Facility Location Models and School Mapping: A Proposal for the Philippines

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ABSTRACT

Facility location models (FLMs) were introduced in the early 1900's as a systematic and scientific method of predicting location. Since then, it has received numerous attention from various fields as a logical and mathematical approach to solve different types of location problems. One of the applications of FLMs is school mapping.

In this article, we conduct an inventory of FLMs by means of exploring the various FLM classifications. We then review how FLMs were used in the context of a school mapping process. We also examine the conflicting factors considered by education planners and stakeholders in several countries.

We see that a unified facility location model with barriers and forbidden regions seem to be appropriate but have not been applied in school mapping thus far. This type of model seems to be applicable in rural Philippine situations.

KEYWORDS

facility location models; school mapping

1 INTRODUCTION

Facility location models (FLMs) were introduced by Weber in [50] as a systematic and scientific method of predicting location. Since then, it has received a lot of attention from various fields as a logical and mathematical approach to solve different types of location problems. Due to the diversity of literature pertaining to FLMs, this paper tries to understand them by focusing on how they are classified. But surveys of the existing literature on FLMs reveal that there is no single taxonomy. Instead, they are classified based on each author's purpose – as will be shown in Section 3.

One of the applications of FLMs is the selection of sites for public facilities. These models become helpful guides when various parameters with conflicting goals are considered for site selection. School mapping exercises frequently have these problems because distance-oriented constraints usually conflict with demand-oriented constraints [40]. Hence, facility location models have been used for various school location problems like attendance [16], transportation [21, 44], accessibility [1, 48, 52], regionalization [46], policy formulation and reviews [28, 49, 53].

The primary goal of school mapping, regardless of the country where it is implemented, is to put schools in locations that are accessible to the target population. However, education policies between countries are different. Furthermore, the situation and needs of each community is unique. Since the problem of school mapping in the Philippine context is considered in this review, variations in the models are anticipated and assessed for its appropriateness in the Philippine situation.

The Philippines is selected as a case study because it implemented a 12-year pre-university education cycle last June 2012. Before then, it was the only Asian country and among three remaining countries in the world that used a 10-year cycle [25]. This nationwide change caused much controversy since it will not only result in a significant change in the education system, but also cause an increase in school funds, manpower, and facilities. A facility location model that can be used to address problems of school accessibility in rural areas of the Philippines will be able to help decision makers in evaluating the current situation of the country, identify the populations with greatest need, and give unbiased recommendations of potential sites for schools.

This paper aims to survey the models with the intention of identifying features that may be used for school mapping. Section 2 discusses how FLMs can be used in school mapping and Section 3 systematically explores the models according to their classifications. Section 4 shows a proposed model for Philippine rural areas.

2 FACILITY LOCATION MODELS (FLMS) AND SCHOOL MAPPING

Site analysis and facility location models are not new. This is a well-developed technique that has been used by planners for more than 50 years in various fields. However, applying them in school mapping was still uncommon 30 years ago. The amount of data and computation resources needed for implementation coupled with its abstract, mathematical nature was enough to deter school planners. According to [19], even the IIEP of UNESCO rejected optimizing solutions as they reviewed techniques that can be utilized to map new schools. Aside from UNESCO, [17] also mentioned that the World Bank did not state location-allocation methods when considering favourable sites as they prepared their "Guidelines on School Location Planning".

But with the current advances in technology, the difficulties they encountered then may be irrelevant now. Computer processing speeds have increased exponentially – from 1MHz then to 4GHz now. Computer memory has also continued to enlarge – from a few kilobytes then up to over 12 megabytes now. Spatial data is now collected and utilized by corporations as well as private citizens. Technology has become accessible via a wide variety of platforms and devices. Moreover, existing public participation tools can address the social limitations that confronted them during that time. Implementing school mapping using facility location models will result in a technology that can monitor conformance and implementation of government policies as well as give unbiased recommendations relating to school mapping.

