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Transportation and Distribution of Strategic National Stockpile Supplies in a Public Health Emergency

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Transportation and Distribution of Strategic National Stockpile Supplies in a Public Health Emergency

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Abstract

In the event of a public health emergency in the United States, it is important that public authorities are equipped to distribute medical supplies to every person in need as quickly as possible. Federal guidelines state that all persons in an area affected by a public health emergency should receive their medical countermeasures within 48 hours of the emergency's declaration. While the CDC has determined a general dispensing plan for each state and county to follow, it is ultimately up to the state and county to formalize and implement detailed plans. A body of academic literature focuses on optimizing the placement and operation of Points of Dispensing (PODs), which are mass dispensing locations the public visits to receive countermeasures. However, very few papers have considered the logistics associated with moving countermeasures from state receiving areas to county-level PODs. This research addresses this gap through service network design and transportation modeling. Specifically, the feasibility of a multi-tiered distribution model is evaluated for a case study region representative of a US state comprised of a mix of urban and rural areas.

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1. Introduction

In the event of a public health emergency in the United States (U.S.), it is important that the federal government is equipped to distribute medical supplies to every person in need as quickly as possible. Examples of such emergencies that have required intervention from the federal government include the terrorist attacks on September 11, 2001 and the 2009 H1N1 influenza pandemic (Center for Disease Control and Prevention [CDC], 2016). Both emergencies required supplies from the federal government because the state and local supplies of the areas in need were not adequate for these events. The Federal Emergency Management Agency (FEMA) has created a timeline of 48 hours between the declaration of an emergency and the treatment of the last person in need in the event of a public health emergency (Fiske, 2015).

The process for the distribution of medical countermeasures, or the supplies given in a public health emergency, is mapped out in Figure 1. The CDC has established Strategic National Stockpiles (SNS) that contain large quantities of medicine and medical supplies. These SNS are located across the United States in confidential locations. After the declaration of an emergency, the first step in the emergency response process is the state in need requests supplies from the federal government's SNS. States purchase and maintain their own medical countermeasure stockpiles, but if the public health emergency (for example, the 2009 H1N1 influenza pandemic) is severe enough to exhaust local supplies, then additional supplies come from the SNS (Stroud, 2011). Some of the medical countermeasures in the SNS are stored in push-packages, which are pre-configured collections of medical supplies that are designed to provide relief for a wide range of public health threats (Inglesby & Ellis, 2012).

