Vaccinating bridge nodes reduces cumulative deaths!

Evaluating Bridge-Node based Methods as Viable Alternatives to Degree-based Methods for Vaccine Allocation in Low Resource Settings

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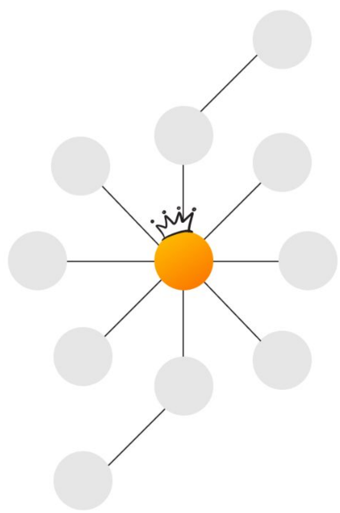
Motivation

- **Vaccine scarcity** demands **efficient allocation.**
- Traditional **degree-based targeting** vaccinates **high-contact individuals** but **ignores network community structure.**
- **Real contact networks have communities** where **epidemics spread rapidly** within but **rely on bridge nodes** to propagate between.
- This is **rarely modeled; age-based** and **degree-based** methods favored.



Problem

Problem Statement: Given network G=(V,E) with communities, limited vaccine supply φ, find target set T* minimizing infections and deaths:

$$T^* = \text{argmin } E[I(G,T)]$$

Hypothesis: Bridge-node targeting outperforms degree-based in low-resource settings.

Our Experimental Benchmark

- 2 datasets, Demography vs synthetic
- 7 node selection methods
- 3 infection rates, 3 vaccine availabilities
- 2 Simulation Models
- Random vs Community-Based Seeds

250+ experiments, 1 benchmark

Evaluation Datasets

LocationType	Nodes	Edges	AvgDegree
BasicsShop	1457	12659	17.37
Home	1648	1864	2.26
School	363	7412	40.83
SocialEvent	1420	19631	27.64
Work	1225	9952	16.24

Table 1: Network statistics for different social contact networks in the Zenodo population-based dataset

LocationType	Nodes	Edges	AvgDegree
Home	3997	5811	2.90
School	895	9805	21.91
SocialEvent	4000	50886	25.44
Work	2516	16688	13.26

Table 2: Network statistics for different social contact networks in the Synthetic population-based dataset

Bridge Node Detection Methods

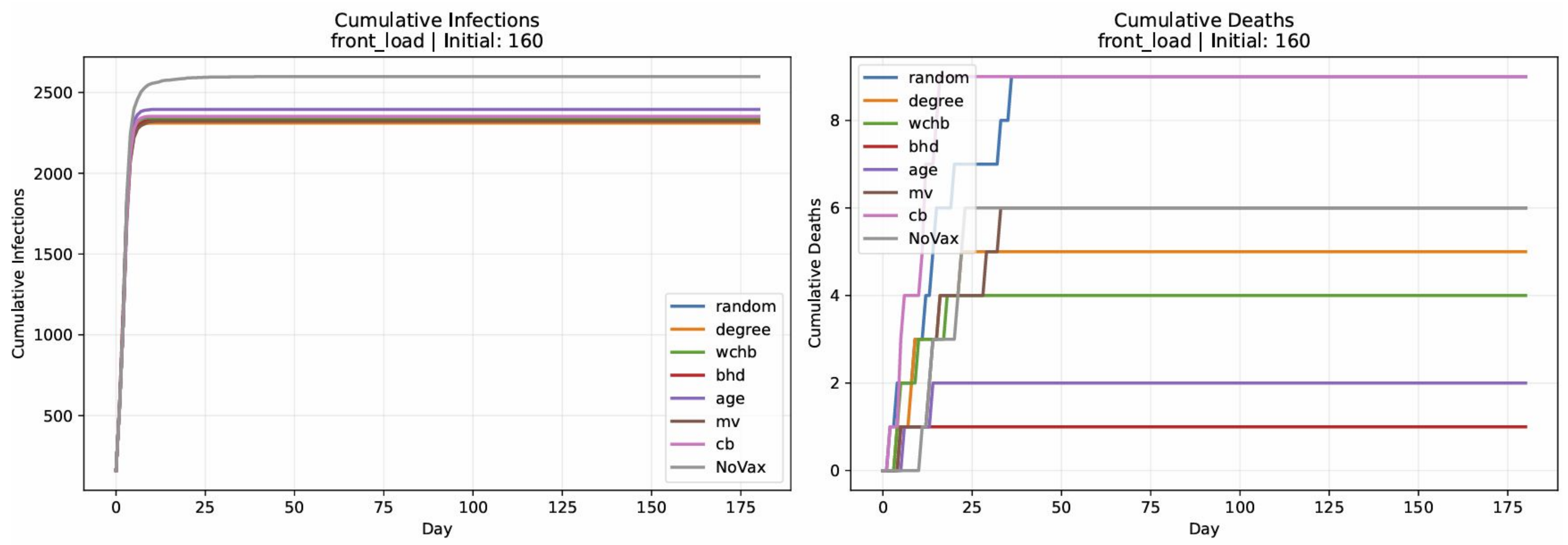
Bridge-Hub Detector (BHD)
Random walks identify community boundaries; landing nodes flagged as bridges. Local-only.

