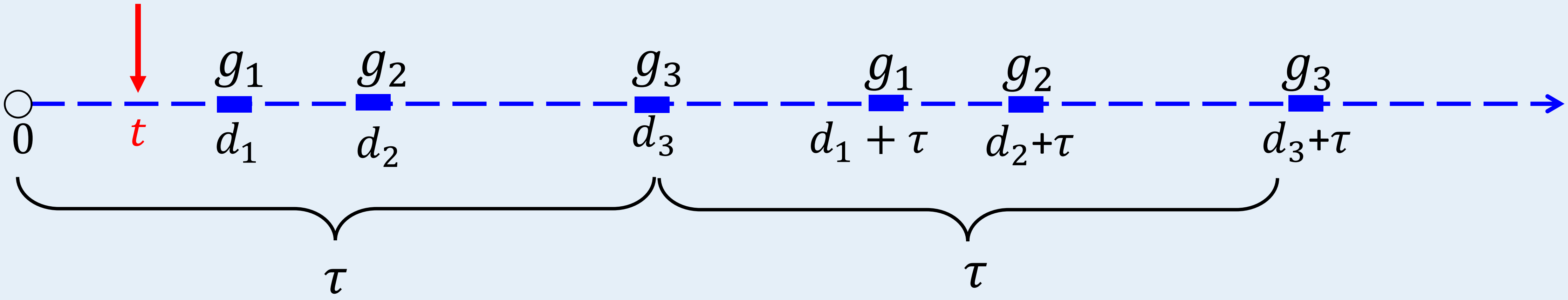


β: The probability of the virus transmits from one infected individual to a susceptible individual per one contact

c: The average number of contacts per individual

Computing the expected detection time

For a given testing strategy (k, τ, G, D), the expected detection time can be computed using a series of calculations and probabilistic analysis.



Expected Detection Time$= \frac{1}{\tau}\sum_{t=1}^{\tau} \mathbb{E}(k, \tau, G, D, \beta, c, t)$

Two models for RH testing strategy (Model 1)

Minimize Expected Detection Time of (k, τ, G, D)

s.t.:

$$k \times P_{time} + m \times T_{time} \leq p \times n \times \tau$$

$$\sum_{i=1}^{k} |g_i| = m$$

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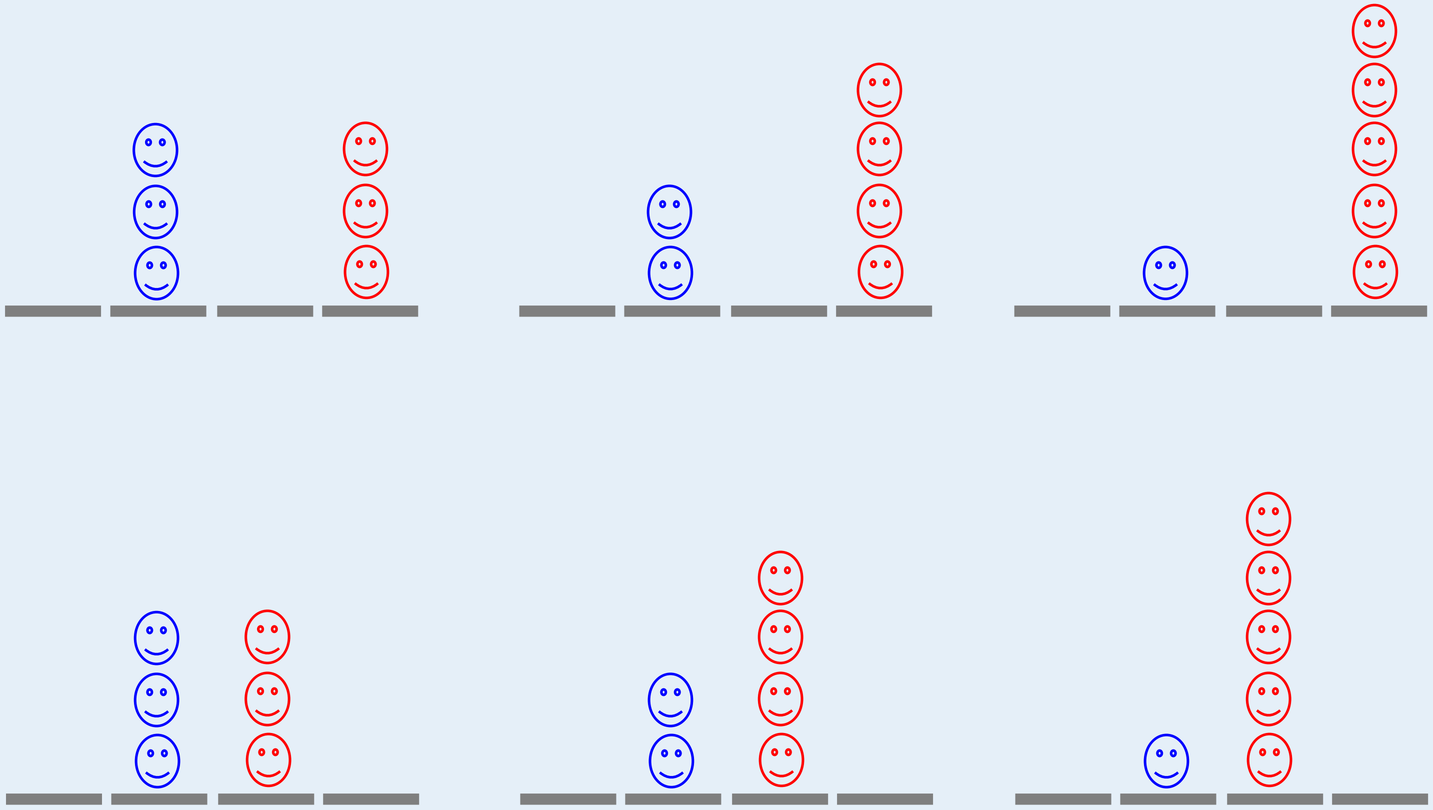
Symmetry Property