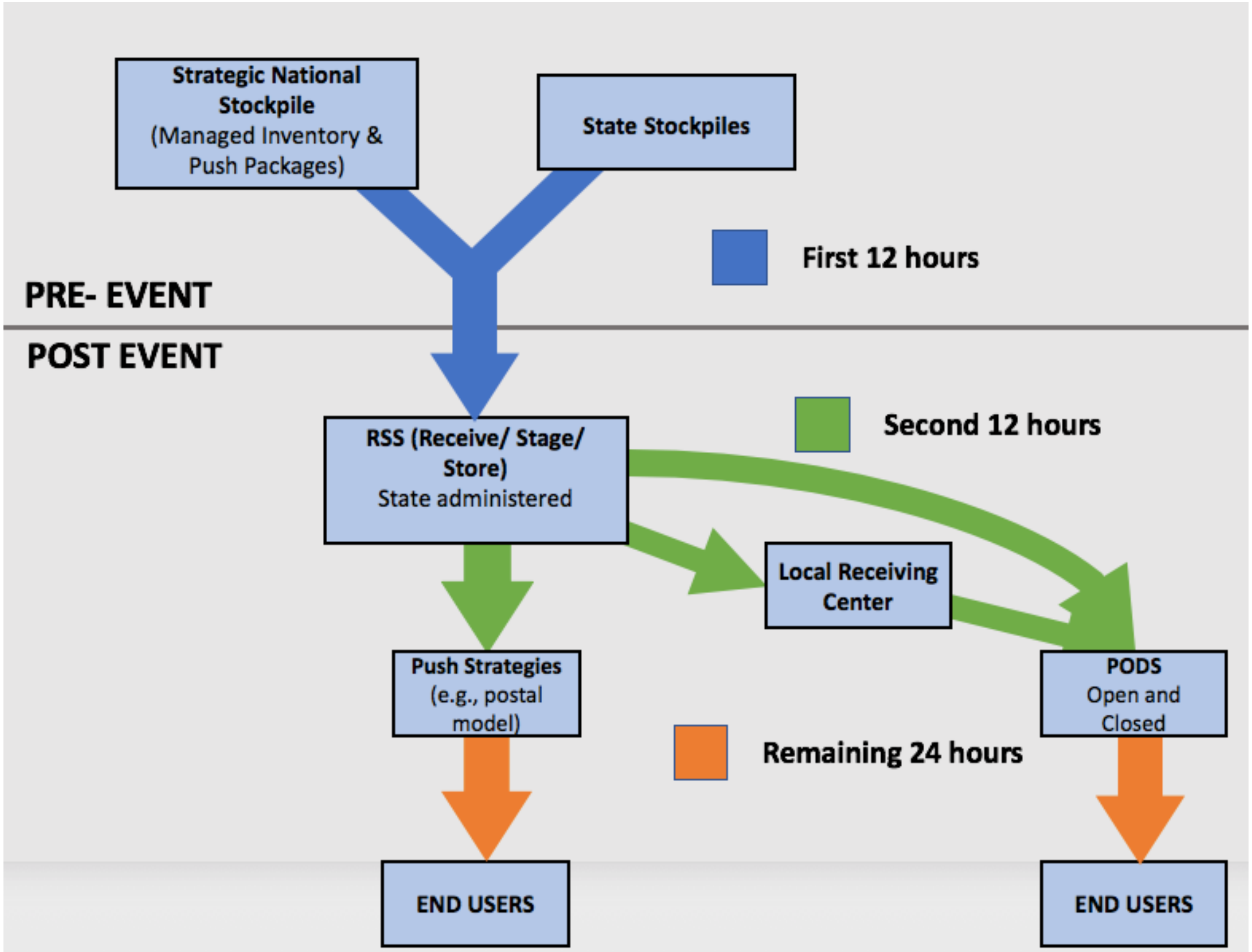

Figure 1- Current Basic Medical Countermeasures Distribution and Dispensing Strategy. Adapted from Stroud.

Push-packages are ready for immediate release and are rapidly deployed in public health emergencies and can arrive anywhere in the continental U.S. within 12 hours (Inglesby & Ellis, 2012). The push-packages contain generic supplies to help in any emergency, whereas the rest of the supplies in the SNS are stored as managed inventory (MI) which can be tailored to the cause of the emergency and sent with or after push-packages (Inglesby & Ellis, 2012). The push-packages and MI assets are shipped from the SNS to the centrally located state distribution center and the supplies are then processed at the state's distribution center (also known as an RSS for receive, stage, and store; Inglesby & Ellis, 2012).

After the supplies are processed by the state, it is up to the county to determine whether the supplies are sent to a local receiving center (LRC) and then sent to points of distribution (PODs) or if the supplies are delivered straight from the RSS to the PODs. The PODs are where the supplies are distributed to the local population and the number of PODs is determined by the population of the state (Nelson et al., 2008). The POD locations are determined by the local health department before the emergency. Having the public come to the POD to receive medical countermeasures is called a pull strategy. Another strategy that the CDC outlines is called a push strategy, which takes medical countermeasure stockpiles to the public through, for example, a partnership with the USPS to implement postal model. A postal model is a method of delivering medical supplies in a public health emergency to each doorstep through the mail system (King, 2012).

The FEMA has set a 48-hour timeline as an objective for the process of distributing the medical countermeasures as described in the previous paragraph (CDC, 2016). Components of the timeline are depicted in Figure 2.