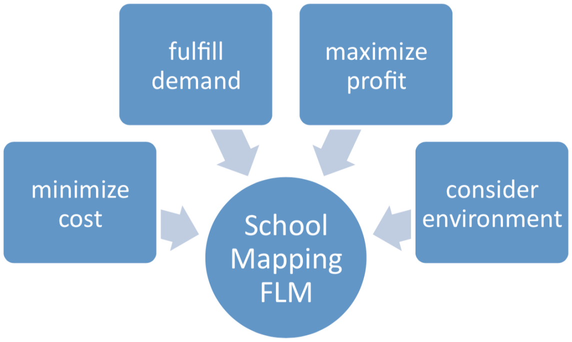

Figure 1: Factors to Consider in a School Mapping Model [14]

As shown in Figure 1, there are many reasons why scientists use facility location models [14]. The general types of reasons are:

(1) to minimize cost,
(2) to fulfil a demand,
(3) to maximize profit, and
(4) to consider the environment.

In a school mapping model, all these factors have to be considered.

According to [11], the method of school mapping started in 1963 in France. It is defined as "a normative approach to the micro-planning of school locations". It can be used to facilitate the organization of education efforts and promote fair distribution of quality education [11].

The first step in school mapping is to select a location for analysis. Second, areas for improvement are examined. Third, education status in the selected geographic location is analysed. Fourth, school parameters that enhance quality are identified. Finally, estimation of facilities and resources is accomplished [11].

3 CLASSIFICATIONS OF FACILITY LOCATION MODELS

Factors and scenarios considered in location problems are varied. Hence, there are also several types of FLMs to address these various needs. The diverse and overflowing literature pertaining to facility location models show that facility location models can be:

(1) used to resolve different objectives,
(2) classified in different ways,
(3) implemented through various methods, and
(4) measured for success through various equations.

Facility location models have been classified in various ways as presented in Figure 2. The four classifications included in this article are based on:

(1) time (enclosed in triangles),
(2) type of facility (enclosed in the squares),
(3) objective (enclosed in circles), and
(4) spatial organization.

Figure 2 shows the different classifications and indicates those that are generally similar in concept by enclosing them in the same polygon shape. Classifications enclosed in the squares are those that generally concentrate on the type of facility. Those enclosed in triangles generally focus on the time aspect of modelling. Those enclosed in circles generally focus on the model's purpose. There are some that focus on the spatial organization of the facilities and the clients, while some consider routes – these are not enclosed in polygons in the representation on Figure 2.

Each paper has its own perspective of how facility location models can be categorized and grouped together, as we can see in Figure 2. This article attempts to put them together in one representation and analyse these groupings. Through this combined representation, the article hopes to achieve:

(1) an overview of the variety in FLMs,
(2) an identification of how each model differs from the others, and
(3) an inventory of the models that have been used for school mapping by marking them on Figure 2.

3.1 Time-based Models

Some facility location models are time-based and they solve a location problem by considering time aspects [36]. Time-based models can be static, dynamic, or stochastic.

In static models, all inputs are known and outputs are computed one-time [36]. While in dynamic models, all inputs are known and outputs are computed for each time interval (also called the planning horizon) [36]. Some dynamic models also have a "close" (meaning the facility is closed) or "open" (meaning the facility is operating) option while considering single or multiple facilities available for each planning horizon [24]. Most hierarchy or interaction-based models, which will be discussed in Section 3.2, also fall in this category. In Section 3.3, objective-based models will be discussed and most of them have also been classified as static models.

Finally, in stochastic (also called random) models, unknown inputs are used to compute an output for each interval [36]. Within stochastic models, there are probabilistic and scenario models [36]. Probabilistic models examine the possible distributions of unpredictable factors. They assume uncertainty of input data (e.g., waiting time is a function of demand and allocation). In France, [27] created a decision aid tool to make recommendations on the creation or closure of classes. Their probabilistic model generates solutions for different student population scenarios by: (1) minimizing the distance-time variable, and (2) modelling the geographic distribution of students using random points in space with a Poisson point process model. On the other hand, scenario planning models examine potential future values of the input data [36]. The approach of scenario planning models may be useful in our proposed school mapping for areas that are prone to large shifts in population.

3.2 Interaction-based Models

Facility location models can also be classified by considering the interaction between facilities [43]. Interaction-based models can be assessed based on facility hierarchy or flow of customers and/or goods.

