DEPLOYING VACCINE DISTRIBUTION SITES FOR IMPROVED ACCESSIBILITY AND EQUITY TO SUPPORT PANDEMIC RESPONSE

CONSIDERING COMMUNITY-SPECIFIC CONVENTIONS IN COVID-19 HEALTH INFRASTRUCTURE TO IMPROVE VACCINE UPTAKE AND EQUITY

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Vaccine Distribution for COVID-19 Herd Immunity

With the proportion of COVID-19-related hospitalizations increasing by 86.9% in the past two months, the pandemic is still far from over in the United States (Quijano, 2023). Achieving herd immunity through vaccinations is the current hope for controlling the spread of the pandemic. As defined by the World Health Organization (2020), herd immunity refers to a state in which a sufficient proportion of the population has developed immunity to a disease through vaccination or previous infection, restricting the propagation of the disease in the group. Because social distancing regulations such as lockdowns can have profound socioeconomic consequences, and the intentional exposure of vulnerable populations to pathogens for herd immunity is highly unethical, vaccinations are invaluable to controlling the spread of COVID-19.

Experts such as Dr. Anthony Fauci predict that the COVID-19 herd immunity threshold may need to be as high as 90% (McNeil, 2020). However, according to the Centers for Disease Control and Prevention (2023), the nation's primary vaccination rate has just reached 69.5%, of which only 17% of people have received the latest COVID-19 vaccine booster. Therefore, herd immunity remains greatly compromised since the majority of the population is still at risk for carrying and transmitting the COVID-19 pathogens.

To improve vaccine uptake, technologically inspired approaches driving successful vaccine distribution strategies can be examined in the state of Virginia. In January of 2021, Virginia ranked last by the percentage of administered vaccines. The National Association of State Chief Information Officers (2021) details that the development of data pipelines connecting statewide vaccine systems and local health district dashboards. These pipelines consolidated 35 disparate efforts across each health district into a unified vaccination effort with insight into vaccine distribution equity. With the growth of COVID-19 health infrastructure, the state quickly rose to

11th in the United States rankings for vaccination efficiency. This story of success motivates Virginia-centric studies on improving vaccine distribution in hopes of extrapolating pandemic response methods to facilitate the nationwide recovery from COVID-19.

There are two key COVID-19 infrastructure developments in Virginia: mobile vaccination clinics and human mobility data. Virginia began to deploy mobile vaccination clinics that can travel from location to location to reach populations with weaker local health infrastructure. Mayfield et al. (2023) found that mobile vaccination clinics have the potential to improve vaccine accessibility for minority communities, with Black and Hispanic populations in Mecklenburg County, North Carolina receiving a larger proportion of their vaccines from these clinics. As such, mobile vaccination clinics are part of a broader strategy to improve the healthcare system by catering to the “rhythm of life of community members” (Mayfield et al., 2023).

Virginia’s data-driven approaches have also yielded increased infrastructure support for integration with SafeGraph, a data analytics provider that tracks mobility location data (i.e. home, work, market, recreation, etc.) for individuals based on anonymized cell phone data (Masters, 2021). To increase vaccine uptake, this technical project focuses on developing computational algorithms that utilize these two aspects of Virginia’s data-driven infrastructure to improve the accessibility of vaccine distribution sites across marginalized demographic groups.

