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Responding to disasters: When and how to activate alternative capacity?

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Abstract

Healthcare coalition coordinators need to assign causalities as well as determine whether to add temporal medical capacity such as setting up an alternative care facility (ACF) during a disaster. We study the thresholds to activate extra capacity and optimal policy of locating ACF capacity to maximize the survival probability of casualties.

Problem settings

- Casualties are assigned by a central authority to the hospital which has n medical units to treat arriving patients. Each medical unit has a service time to a patient. Each patient has a survival probability after treatment, which is a decreasing function of time elapsed till receiving treatment (**Figure 1**).

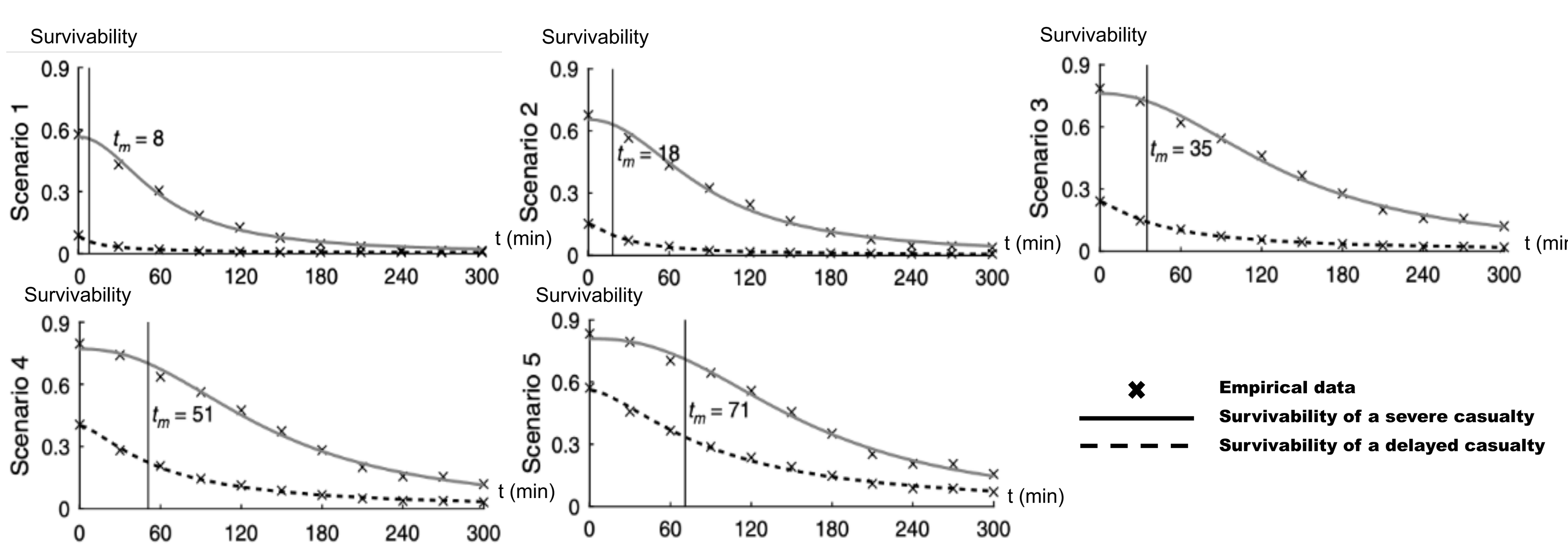

Figure 1. Survival probability functions under five scenarios, from the worst (scenario 1) to the best (scenario 5)*.

- With a goal of maximizing the total number of survivals after treatment, the central authority may also decide to locate one temporary medical facility, called an ACF, near the disaster site, with lower service quality, which results in a lower survival rate to patients treated there (**Figure 2**).
- In the presence of both the hospital and the ACF, the central authority may assign each patient to one of them. The central authority may also decide relocating one or more ACF capacity units back to the hospital.