- Two groups, every 4 days



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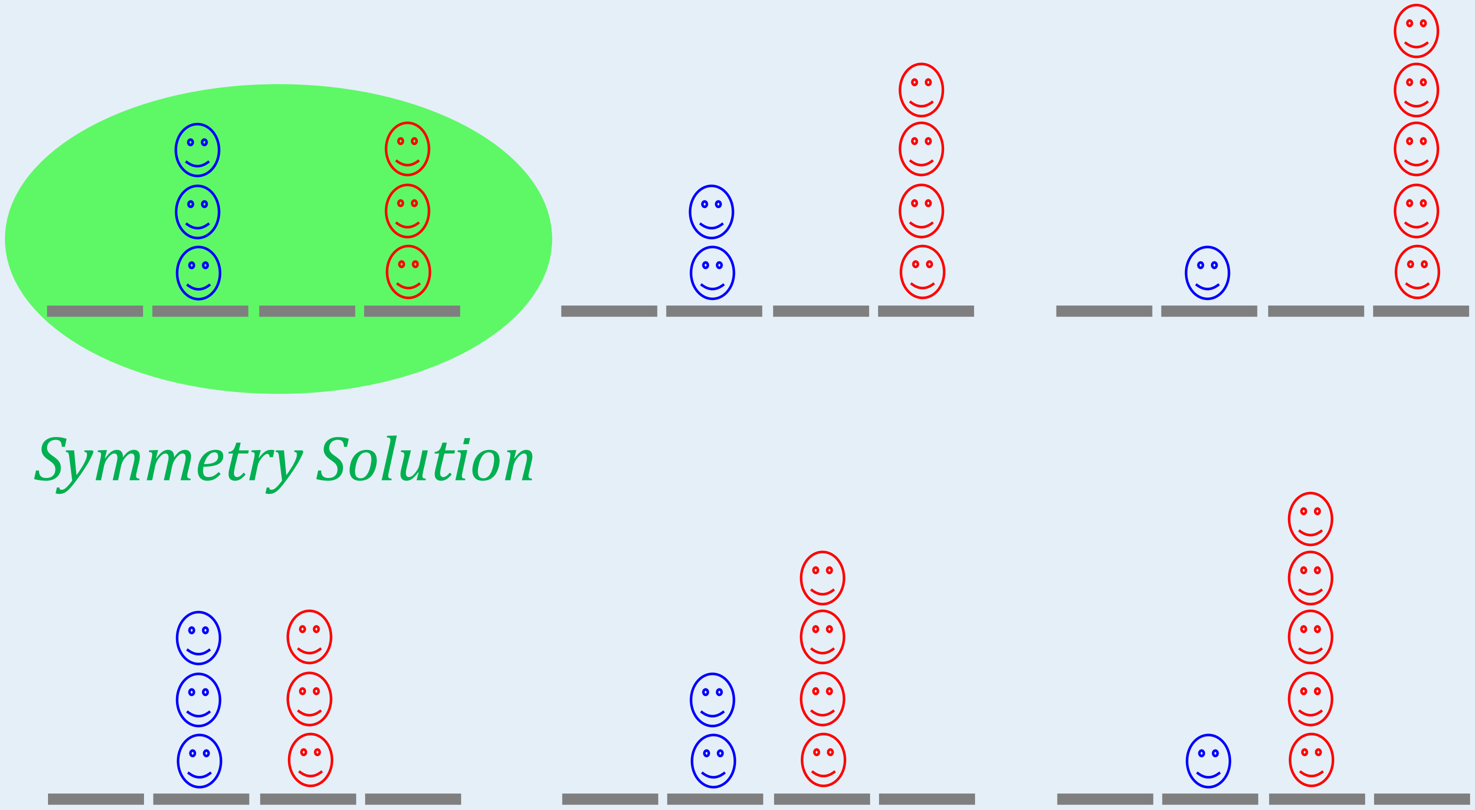

