# A DECISION SUPPORT SYSTEM FOR THE OPTIMAL ALLOCATION AND DISTRIBUTION OF COVID-19 VACCINES USING ANALYTIC HIERARCHY PROCESS (AHP) AND INTEGER PROGRAMMING (IP) MODELS

**ABSTRACT**

As the Philippines continues to vaccinate its population to manage the spread of COVID-19, prioritizing individuals to receive vaccines with respect to the COVID-19 situation in their respective areas requires careful planning. Our study developed a location-allocation model that optimally schedules the COVID-19 vaccine rollout of a community. We applied the analytic hierarchy process (AHP) to prioritize communities in the vaccine rollout. Consequently, an integer programming (IP) model was formulated to assign individuals to their respective vaccine stations in accordance with the rollout prioritization of their community, as well as the minimum number of vaccine stations to open. The AHP-based IP model proposed in this study is implemented into a decision support system (DSS) which not only assigns individuals to vaccination stations, but is also flexible to consider different local government prioritization driven by their COVID-19 situation. Furthermore, the vaccine rollout framework in this work is applicable to other vaccine-preventable diseases (e.g., rabies, measles, etc.) should LGUs embark on adapting this approach.

**Keywords: analytical hierarchy process[1], integer programming [2], local government units[3], optimal allocation[4], decision support system[5], vaccine rollout[6].**

## 1. Introduction

In the Philippines, scheduling the COVID-19 vaccine rollout has been a challenging task. The local government units (LGUs) have to carefully work with limited resources to avoid underutilizing vaccines while also planning prioritization schemes in the rollout. Advisory groups in the Philippines determined which regions should be prioritized in the rollout, but their indicators do not apply to small communities (*The Philippine*). Additionally, different LGUs enforce different strategies (e.g. prioritizing denser communities and/or communities closer to vaccination sites) in their vaccination campaigns, combating the same logistical issues but requiring a more dynamic approach to solve the same problem. This is where the challenge is imposed. Even when vaccines are abundant, achieving herd immunity is still a challenge due to the LGU's lack of a systematic tool that addresses these logistical and prioritization concerns in scheduling the vaccine rollout of its municipality. Hence, this study aims to develop a decision support system that optimally schedules the vaccine rollout of a municipality, while also considering the preferences of the LGUs in determining the prioritization of communities in the rollout.

## 2. Literature Review

Recent studies on COVID-19 vaccines distribution (Lusiantoro et al.) have been looking into optimal solutions using location-allocation models. The work of Han suggests the need for vaccine distribution plans with prioritization as these plans generate results where the most needed and the most vulnerable population are vaccinated first, and thus, curbs the spread of the infection and the mortality rate more effectively. To our understanding, however, the models they propose did not cater to one important factor in public vaccination: the differing prioritization schemes implemented by the LGUs (Sprengholz et al.). Thus, this study takes inspiration from the work of Saaty, Peniwati and Shang in combining integer programming and the analytic hierarchy process (AHP) to incorporate priorities in determining the allocation of vaccines and individuals in the vaccination rollout.

## 3. Hypotheses/Objectives

In this paper, we continue to view the vaccine rollout situation as a location-allocation problem where we determine the optimal assignment of target individuals of communities to vaccine stations in order to meet their demands. A multi-criteria decision-making technique called the AHP was used to allow LGU-specific prioritization of individuals in the rollout. Furthermore, this study developed a web-based decision support system (DSS) that implements the AHP and IP model that is readily available online, and is easily accessible to the LGUs.

## 4. Research Design/Methodology

The AHP is used to determine the prioritization of communities in the vaccine rollout based on the number of COVID-19 cases, the population density, and the proximity of the community to the available vaccine sites, as determined by consultations with the partner LGUs. Formally, these criteria are labeled as *Cases*, *Density,* and *Distance* in the AHP hierarchy respectively, as seen in Figure 1.