In a hierarchical model, higher nodes have more functionalities than lower nodes. The clients are placed in the lowest level in a

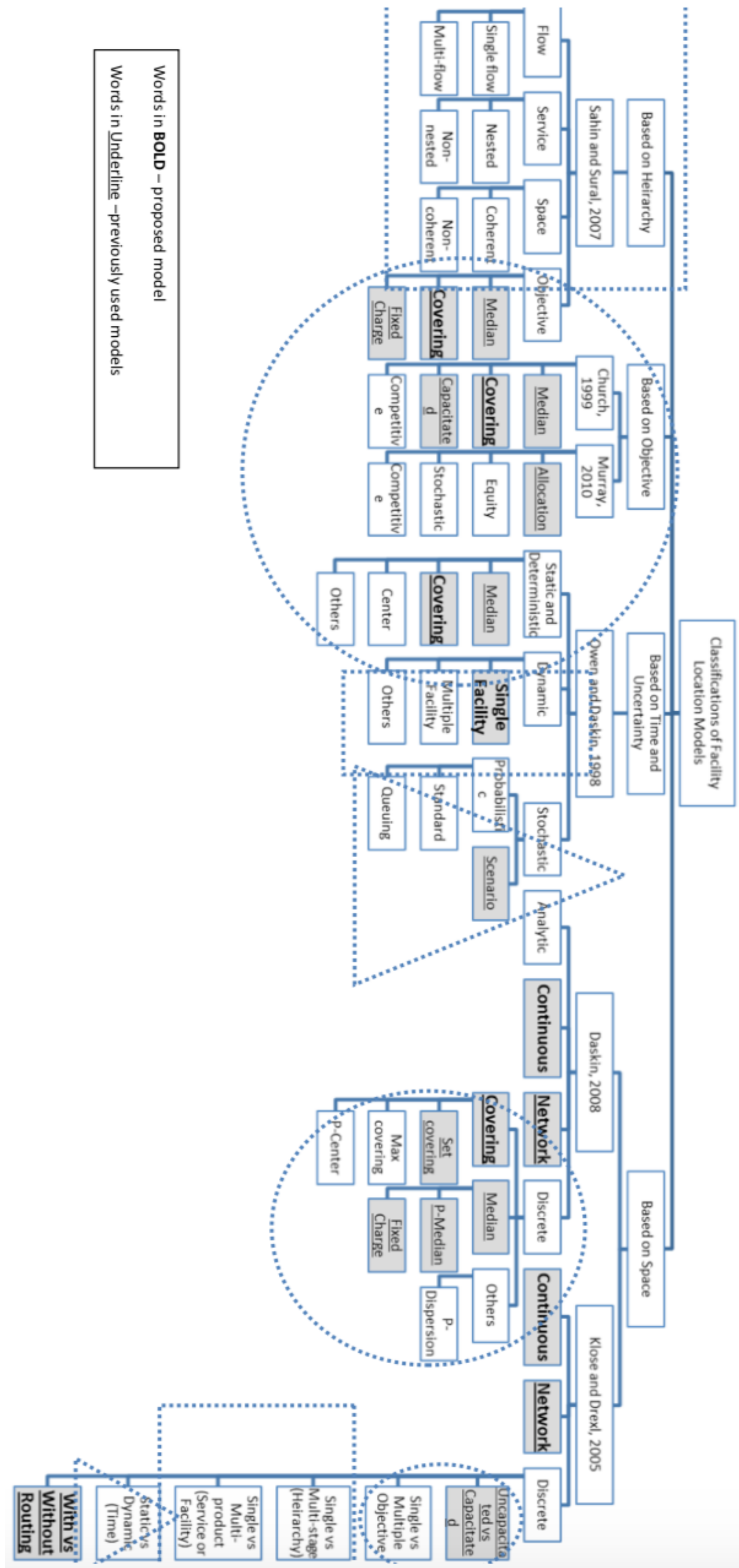

Figure 2: Classifications of Facility Location Models

network whose nodes are designed to represent facilities and customers [43]. Aside from node functionality, service availability can also vary at different levels of the hierarchy. In a nested structure, the higher-ranking facility performs all the functions performed by a lower ranking facility as well as some other function. In a non-nested structure, each facility level performs varying functions [43]. Whereas multi-stage models locate facilities on several hierarchically layered levels [24]. Aside from node functionality and service availability, the spatial configuration of the facilities can also be considered. Coherent models assign all demand sites in a specific lower level facility to a corresponding higher-level facility, similar to fulfilling the demands of capacitated single facility location problems. On the other hand, non-coherent models have lesser restrictions on the spatial organization between levels [43].