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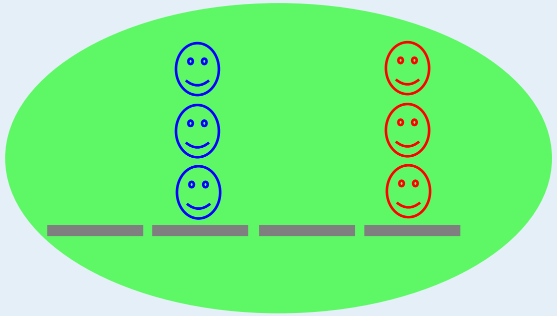

- Three groups, every 5 days

Symmetry Property

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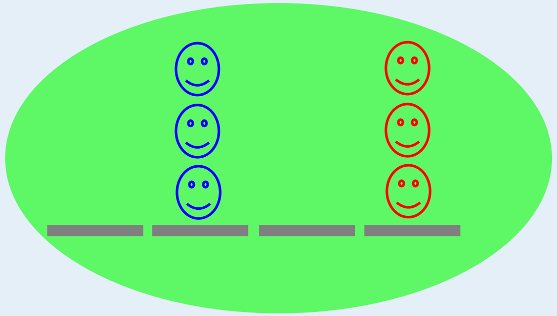
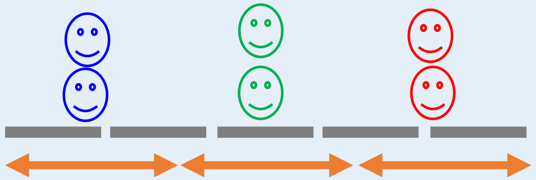


- Three groups, every 5 days

$d_1 = \frac{5}{3}$ =1.66
$d_2 = 3.33$
$d_2 = 5$



No Symmetry Solution in Discrete Space

Symmetry Property

Theorem. For a given, k as the number of groups and τ as the interval test, the optimal testing strategy of the (continuous) search space always is a symmetry strategy for the following cases

- $\beta \to 0$
- $c \to 0$
- $\beta \to 1$
- $c \to +\infty$

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For $0 < \beta < 1$ and $c > 0$, we ran a brute-force algorithm which tries so many setting of the parameters.
As the result, again the symmetry property holds.
So, providing a theorem for that, is an *open problem*.

Model : Some results

m	n	p (%)	Max_{τ}	Max_{g}	c	k	τ	G	D	Exp. Detect Time
50	10	5	4	22	17					
50	10	5	7	30	9	2	5	{28,22}	{2,5}	1.73
90	15	5	7	30	15	4	6	{25,20,25,20}	{1,3,4,6}	1.43
90	15	10	7	30	15	3	3	{30,30,30}	{1,2,3}	0.90