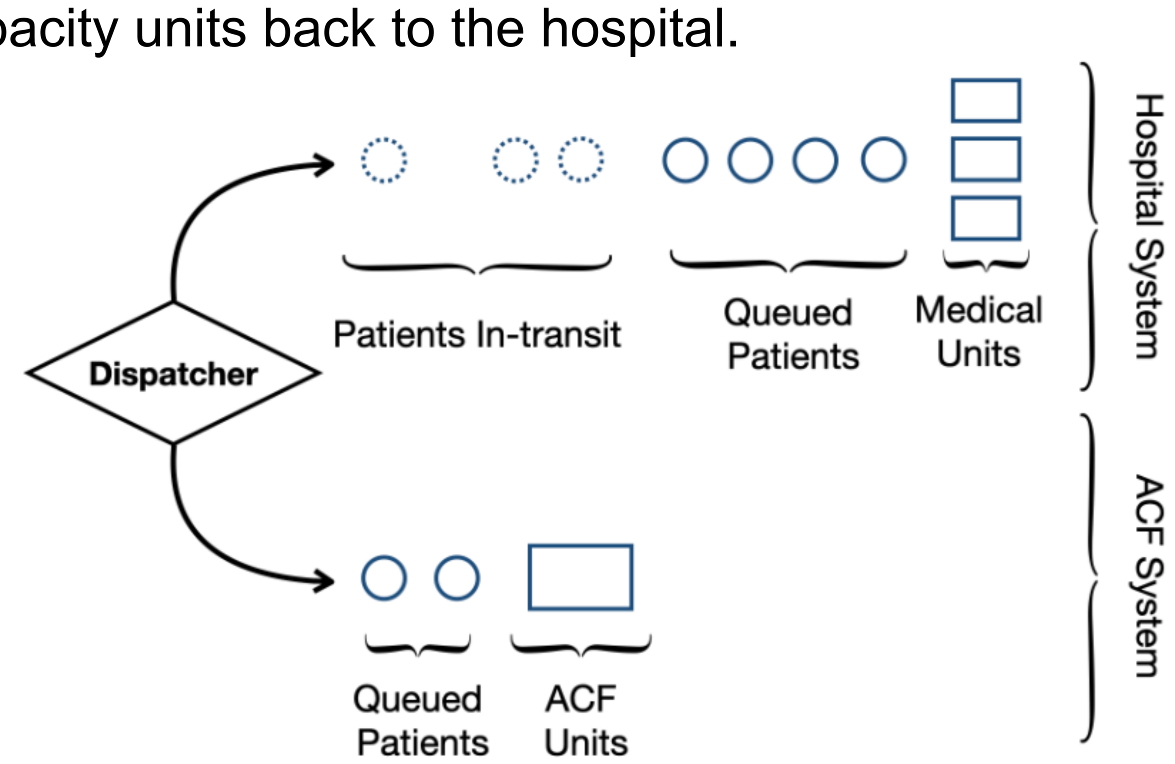

Figure 2. Illustration of the system with two queues

System Optimal Principle

- When a patient is assigned, it is assigned to a location where the marginal gain in terms of number of survivals is larger.
- When medical units are located/relocated, the marginal gain and loss in terms of the resulting survivals at the two locations shall be equal.

Policy analysis

- We consider the marginal effect in terms of number of survivals due to an incremental unit of medical resource.
- In the hospital subsystem, we assume the dispatcher is able to estimate the expected travel plus waiting time for EACH casualty with a given number of medical units available.
- For a casualty, there are two expected time till treatment, each time corresponding to one survival rate at a capacity level n or $n-1$. The two survival rates have a difference Δ_i. The marginal survival effect would be $\sum_i \Delta_i$.