In a flow model, clients and/or products flow through the layers of hierarchical systems. The interaction between nodes can be one-directional (single flow), bidirectional (multi flow), or multi-product. A single flow starts from lowest (or highest) level and ends at highest (or lowest) level. On the other hand, multi-flow structures start from any lower level and end in any higher level. A multi-flow model may be represented using multi-objective models and can be used for more complex location decisions [43]. Aside from the flow of products, the type of product is also considered in multi-product models. Multi-product models separate node demand with respect to product type [24].

Single-flow, one-directional models with a non-nested structure are generally applicable for education systems [43] and school mapping problems. These model qualities may be appropriate when representing school networks in our proposal. It can also be observed in most FLMs that are used for school mapping.

Although interaction-based models are applicable to school mapping, only a few studies have focused on these types of models. Most recent is the study by [3] where they present a model that was used in Portugal as the country was redefining its region's urban hierarchy. They utilized a multi-period, multilevel location model for urban hierarchy planning. Their model aims to maximize the accessibility of various public facilities as it considers the spatial distribution of Portugal's population growth.

3.3 Objective-based Models

Facility location models can also be classified based on their approach to solve a location problem by considering specific goals. Objective-based models are often used in conjunction with other models. In [8], a framework was presented wherein models are classified based on their objectives, variables, and parameters. Since then, many other authors have also given their opinions on labelling and grouping together objective-based facility location models (see Figure 2).

The first type of objective-based model is the covering model. Covering models assume a crucial coverage distance or time interval to satisfy requirements [15]. It does not minimize the average distance but dictates a maximum acceptable travel distance or time. Distance is viewed as binary wherein a node can or cannot be covered [15]. Covering models are further classified into set covering, max covering, and p-center models.

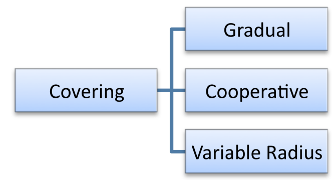

Figure 3: Other Categories of Covering-based Models [6]

Set covering models seek to reduce the total facilities required to cover all the clients [43]. However, it cannot distinguish demand levels [15]. Max covering, on the other hand, can distinguish demand size and permit some nodes to be uncovered [15]. Max covering maximizes the covered customers within a particular number of facilities [43] . As such, it tends to situate facilities in crowded areas [15] . In contrast, p-center models ignore demand levels and puts sites in less congested but more central locations [15]. It computes for the shortest possible distance needed to cover all nodes.

In [42], the school relocation problem of Japan was formulated as a capacitated set covering problem with numerical measures to evaluate the effectiveness of proposed solutions. They used these models in a decision support system that they created to facilitate discussions of policy makers on school grouping and closure.

Other categories for covering-based models have been discussed by [6]. They are called gradual, cooperative, and variable radius covering models (Figure 3). Gradual coverage presents several increasing coverage radii, i.e., fully or partially covered customers. Cooperative coverage is determined by several facilities in the customer's neighbourhood where the facilities are cooperating to provide coverage. Finally, variable radius coverage is directly related to the physical characteristics of the facility, i.e., location model where only the budgetary constraint is specified, and the coverage radius is a function of the amount of money allocated to a given facility.

The second type is the median model. Median based models compute for the shortest distance between the demand node and the facility [15, 36]. They consider true distances and gravitate towards congested areas. Median problems attempt to reduce the client's average travel distance and are utilized for situating public and private facilities. In [18], it was proven that a subset of the demand nodes can adequately provide at least one ideal solution to the p-median problem [36]. The p-median is perhaps the most commonly used location model for school mapping. In the municipality of Coimbra in Portugal, [47] introduced a p-median based model that considers the Coimbra Education Charter 2006-2015 to propose a solution to their school location problem. Recently, [35] proposed an allocation model using the p-median problem to determine the best location to place a limited number of schools in Dakar, Senegal. The p-median problem disregards facility location costs at different places [15], unlike the fixed charge or capacitated models.

The third type is the capacitated model. Fixed charge or capacitated models consider the cost of locating at each potential site. It aims to reduce the aggregate cost of facility construction and transportation [43]. Fixed charge models are further classified into capacitated and uncapacitated models. Capacitated, single stage models examine inadequate capacity while uncapacitated, single stage models examine conflicts between fixed operating and variable delivery cost [24].