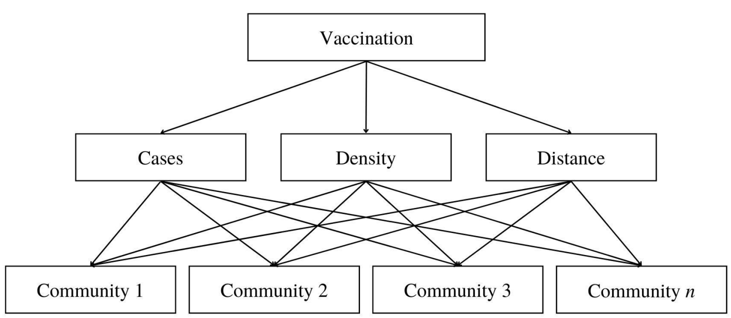


***Figure 1.*** *Hierarchy Structure of the AHP model in determining the prioritization of communities in the vaccination roll-out in which the top level is the goal, the second level represents the criteria, and the bottom level are the alternatives*

The pairwise comparison matrix between criteria is scored by health decision-makers of the LGUs, while data for the criteria are obtained from open-source repositories. Results from the AHP are then used as weights in an integer programming (IP) model to determine the assignment of individuals to the vaccine stations. This is with respect to the prioritization of their community in the rollout, as well as the minimum number of vaccine stations to open.

This AHP-IP methodology is implemented in a web-based Vaccination DSS using the PuLP library of Python. While the user may score the AHP pairwise comparison matrix manually in the DSS, users may also use four predefined pairwise comparison scores (see Table 1) for their convenience. Additional features include a consistency ratio checker that ensures the consistency of the decision-maker in inputting scores in the pairwise comparison matrix, and an error checking functionality for ensuring appropriate data entry.

***Table 1**. Preset Pairwise Comparison Scores*

| Preset Pairwise Comparison Scores | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Preset 1 | | | Preset 2 | | | Preset 3 | | | Preset 4 | | |
| | Cases | Density | Distance | Cases | Density | Distance | Cases | Density | Distance | Cases | Density | Distance |
| Cases | 1 | 1 | 1 | 1 | 7 | 7 | 1 | 1/7 | 2 | 1 | 2 | 1/7 |
| Density | 1 | 1 | 1 | 1/7 | 1 | 2 | 7 | 1 | 7 | 1/2 | 1 | 1/7 |
| Distance | 1 | 1 | 1 | 1/7 | 1/2 | 1 | 1/2 | 1/7 | 1 | 7 | 7 | 1 |
| Consistency Ratio | 0.0000 | | | 0.0516 | | | 0.0516 | | | 0.0516 | | |

## 5. Data/Model Analysis

To demonstrate the use of the DSS, a sample Municipality *Z* was considered as a case study. The decision-maker aims to vaccinate its target individuals using pairwise comparison *Preset 4* where *Distance* has very strong importance. We find that the Vaccine Rollout Schedule generated by the DSS for Municipality *Z* has successfully assigned all individuals of the communities to the vaccination stations, satisfying all model constraints. Consequently, communities that are near to vaccination sites are prioritized in the vaccine rollout. Sensitivity analysis results suggest that for the vaccine rollout to reach low priority communities fast, LGUS should either identify more vaccination sites close to these communities, or increase the capacity of the existing sites by increasing human resources and seating capacities.

## 6. Limitations

The decision for choosing the criteria of the AHP Model presented in this study came from consultations with LGUs of the Philippines who mostly oversee rural areas. Health decision-makers of urban areas may have other factors to consider aside from the criteria mentioned. Also, developments in the model to determine which of the individuals in the community should be prioritized are still underway. Additionally, it might be also interesting to further enhance the functionality of the current DSS to include scheduling auto-SMS features. Lastly, this study only focuses on addressing vaccine deployment from vaccination sites. Overall success of the vaccination campaign is still dependent on other epidemiological contexts.

## 7. Conclusions

This paper proposed a DSS that captures the knowledge and preferences of the local government unit decision-makers in prioritizing communities for COVID-19 vaccination rollout in the Philippines. The DSS implements a model that is systematic and consistent even when confronted with the unique COVID-19 situation of a municipality, where LGUs may be able to come up with a vaccination rollout schedule for their communities in less than 10 minutes. Hence, this DSS potentially outperforms conventional and time-consuming manual decision-making processes. Additionally, the methodology undertaken in this study may be modified to fit the logistical problems, most specifically the vaccination rollout, of other vaccine-preventable and vaccine-curable diseases.

## 8. Key References

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