Reformulating the Algorithmic Problem of Vaccine Distribution

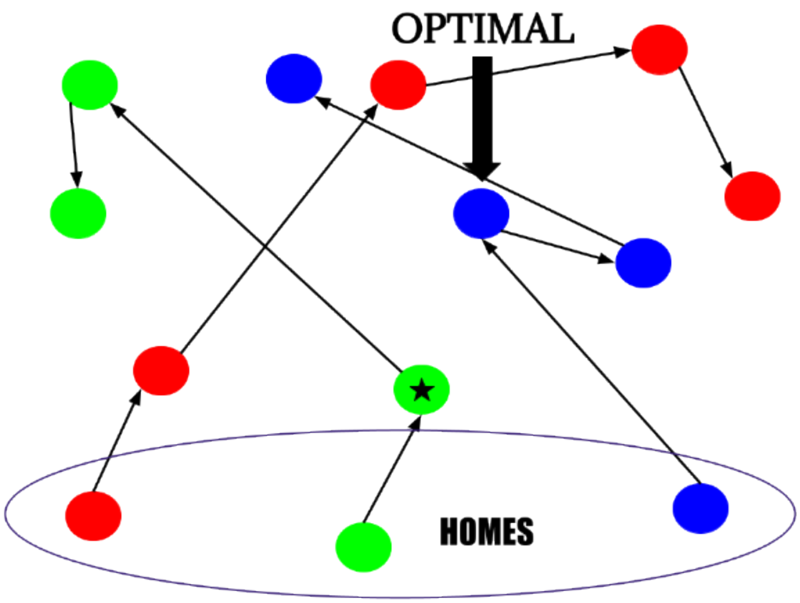

Figure 1: Facility Location for Mobile Individuals (Source: Li et al., 2022)

The problem of determining vaccination centers falls under the general class of facility location problems. Akwafuo et al. (2022) target a variant of this problem by presenting a facility location model and algorithmic framework to place facilities/depots for epidemic health support. Facility location has been conventionally framed using the *k-supplier problem*. Given a set of client and facility locations, *k-supplier* returns the *k* facility locations that minimize the maximum distance between a client and their closest facility (Nagarajan et al., 2020).

The *k-supplier* formulation of vaccine distribution fails to account for new COVID-19 vaccine infrastructure developments. Rather than setting up permanent vaccine distribution sites, the government can now deploy mobile vaccine clinics and utilize mobility data on human movements from data analytic services such as SafeGraph (Masters, 2021). Because these developments provide policymakers with the potential to better determine the movement patterns of Virginia citizens and allocate vaccination clinics in accordance with human conventions, the problem of deploying vaccine centers must be re-examined in this new context.

Figure 1 depicts the importance of considering human movement patterns for vaccine distribution. In this example problem, each client is represented by a color (red, green, blue) and the circles represent locations visited by clients throughout the day. Each client also has a home location labeled at the bottom of the figure. The *k-supplier* approach only utilizes information on the clients' home locations, reducing the distance that clients must travel to reach the facility closest to their homes. Supposing that facilities can be placed at any non-home location, the *k-supplier* approach selects the starred green location as a vaccination center. However, an alternative approach recognizes that a client has the option of traveling from any one of their visited locations, and places facilities accordingly to minimize that travel distance. By making a small detour in their daily movement patterns, the maximum distance between any individual and the "OPTIMAL" location is less than the starred green location identified by the *k-supplier* approach.

By emphasizing the mobility of human populations, this new problem setup motivates the development of computational algorithms that integrate data-driven approaches with the flexibility of mobile vaccination units. The algorithms are analyzed using theoretical computer science to provide guarantees on the equitable access of vaccines across demographic groups. The accessibility of the vaccine centers placed by the algorithms are also evaluated in an experimental context using synthetic population data created by Machi et al. (2021) based on the 2019 U.S. Census tract of Charlottesville City and Albemarle County in Virginia. Finally, successful algorithms that utilize new COVID-19 infrastructure developments to provide a more accurate measurement of accessibility and equity are recommended to the Virginia Department of Health (VDH) to supplement the current practices.

Vaccine Distribution Infrastructure and Human Conventions

Vulnerable populations have less access to vaccines (Andrews et al., 2022). Found at the center of vaccine deserts, refugee, immigrant, and migrant communities suffer from a lack of transportation options to reach clinics and face conflicts between clinic and work hours (Ndugga et al., 2021). Black and Hispanic communities also have a lower vaccination rate, exacerbating the disproportionate impact of the COVID-19 pandemic on these communities.

Because a lower vaccination rate is often attributed to hesitancy, policymakers have deprioritized the top-down allocation of accessible vaccines to these populations. As a result, the potential facility locations in counties consisting of more than 42.2% Black residents were less likely to be converted to COVID-19 vaccine centers than the facilities in counties consisting of less than 12.5% of Black residents (Hernandez et al., 2022). Therefore, it is important to recognize that this assumption of hesitancy is self-reinforcing as the inequity gap widens due to a lack of accessible vaccine resources for these groups. Moreover, well-grounded medical racism concerns in Black communities were exploited to spread deliberate disinformation on vaccine compliance to further political agendas (Diamond et al., 2022).