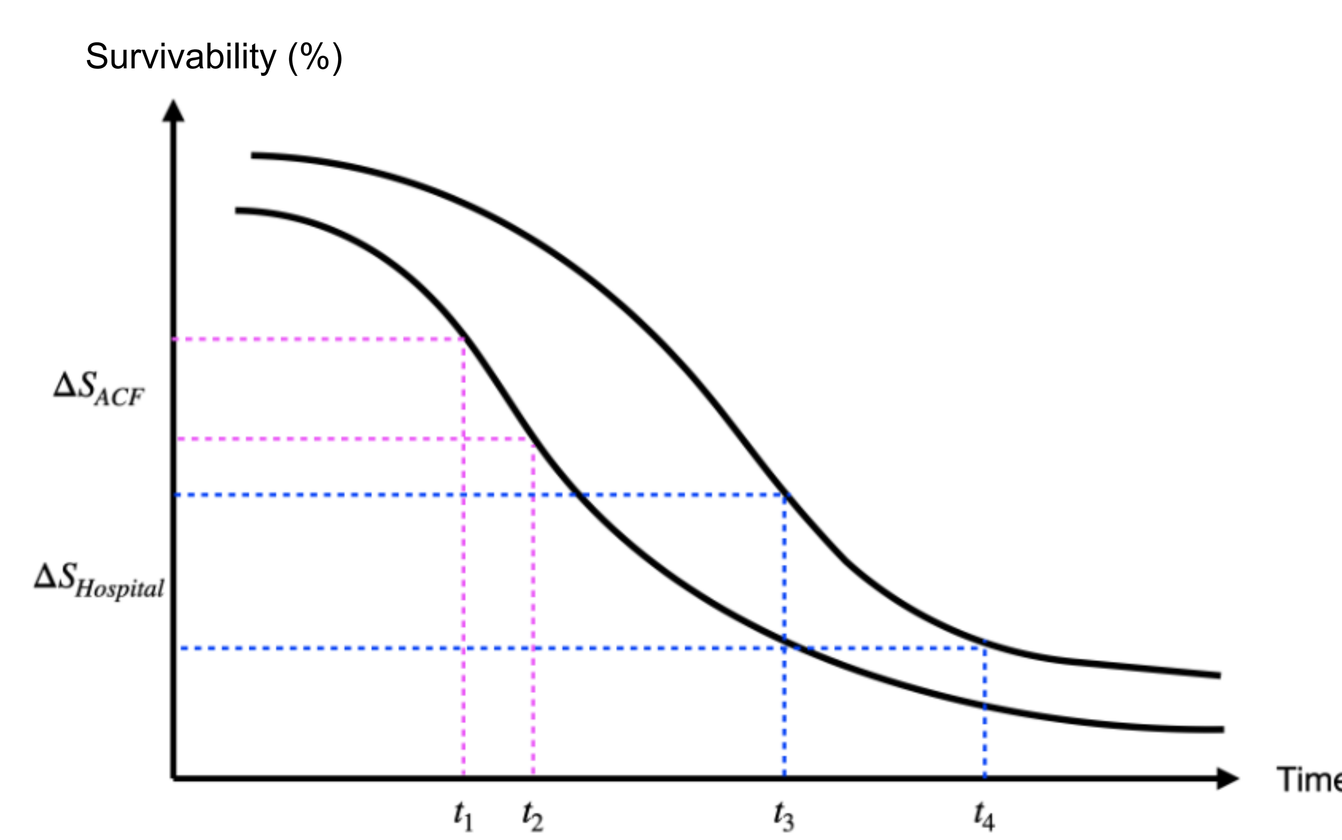

Figure 3. Marginal Effect on Survival Rate

- The unit at hospital maintains a higher survival rate than at the ACF location (**Figure 3**).
- The tipping point for relocating one unit of medical resource shall satisfy $\sum_{ACF} \Delta_i = \sum_{HOS} \Delta_i$.
- Two ways of estimating total sojourn time and marginal survivability:

$$M1: Total\ Sojourn\ time = travel\ time + \frac{n_{on\ the\ way} + n_{in\ the\ queue}}{c\mu}$$

$$M2: Total\ Sojourn\ time = \max(travel\ time, \frac{n_{on\ the\ way} + n_{in\ the\ queue}}{c\mu})$$

Simulation Results

Table 1. Simulation Policy

	Goal	Method	Classes
Policy1T	Shorter expected time	M1	10% severe 90% minor
Policy1P	Higher expected survivability	M1	10% severe 90% minor
Policy2T	Shorter expected time	M2	10% severe 90% minor
Policy2P	Higher expected survivability	M2	10% severe 90% minor
Policy3T	Shorter expected time	M1	100% minor
Policy3P	Higher expected survivability	M1	100% minor
Policy4T	Shorter expected time	M2	100% minor
Policy4P	Higher expected survivability	M2	100% minor