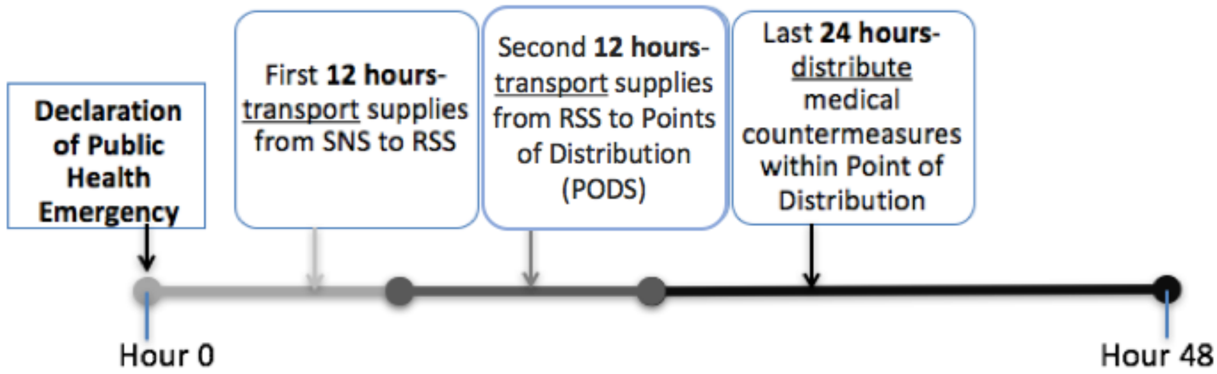

Figure 2. FEMA's 48-hour Timeline Objective.

According to the CDC, this timeline begins with the declaration of the emergency, then 12 hours are allotted for the shipment of supplies from the SNS to the RSS, then another 12 hours are allotted for the processing of the supplies at the RSS and the shipment to the PODs, and then the remaining 24 hours are given for the dispensing of the medical supplies within the PODs (Nelson, Chan, Chandra, 2008).

Currently, the CDC has a program for 72 major cities and metropolitan areas in the U.S. called the Cities Readiness Initiative (CRI), which uses federal funding to prepare these cities for a large-scale bioterrorist attack (CDC, 2016). The CDC has been training and conducting studies with these cities to improve the success of providing mass antibiotics to 100% of the identified population within 48 hours of the declaration of an emergency (CDC, 2016). While research has been conducted on major cities that are located near major grounds of transportation, there has yet to be a complete analysis for the distribution and dispensing of supplies in a smaller and more remote county, such as a county with a size of around a quarter of a million people located far from the state's RSS. Is it possible to distribute all medical countermeasures within the given 48-hour timeline to the population of such a county? Because there has been no research to examine the entire distribution and dispensing strategy for a small and remote county, this research will help determine whether the logistic activities of the medical countermeasures in the given timeline are attainable for a county. A case study county with an approximate population of 250,000 people located far from the state's RSS will be used to demonstrate the research methods. The state and county, referred to as State X and County X, will remain confidential due to the sensitivity of state emergency plans communicated to this research team by their public health partner. This case study can assist counties with similar characteristics in their preparation for transportation of medical countermeasures in a public health emergency.

2 Problem Statement

This research project uses County X as a case study to determine if it is possible to disperse medical countermeasures to County X's entire target population in a public health emergency within the 48-hour timeline. The main purpose of this research is to examine the second phase or the logistic activities from the RSS to the POD in the second 12 hours. The research tasks conducted that are discussed in this paper examine the total duration of the logistic activities are summarized below:

Task 1: *Gathering case study data.*

To develop a set of transportation routes for County X, actual data and information was collected from the state's public health partner on their emergency response plan including their service network design. Additionally, distance data was collected from Google Maps.

Task 2: Selecting the location of the PODS for County X.

The state's public health partner for this research has determined that County X requires 4 POD locations based on their population size. To study the total duration of the logistic activities, actual locations are decided to examine travel time. Data for the demand points are gathered from the U.S. Census Bureau and a distance matrix is calculated using Google Maps API. Locations for the PODs are determined using a P-Median capacitated model system that minimizes the distance the population must travel to receive their medical supplies while balancing the number of people that will visit each POD.

Task 3: Computations of distribution and dispensing duration.