Community-Based Bridge (CB)
Louvain partitioning + cross-community edge ratio weighted by distinct communities connected.

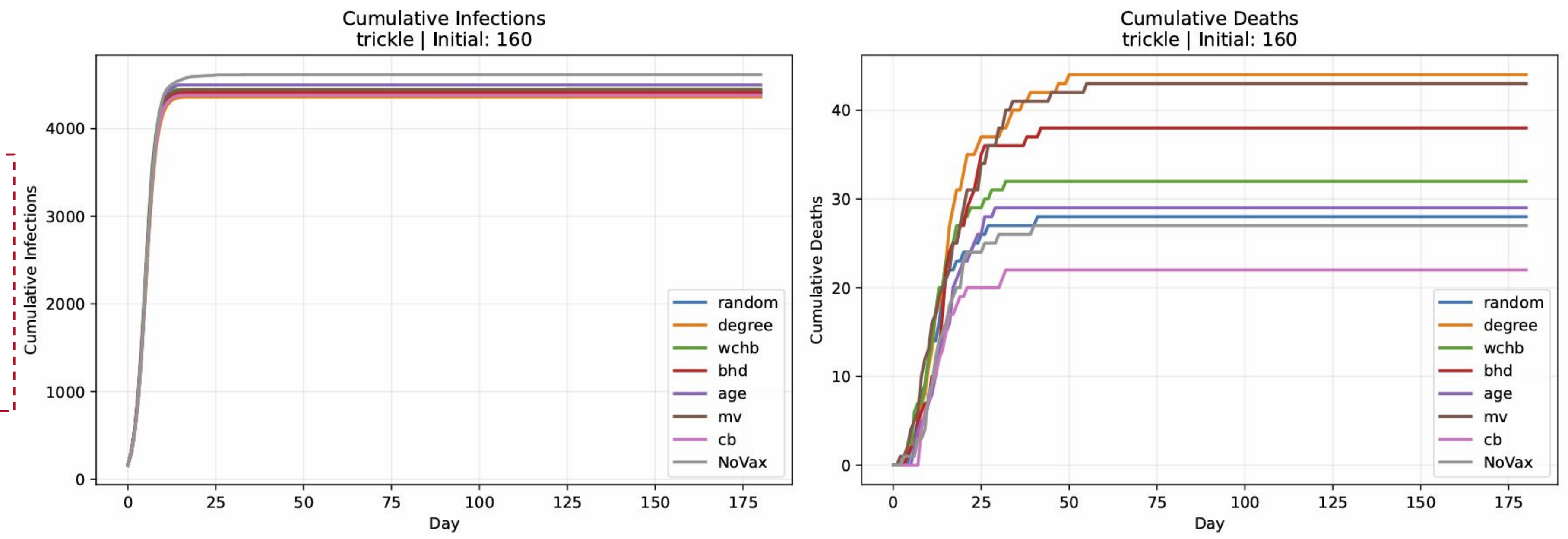
Weighted Community Hub-Bridge
Composite: S = α·Bridge + (1-α)·Hub. Balances inter/intra-community connectivity.