The relationship between vaccine distribution technology and the social interpretation of equitable accessibility can be analyzed through the framework of *infrastructure*. *Infrastructure* presents a strong relational focus on the role technological systems play as a part of human organizations (Star, 1999). One defining aspect is *links with conventions of practice*, which describes the reciprocal nature of the feedback loop between technology and social conventions. Studying the transit-based spatial accessibility to COVID-19 vaccination sites at the census tract level in the Chicago Metropolitan Area, Liu et al. (2023) found that the inner city has a lower spatial accessibility score, which also coincides with an increased density of minority Black and

Hispanic populations in these areas. These groups find vaccination sites at car-centric locations inaccessible because of different *conventions of practice* pertaining to the mobility patterns of these minority communities.

Peters (2022) concludes that it is critical to address specific groups, enhance access to vaccines, and embed vaccine knowledge in routine practices to improve vaccine uptake. Preliminary studies support Peters' conclusion: when computational algorithms consider mobility and demographic data, they produce vaccination site recommendations for minority populations that are significantly different from the standard approaches (Mehrab et al., 2022). From this perspective, the incorporation of human conventions into vaccine distribution methodologies facilitates improvements in accessibility for underserved populations.

Another *infrastructure* tenet is *built on an installed base*, which describes the tendency of infrastructure to inherit from and preserve the fundamental structure of preceding legacy versions. Although the development of mobile vaccination clinics removes many conventional constraints associated with vaccine distribution, algorithmic studies such as Shukla et al. (2022) still constrain their vaccine sites to local pharmaceutical infrastructure. From a different angle, the human and social base of COVID-19 vaccination infrastructure must also be extended to encompass minority groups. Strully et al. (2021) surveyed 31 health professionals working closely with marginal populations in New York. They found that it is essential to integrate communities into the vaccine campaign through well-established cultural centers and community leaders to develop sustainable and equitable vaccines. Altogether, the initiative to extend the flexibility of vaccine site deployment requires extensive reworking of the technical and social infrastructural base.

Thematic Analysis of Vaccine Policies and Research Briefings

Referencing Langdon Winner's phrase "pandemic artifacts have politics", Hofmänner (2023) presents the disparity in vaccine accessibility leading to vaccine inequity as a failure of policy. This prompts the question: How can policymakers consider client-specific mobility conventions (i.e. mobile clinics, movement data, transportation options) in vaccine distribution infrastructure to improve the accessibility of vaccines for disadvantaged demographic groups?

To tackle this question, I plan on conducting thematic coding research on COVID-19 vaccine reports published by the VDH to identify the contexts in which vaccine inequity, minority demographic groups, and human conventions are addressed. Furthermore, I plan to apply the same methodology to the research content and weekly briefings produced by the Biocomplexity Institute and Initiative (BII), a research organization headquartered at the University of Virginia that collaborates with the VDH to strengthen pandemic response methods (Biocomplexity Institute and Initiative, n.d.). Analysis conducted on the BII's publications will examine the technical aspects driving COVID-19 policy changes.

The importance of understanding the sociotechnical interplay in COVID-19 responses extends beyond health considerations. Reactions to the pandemic have resulted in profound transformations rooted in long-term processes on valuation shifts regarding the transparency of leadership and the political influence of statistical measures of health (Ascione, 2023). By examining the thematic discourse through both sociopolitical releases and technical development, I expect to make observations on the temporal progression of contexts and speak to the sociotechnical alignment in COVID-19 responses.

Conclusion

With the demographic disparity in vaccine accessibility exacerbating the disproportionate health consequences of vulnerable groups, new vaccination infrastructure such as mobile vaccination clinics and mobility analytics have emerged to support policymakers in targeting minority communities. To make the most effective use of these resources, computational models must be updated to reflect the data-driven knowledge on human conventions and incorporate it into vaccine distribution algorithms that can be implemented by state health infrastructure. Accurate models and improved algorithms help control the spread of COVID-19 by facilitating herd immunity through vaccination.

A thematic analysis of COVID-19 vaccination policies and technical developments will produce a quantitative evaluation of the temporal trends in the sociopolitical contexts of COVID-19 vaccine methodologies from different perspectives. It will yield insight into the efficacy of targeting human conventions to reach marginalized communities, and pave the way for future pandemic response methods.

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