This research will be executed as a networking problem using the POD locations determined through this research and information supplied by the state's public health partner to determine the time frame of the shipment of medical countermeasures. This network problem will be comprised of processes and events that begin with the RSS and end with the delivery of the supplies to the PODs and will examine routing options for the transportation of the medical countermeasures.

3 Literature Review

3.1 Distributing Medical Countermeasures Plan

As a part of the CRI, the distribution of medical countermeasures for selected cities and surrounding metropolitan areas is heavily funded by the government. The CRI timeline of 48 hours for dispensing of medical countermeasures has not been analyzed for feasibility in areas outside of cities funded under this program. In one case, the feasibility of the POD model during a bioterrorism attack in Rhode Island, which constitutes as a public health emergency is analyzed (Corvese, 2011). This study examines throughput of PODs in the CRI plan to determine feasibility for the whole state of Rhode Island. This work is distinguished from Corvese's by examining the total duration of the logistic activities including not only POD throughput, but POD selection methods and transportation calculations. Previous studies have also examined emergency preparedness on a state level, but this work aims to examine the emergency preparedness on a county level.

3.2 POD Selection

The process of selecting POD locations is considered a discrete facility location problem, or location-allocation. In selecting POD locations, important factors in the decision of the placement of a POD are the demand each POD location will serve and the distance that the population will have to travel to reach the POD location. Literature that discusses facility selection reviews the P-Median model which finds "the location of P facilities so as to minimize the total demand-weighted travel distance between demands and facilities" (Owen & Daskin, 1998). The P-Median model calculates the weighted travel distance between demand and facilities using the distance between the demand points and potential POD locations and the demand quantity that each potential POD location would service. The mathematical notation for it is as follows:

Inputs:
i= index of demand node
j= index of potential facility site
d_i*= demand at node i*

c_{ij} = distance between demand node i and potential facility site j
P= number of facilities to be located

Decision variables:

$$X_j = \begin{cases} 1 \; if \; we \; locate \; at \; potential \; POD \; location \; j, \\ 0 \; if \; not. \end{cases}$$

$$Y_{ij} = \begin{cases} 1 \; if \; demands \; of \; node \; i \; are \; served \; by \; a \; POD \; at \; node \; j, \\ 0 \; if \; not. \end{cases}$$

The P-Median problem is written as the following integer linear program:

$$\text{Minimize } \sum_i \sum_j d_i c_{ij} Y_{ij} \qquad (1)$$

$$\text{Subject to: } \sum_j X_j = P, \qquad (2)$$

$$\sum_j Y_{ij} = 1 \qquad \forall i, \qquad (3)$$

$$Y_{ij} - X_j \leq 0, \quad \forall i, j, \qquad (4)$$

$$X_j \in \{0,\ 1\} \quad \forall j, \qquad (5)$$

$$Y_{ij} \in \{0,\ 1\} \quad \forall i, j, \qquad (6)$$

The objective function (1) minimizes the total weighted distance between the potential POD locations and the demand points. Constraint (2) requires that exactly *P* PODs are selected by the model, which is 4 in the case of this research as decided by the state's public health partner. Constraint set (3) ensures that each demand is assigned to one facility and (4) ensures assignment to only sites where facilities have been located. Constraint sets (5) and (6) ensure results are binary (Owen & Daskin, 1998).

This P-Median problem is uncapacitated, which means that the PODS selected can have any range of demand as long as the total weighted distance is minimized. For a POD that is trying to process demand within a 24-hour period, a capacitated P-Median model allows a more equal distribution of demand across the PODS so that one POD is not overwhelmed with the population they are assigned to dispense medical countermeasures. Owen & Daskin (1998) discuss this version of the P-Median Model later in their paper and the modifications to the above linear program include adding input:

Q= value of capacity to not exceed

With added integer linear program constraints:

Subject to: $\sum_i d_i Y_{ij} \leq QX_j \quad \forall j.$ (7)

With an appropriate choice of value for Q, these modifications will ensure that the capacities are approximately evenly distributed amongst PODs.