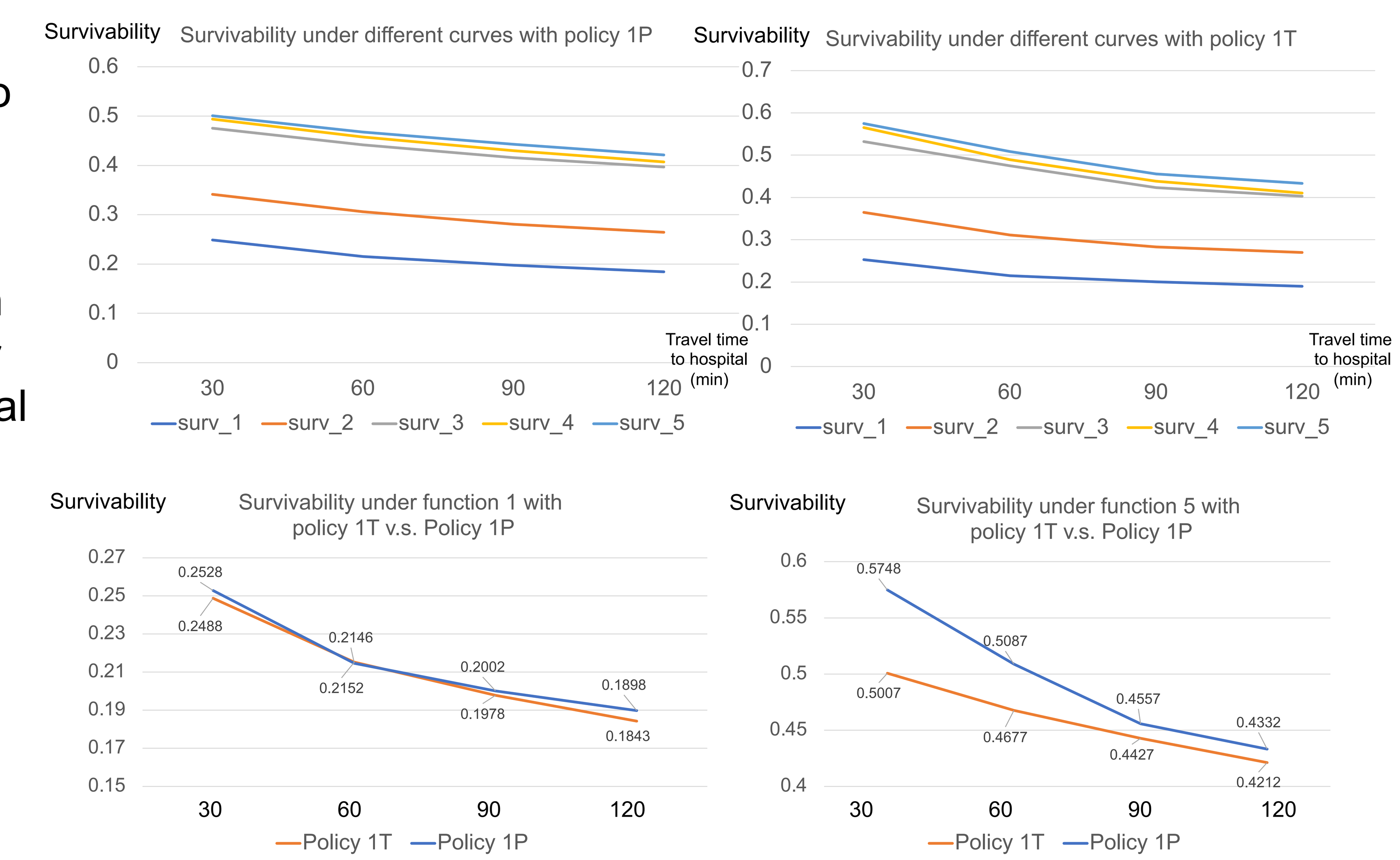

Figure 4. Simulation Results

Conclusion

- Casualties should be sent to the facility with higher survivability considering travel time and queue at the facility.
- The difference between two estimating methods is not significant.
- Accurate estimates of survivability can improve the average survivability of the casualty compared with just sending patients to nearest care facilities (p-value < 0.05).

Future Work

- Develop accurate estimation of marginal survivability and test the corresponding policy.
- Apply reinforcement learning to find explainable optimal policies.
- Develop an algorithm to determine ACF opening conditions and time.
- Integrated policies for ACF opening and casualty dispatching.

* Mills, A. F., Argon, N. T., & Ziya, S. (2013). Resource-based patient prioritization in mass-casualty incidents. *Manufacturing & Service Operations Management, 15*(3), 361-377.