Objective-based classifications were created in [34] but different terminologies like allocation, equity, stochastic, and competitive models were suggested. His classifications are derived from [12]. In his classification, allocation models encompass the median and covering models; equity models encompass the covering and centre problems; stochastic models address issues of uncertainty in data input and parameters; and competitive models optimize market share given competitors. Studies that use location-allocation models for school mapping are not new. In [32], spatial properties of public school districts were analysed by means of location-allocation models, specifically, the Allocate function of Arc/Info. His paper showed several maps containing simulations that consider travel time, freedom of choice, and adding a new school. In [37], social demographic data was linked with school catchment areas through voronoi polygons and location-allocation models to measure school performance. Voronoi polygons are a method for dividing an area into regions so that all locations closest to a particular sample point are enclosed within a single polygon [26].

Finally, multi-objective location models consider various objectives in siting of facilities [24]. Allocation of educational resources examine three conflicting parameters: spatial accessibility, equity, and efficiency [29]. The efficiency criterion usually conflicts with equity as distance oriented constraints usually conflict with demand-oriented constraints [40]. The proposed FLM for rural areas may use max covering models as it considers the conflicts of distance and demand in school mapping.

3.4 Space or Distance-based Models

Facility location models can solve a location problem by considering the space or distance between locations [15]. Distance-based models can be analytic, continuous, networked, or discrete.

Analytic models assume that demand is distributed evenly over the intended locations [15] and is typically solved using calculus. Continuous models assume that demands arise at disconnected points [15] i.e., facilities can be placed on any location [24]. In continuous models, distance is computed through metrics i.e., right-angle, Euclidean, straight line, l-distance [24]. In [41], location models were classified into continuous space and discrete network based models. Network models assume that demand is within a network composed of nodes and links [15]. In networked models, distance is computed through paths in a graph [24]. Demand points are represented by nodes in the network and possible facilities are a subset of the nodes [24]. Hub location models are composed of hub and spoke networks and is equivalent to a complete graph (a graph without special characteristics) [24]. Finally, discrete models assume that demands arising in nodes and facilities are restricted to candidate locations [15]. In discrete models, distance may or may not exist [15].

In [45], the generic districting problem was solved by utilizing network-based representations in a school network assignment. They present a fast, iterative, twin network hybrid heuristic. This network hybrid utilizes two separate network models whose required inputs and outputs complement one another. Another strategy was presented by [33]. They solved the school network planning for Dresden, Germany using a generalized nested logit (GNL) model.

The strong relationship between location and routing decisions are evident in numerous papers [24]. In routing location models, client demand is addressed by routes that simultaneously cover various customers [24] – which is also the goal of school mapping. Hence, school redistricting problems can also be viewed as transportation problems. In an early paper by [30], he used a transportation procedure to conduct school districting assignments in the states of Wisconsin and California. Similarly, studies that analyse the proximity of schools to major roads [1], the relationships between school district size and bus transportation costs [21], the mode of school access [44], and factors that influence active commuting to school [48], prove that there is a close relationship between school location and transportation networks.

To conclude the evaluation of FLMs, the proposed model may use scenario planning models since rural areas are prone to large shifts in population at different points in time. Single-flow, one-directional models with a non-nested structure may also be used as this is the usual structure of education systems. Max covering based models may also be applied as it considers the conflicts of distance and demand in school mapping. Finally, a combination of continuous and network models may be useful in representing students, schools, and transportation routes.

4 PROPOSED FACILITY LOCATION MODEL FOR EDUCATION PLANNING IN THE PHILIPPINES

Last June 2012, the Philippines increased its 10-year pre-university education cycle to 12 years. This nationwide change in the education system also included a sizable increase in the education budget to increase and improve the number of education facilities that will serve the population.

A customized facility location model that can show locations with greatest demand for primary (also called elementary) education facilities in the Philippine rural setting is proposed. The aim of this model is to:

(1) Help the government and the general public see the remaining inequalities in access to, and quality of, education that persist in the country.
(2) Show the locations with greatest need and expose the areas with weak government support.

Owing to the nature of data and local circumstances in the Philippines, the proposed model should be able to:

(1) map students (demand) as continuous areas (municipal/town) not points on a map,
(2) consider barriers to travel and forbidden regions (i.e., rivers without bridges and mountains without roads),
(3) consider existing facilities (i.e., location of schools, presence of roads),
(4) be dynamic – allowing for moving populations since it is addressing fringe areas, and

(5) consider transportation routes.