A mathematical software is needed to solve the P-Median problem required for POD location selection because the system of equations in selecting the facilities is too complex in part because there are too many constraints to consider simultaneously and too many possible feasible solutions to evaluate. Researchers have used ARCMAPS for similar location-allocation problems, selecting locations for points of distribution prior to disaster (Milburn & Rainwater, 2013).

4 Task 1: Gathering and Computing Case Study Data.

4.1 Public Health Partner's Service Network Design and Distribution Details

The state's public health partner has a SNS service network design for the state during a public health emergency, with County X's full multi-tiered distribution model pictured in Figure 3 (Public health partner, 2017).

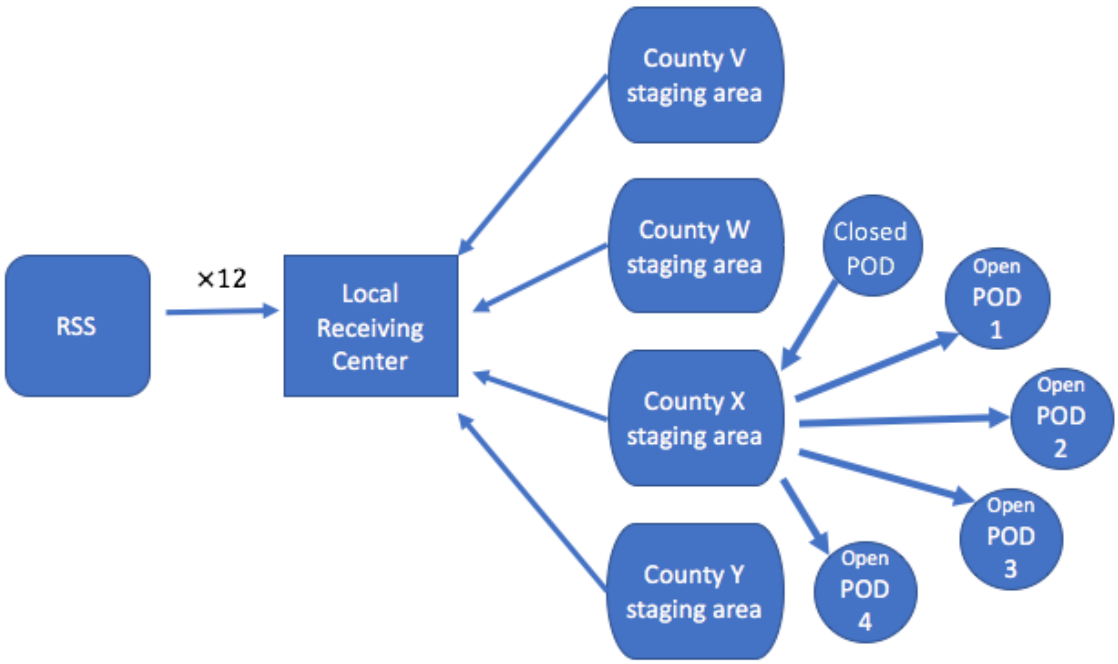

Figure 3. County X's Current SNS Service Network Design

The state's public health partner's model is a regional distribution site model, with the 12-hour push-package containing supplies for 1 million people received in pallets at the state level RSS. The 1 million doses are estimated to be received within 7 hours of the request of the state to the SNS, which is 5 hours quicker than the given plan by the CDC of 12 hours for SNS to RSS transportation (Public health partner, 2017). They arrive at the state RSS via C130s or tractor trailers and each pallet contains enough medical countermeasures for 9,600 people, or an estimated 104 pallets. There the doses are broken down by LRCs, according to the populations of the counties assigned to each LRC including the population for the Closed PODs. Once the 12-hour push-packages are received and broken down (which should take approximately 7 hours to process), they are sent to LRCs throughout the state (Public health partner, 2017). A truck can be dispatched as soon as the medications have been loaded onto it. On average, a longhaul tractor trailer truck travels at a speed of 40 mph over the complete course of the trip, including the stop time (Hertz, 1989). The loading should take less than 30 minutes if two people are offloading the push package containers with loading docks for a full tractor-trailer which are assumed to be at the RSS (LLIS, n.d.). The state's public health partner currently has a vehicle planned to deliver supplies to each of the LRCs. There are 12 of these LRCs across the state and each LRC is responsible for approximately 5-6 of the counties it oversees. These counties have various population sizes ranging from 16,000 to 260,000 people under one LRC in particular. Individual counties are responsible for picking up the supplies from the LRC and bringing them to their County Staging Area (CSA; also referred to as an alternate staging area). The unloading of a full truck with no loading dock, which the LRC will not possess, will take approximately 1 hour with three to four people unloading push package containers with fork lifts for a full truck. This is the stage where first responders and their families receive treatment. From the CSA, the county takes supplies to the Open PODs, which are PODs that are open to the public. Some populations are treated in locations other than Open PODs (e.g., Closed PODs, PODs reserved for private organizations, and hospitals). Those locations are not within the scope of this research.