Modularity Vitality (MV)
ΔQ = Q(G) - Q(G\v). Nodes whose removal increases modularity act as structural glue.

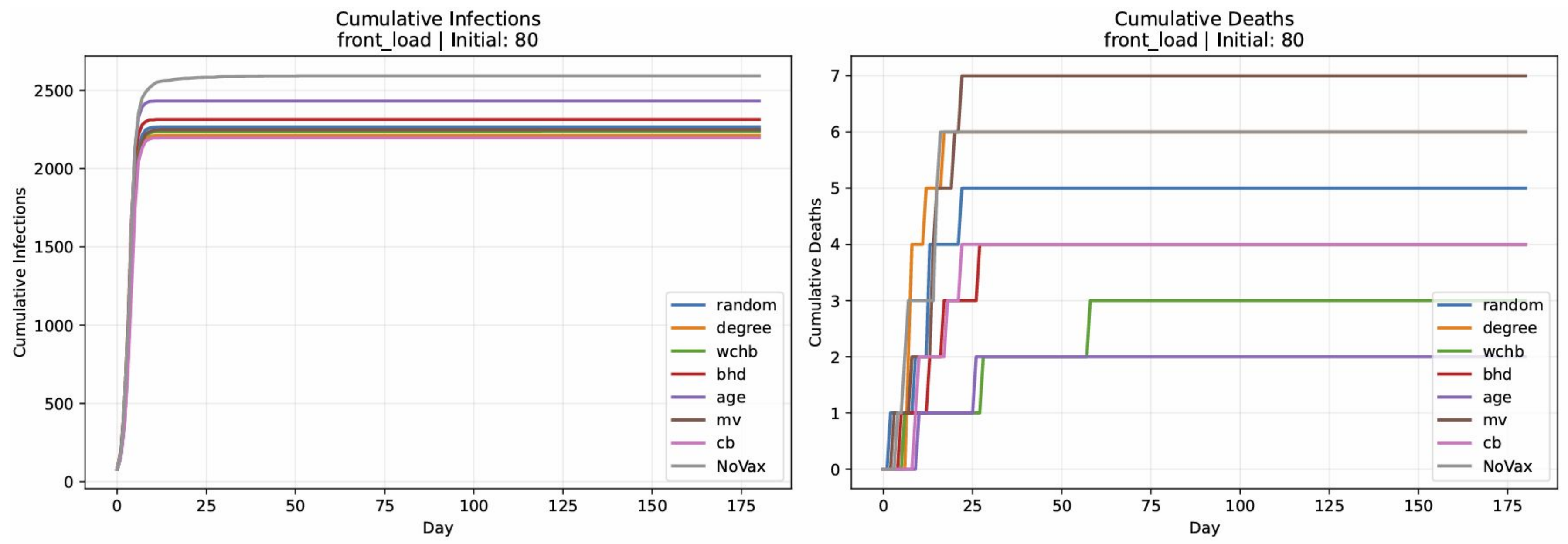
Key Experimental Results



Random initialisations, trickle vaccination, initial infected nodes: 160, Zenodo dataset



Random initialisations, trickle vaccination, initial infected nodes: 160, Synthetic dataset



Random initialisations, front-load vaccination, initial infected nodes: 80, Zenodo dataset

Insights from Large-scale Experiments

Overall Performance Ranking: BHD › Age ≈ WCHB › MV › Degree › CB › Random › NoVax

✓ **Bridge › Degree for Deaths:** Bridge nodes outperform degree, upto 50% lower deaths.

✓ **Front-load Amplifies Gap:** Early deployment improves bridge methods' performance.

✓ **Clustered Seeding Favors Bridges:** Upto 70% lower cumulative deaths than NoVax.

✓ **Local Info Suffices:** BHD matches global information-based methods.

✓ **Network demographic affects methods:** Age-based performs well when average population is older (Synthetic dataset), but underperforms bridge nodes in other scenarios.

What's Next? Eval on larger datasets, city-scale population, additional demographic data.