Figure 3 shows where the proposed model fits in comparison with the other models used for school mapping.

4.1 Unified Model

Currently, geographic point data pertaining to student residence is lacking for the Philippines. Hence, the proposed model should be able to map students (demand) as continuous areas (towns) – not points on a network map. In [13], client demand was portrayed as contiguous areas instead of points. There are only few integrated continuous and network models [5] because they require significant spatial detail. However, using the argument that technology has significantly advanced within the past 10 years prompts us to re-examine these hybrid models.

We examine the unified model proposed by [39] that integrates continuous and network models. As discussed in Section 3.4, continuous models assume that points in the Euclidean plane can be used to represent current and proposed facilities. According to [39], the traditional continuous Weber problem identifies a new facility from a set of current facilities so as to reduce the average distance between facilities. Solutions for the classic Weber problem were given by [31, 51]. Meanwhile, network models represent new and existing facilities through nodes of a network, as shown in Section 3.4. The p-median problem can also be seen as a continuous multi-source Weber problem that is represented in a network [24]. We aim to use network models to represent the location of school facilities in our proposal.

4.2 Barriers to Travel and Forbidden Regions

The Philippines is composed of over 7,100 islands. Therefore, the proposed model should consider natural barriers like mountains and bodies of water when proposing a school map. In [2], solutions for ideal single facility location problems (also referred to as Weber facility location) was described with forbidden regions and barriers to travel. In [10], a solution to the constrained classical Weber problem with forbidden regions was demonstrated. Meanwhile, [23] has shown how to reduce the non-convex Weber problem with line barriers to convex optimization problems. However, problems that include barriers is still a matter of research due to the non-convexity of the objective function [38]. Subsequently, [38] present that the Weber problem with mixed distances includes Weber problems with polyhedral barriers and embedded networks as special cases. Soon afterwards, the same authors establish that the Weber problem with embedded networks and the Weber problem with polyhedral barriers have the same mathematical structure. Hence, it can be considered as a unified model that integrates continuous and network location models [39].

Another solution for Weber problems with barriers was presented by [7]. Their location and allocation heuristics are able to simplify the multi Weber problem with barriers into single facility problems and a set-partitioning problem [7]. The conflicts between the proposed facilities and the equivalent decrease in transportation cost imply an extended or multi criteria model of the generalized multi Weber problem (with and without barriers) [7].

Meanwhile, a possible solution that can be used for forbidden regions in this proposal is the algorithm presented by [20]. They present algorithms where unrestricted single-facility median problems in the plane are solved in polynomial time. In [22], error bounds as an outer and inner polygon was shown for the approximate solution of forbidden regions in continuous location problems using a sandwich algorithm.

4.3 Other Considerations

In [54], 70% of Filipino children live within the town where their schools are located. Therefore, this FLM will seek to address the needs of the remaining 30% who live more than 5 km from an elementary school [4]. This proposal hopes that addressing the concern of the last percentage of the population will still be prioritized, even though [9] has shown that it will be more costly. Access to education is a basic right that remains a tragic problem for children in rural areas, especially for developing countries with limited financial resources. The goal of this proposed model is to be able to suggest possible school locations for the fringe areas in conjunction with the existing locations in the more populous areas. Since less populous rural areas are prone to irregular shifts in population, the proposed model should be dynamic and consider planning horizons.

Also, depending on the availability of data, the proposed model should consider transportation routes. Reports of children crossing streams and climbing hills are not new in the Philippines. Due to the inadequacy of education facilities, children are forced to go to schools that are very inaccessible for them. A model that will be able to analyse and show these difficult to access areas will be useful for education resource allocation and planning purposes.

5 CONCLUSION

Using FLMs to implement school mapping is helpful for decision makers as well as local residents. After reviewing how FLMs were used in the context of the school mapping process in several studies, a proposed model that may be suitable for the rural Philippine education sector can now be conceptualized. We propose that a unified facility location model with barriers and forbidden regions seem to be appropriate but have not been applied in school mapping thus far. The benefits of the proposal encompass new applications of operations research theories on school mapping as well as the use of technology for social benefit and governance.

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