For this transportation piece, drivers are assumed to not be a limiting source. The state's public health partner's selected drivers for the transportation of the medical countermeasures will be utilized and will all possess commercial driver's licenses. Trucks are rented from private companies (i.e. Penske and Ryder) and the requests to rent trucks are made as soon as the request for SNS push-packages are made. Optimally, this request is early enough for the trucks to be waiting on standby at the state RSS by the time the push-packages arrive.

Each 53-foot trailer can hold 250,000 doses and each 48-foot trailer can hold 230,000 doses (Public health partner, 2017). Once the trucks are loaded and brought to the LRC, many counties of the state would not require a full tractor-trailer to deliver their doses. A Ford F150 can hold 2 pallets or 19,200 doses. The pallets delivered to county are wrapped in plastic and must be broken down into the doses allocated to each POD (open and closed) at the CSA.

From this model, the state's public health partner has three open questions, (1) can the target dispensing timeline be achieved for County X, under some assumed operating scenario (e.g. make some assumption about whether the trailer delivering to the county is loaded first or last at the RSS, and whether the trucks will execute direct routes to each LRC or routes that visit a group of LRCs), (2) which trucks should leave the RSS first in order to assure a timely delivery of supplies to all State X's counties, and (3) should the state's public health partner continue with the plan for individual trucks to deliver to each POD or should some trucks make multiple stops. These questions in relation to County X can be examined with the results of the main objective of this study.

4. 2 Distances

To begin building the networking model for the logistic activities phase of the 48-hour timeline, the data for the distance from the RSS to all LRCs and from the LRCs to the counties needs to be calculated. The research team had access to the addresses of the 12 LRCs. The general area of the state's capital is used for the RSS because its actual location within the capital is confidential. Using Google maps, the distance from State X's capital to each LRC is calculated using the shortest route that uses main highways and interstates. Only the distance to the LRC which has County X in its domain is reported here for privacy reasons; it is 197 miles.

To calculate the distance from the LRC to the CSA, first a staging area for each county must be chosen. Reasonable choices in practice include venues such as county courthouses, health units, hospitals, and school gymnasiums. In the case of this research, CSAs were selected based on criteria provided by our public health partner. For the sake of privacy, these locations cannot be disclosed, but the distances from the relevant LRC to the CSAs in County X are provided in Table 1.

After the CSA for all counties were selected, the distance from each CSA from the designated LRC is calculated. The distances for County X's LRC (LRC X) distance is highlighted in Table 1.

Table 1. Distance from LRC X to CSA.

LRC X	**Distance to CSA (miles)**
County W	15.8
County X	6.3
County Y	29.5
County Z	6.3

Once all distances from the LRCs to the CSAs were calculated, total distance travelled from the state RSS to each county's CSA should be summed to recognize which counties will have the furthest to travel (RSS to LRC distance + LRC to CSA distance). Out of the 12 LRCs, the counties under LRC X (the LRC that contains County X in its domain) have the furthest distances to travel which should be considered in the vehicle dispatching decisions made at the RSS.