Two models for RH testing strategy

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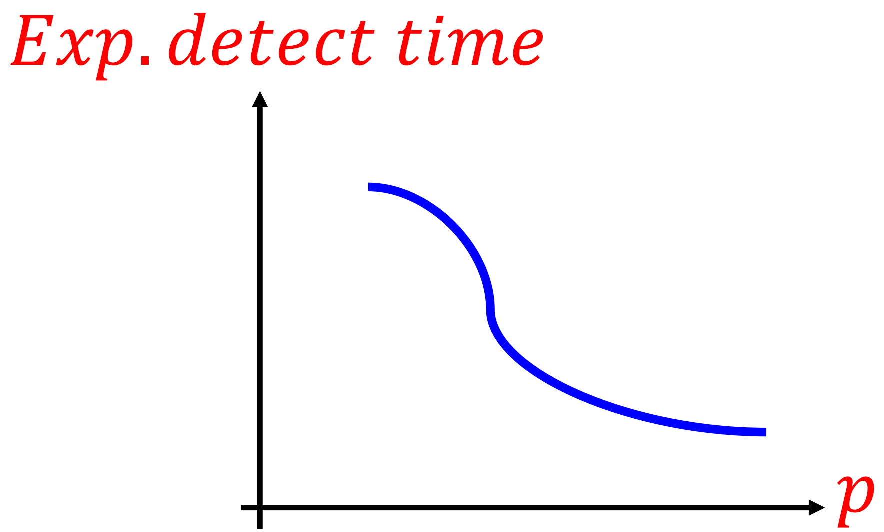
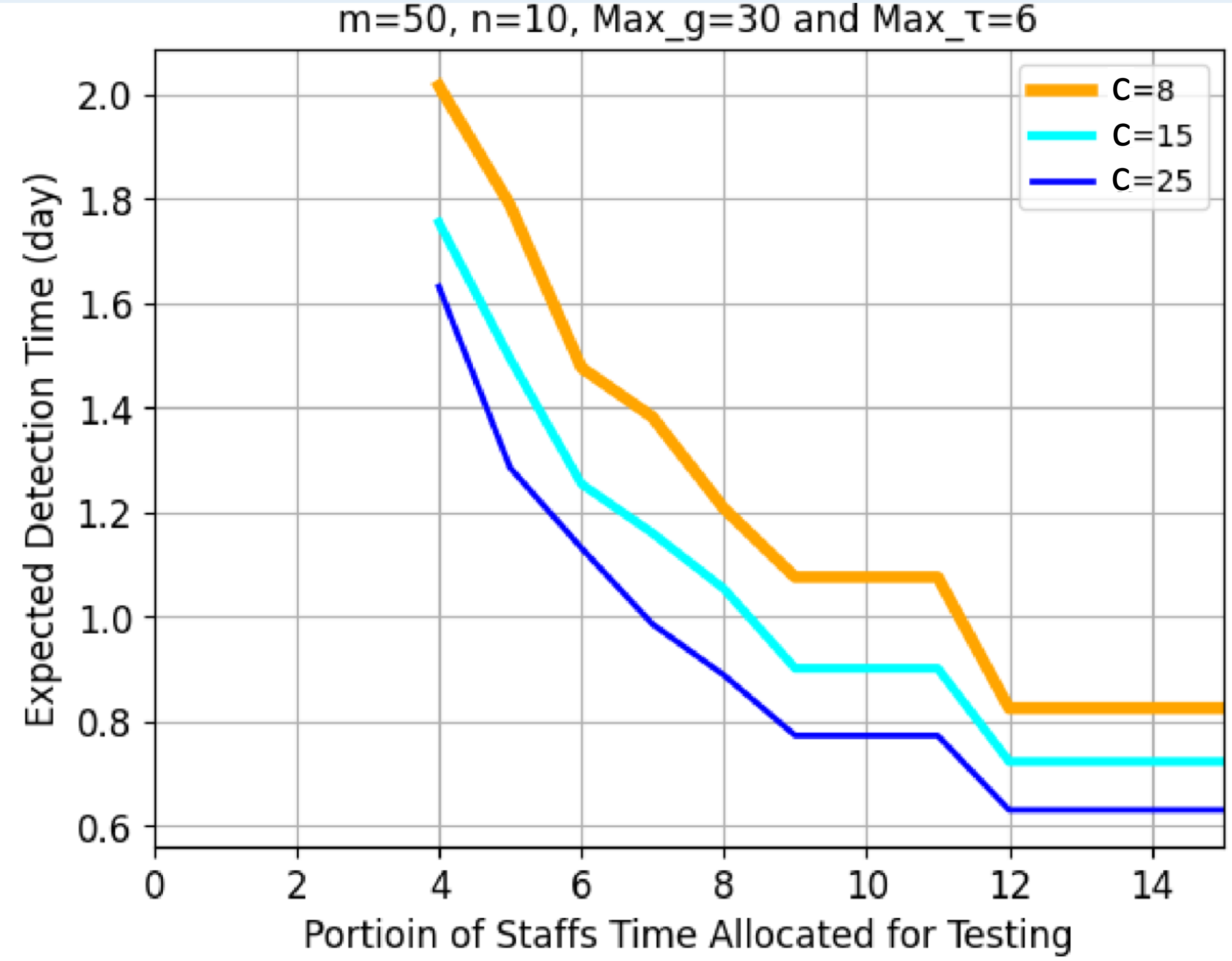
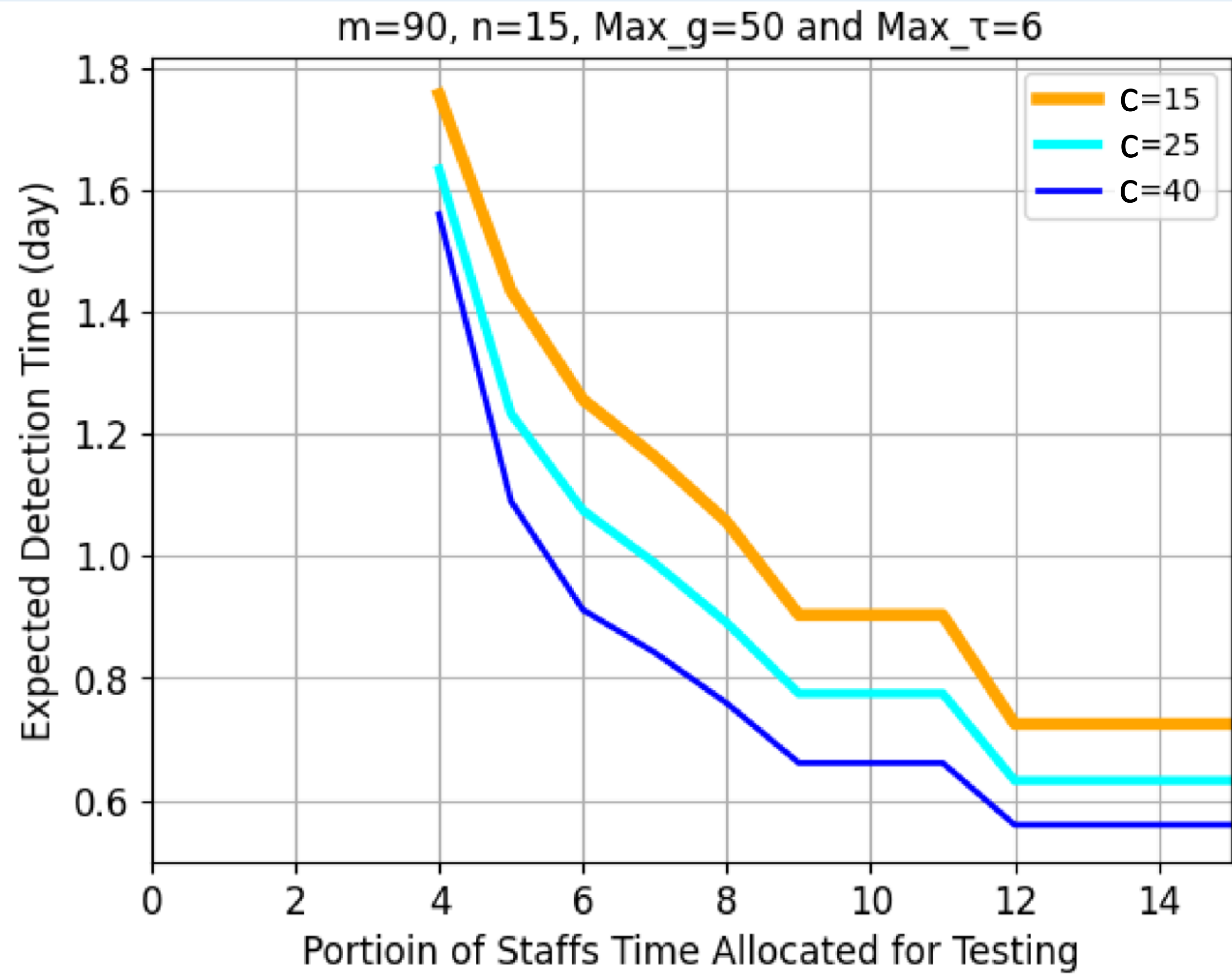


Trade-off solutions





References

- [1] https://www.rki.de/DE/Content/Infekt/EpidBull/Archiv/2021/Ausgaben/18_21.pdf?__blob=publicationFile
- [2] E. C. for Disease Prevention, Control, Surveillance of COVID-19 in long-term care facilities in the EU/EEA, ECDC Stockholm https://www.ecdc.europa.eu/en/publications-data/ surveillance-COVID-19-long-term-care-facilities-EU-EEA (May 2020).745
- [3] C. for Medicare & Medicaid Services, et al., COVID-19 nursing home data, Baltimore, MD: US Department of Health and Human Services, Centers for Medicare & Medicaid Services.

Acknowledgement

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- *Helmholtz-Zentrum Dresden-Rossendorf e.V.* (*HZDR*)
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