5 Task 2: Selecting the Location of the PODS for County X.

The team's public health partner has pre-determined that 4 PODs are required in County X based on population size and area. These locations have not been determined by the state. The process of selecting POD locations is described in this section to allow the method to be replicated for other areas. To identify the ideal location for the 4 PODs for County X, a capacitated P-Median problem is used meaning both demand points and possible facility locations must be included. Just as Milburn and Rainwater (2013) used census tract data for their demand points in their P-Median model, this research gathers the census tract centroid's latitude, longitude, and population for all of County X found on the US Boundary website.

A POD location ideally is situated in a place that is "both familiar and easily accessible to the community" (HCA, 2017). Examples are schools, community centers, etc. that can serve a large group of people in a small amount of time. For this research, schools were chosen as potential POD locations or facilities because they would be dispersed across the county in populated areas, they are easily accessible with large parking lots for staff, students, pick-up, and/or drop-off, and their locations are familiar to a majority of the community. A complete list of educational resources for every county are listed on the website EducationBug. The full list of schools under County X on the website are the possible facility locations for this research and their latitude and longitude were found using the website GPS-coordinates.org.

AMPL, or A Mathematical Programming Language, solves high-complexity problems for large-scale mathematical computing. Since the capacitated P-Median problem for this work falls under this category with 62 nodes in the network and 960 pairwise distances to examine, AMPL is an appropriate tool in selecting potential POD locations. Referencing an AMPL code from a similar capacitated P-Median model, a distance matrix must be created (Milburn, 2017).

Instead of finding 960 distances individually on Google Maps, Google Maps API gives users several ways of retrieving data from Google Maps. One of the features on Google API includes a distance matrix option which returns a matrix of distances for the recommended routes between given start and end points. These start and end points are encoded polyline algorithms facilitating storage of a series of coordinates as a single string. Referencing an instruction set written for Mullin's (2017) work in Google Maps API at the University of Arkansas, Matlab, which is a high-level language and interactive environment that can develop algorithms, can encode a set of latitude and longitude points using a given function into a polyline. In Matlab, the function, the coordinates for the facilities, and the coordinates for the demand points are the inputs for the encoding. The facilities and the demand points are encoded separately because the google maps API query requires the origin encoding and destination coding to be separate to calculate the distances. An API key which identifies application for purposes of quota management is also needed and is acquired by creating an API account on Google. The Google Maps Distance Matrix API request is in the form of a URL and is given here:

> https://maps.googleapis.com/maps/api/distancematrix/json?units=imperial&origins=enc:YOUR.ORIGIN.ENCODING:&destinations=enc:YOUR.DESTINATION.ENCODING:&key=YOUR.KEY

The YOUR.ORIGIN.ENCODING is the polyline encoded in MATLAB for the demand point locations, and the YOUR.DESITNATION.ENCODING is the polyline encoded in MATLAB for the 30 potential facility locations. This returns a list of distances in JSON data, which can be converted to a list of just the distances by using any JSON Online Editor. For this research, the JSON data returned from the query was edited using Tryit Editor v3.5.

After creating a distance matrix using the steps above, the P-Median capacitated AMPL model was then modeled after an example model. After the problem was coded, the distance matrix was included and the demand values (the census tract populations) for each demand location in I were established. To determine a reasonable value for facility capacity, the census tract populations were summed and divided by 4, so that the population is divided evenly amongst the PODs. An additional 6% is added on to the capacity for each POD to allow some flexibility in assigning census tract locations to PODs.

The results from running this model in AMPL are summarized in Table 2.

Table 2. Selected facilities and their assigned demand.

FACILITY	**DEMAND POINTS ASSIGNED**	**TOTAL DEMAND**
2	15,16,18,24,25,26,27,28	50,663 people
19	1,2,4,5,7,9	45,554 people
24	8,10,11,12,13,14,19,20,31	53,141 people
27	3,6,17,21,22,23,29,30,32	53,707 people

The results show that the demand locations 2, 19, 24, and 27 should be selected as the POD locations with the values under the TOTAL DEMAND representing the total population allocated to each location. The numbers 2, 19, 24, and 27 represent schools that were named in the model using numbers 1-30. Table 3 shows which demand point was allocated to which facility location. Each demand point should be assigned to only one facility and after checking that this is true and that the demand points assigned to each facility were reasonable, these four locations are established as the four POD locations.

6 Task 3: Varying Computations of distribution and dispensing duration.

6.1 General Model Duration

Using the data gathered in Task 1 and the locations found in Task 2, the logistic activities duration can be calculated. From the data gathered, the first step in the distribution process is processing the 12-hour push packages at the state RSS which takes approximately 7 hours. Next, the trucks must be loaded before shipping to the 12-LRCs. The specific dosage amounts State X receives are included in Section 4.1. The population for each county, found through the 2015 Federal Census, can be used to calculate the numbers of doses, pallets, and trucks each county needs. According to the state's public health partner, a 53-ft trailer can hold 250,000 doses (26 pallets) and a 43-ft trailer can hold 230,000 doses (24 pallets). The following equations were used to determine the resource amounts and non-integer values were rounded up to the nearest integer.

Doses Needed= County population

Pallets Needed = County population / 9,600 doses

Trucks needed (53-foot) = Number of Pallets / (250,000 doses / 9,600 doses)

Trucks needed (48-foot) = Number of Pallets / (230,000 doses / 9,600 doses)

*trucks are packed by pallet which contain 9,600 doses each; truck type depends on what private companies have available

Most tractor trailers are 53-foot vehicles and will be used for the duration calculations in this work. Using the calculations above, State X will require 12 53-ft trailers total with LRC X having the second largest population but the farthest distance to travel. If the RSS is to load trucks for LRCs with the largest population first then LRC X will be the second county loaded, but if LRCs with the farthest distance to travel are loaded first then LRC X will be the first to be loaded. For this distribution calculation, the option with the largest population will be selected as to compute the worst-case scenario duration for the logistic activities. As stated in Section 4.1, it takes about 30 minutes to load a full truck of 26 pallets with two people and a loading dock which would be available at the RSS. If LRC X is the second highest population, then an LRC with an approximate population of 700,000 is loaded first and requires 3 trucks (700,000 people/ 250,000 doses per truck) which will take 1.5 hours to load. Then LRC X with a population of 530,000 requires 2 trucks and will take 1 hour to load. The duration of the drive from the RSS to the LRC is 4.925 hours using 40 mph as the average speed of the truck and 197 miles found in Table 1 as the distance. At the LRC, it would not be sensible to unload an entire truck just to reload again, so the smaller counties are unloaded off County X's truck at LRC. Since there would be no equipment at the LRC, from Section 4.1 we know that it takes about an hour for 3 to 4 persons to unload a truck with 26 pallets, so for 3 to 4 persons to unload 4-5 pallets for the two smaller counties it would take 0.175 hours. The distance for County X's CSA in Table 1 is assumed to be travelled at 30 mph which is the average for country and side roads. At this rate the truck arrives at the CSA in 0.21 hours and the truck is unloaded in 0.825 hours (1 hour for unloading – 0.175 hours for pallets already unloaded). After the truck is unloaded, the pallets for PODs can be loaded assuming Ford F150s are tasked with carrying the 5-6 pallets needed for each of the 4 PODS. If Ford F150 trucks are loaded simultaneously, then to load 6 pallets for each POD should take approximately 0.23 hours if it takes 1 hour for 26 pallets. The maximum POD distance from the CSA is used to calculate the last driving duration which is 9.6 miles at 30 mph, 0.32 hours. Then the trucks are unloaded for the 0.23 hours and this is the final step of the transportation activities following the general model given and are summarized in Table 3. The estimated total of 16.19 hours for this portion of the dispensing process exceeds the 12 hours allowed per the FEMA timeline.

Table 3. Total Complete Time for General Model Logistic Activities

LOGISTIC ACTIVITY	HOURS TO COMPLETE
Processing Doses in the RSS	7
Loading largest pop. truck with loading docks	1.5
Loading 2 trucks for LRC X	1
Driving to LRC	4.93
Unloading smaller counties	0.21
Driving to CSA	0.83
Unloading truck	0.12
Loading Ford F150s	0.32
Driving to furthest POD	0.12
Unloading	0.12
Total Time:	**16.19**

To have a complete review of County X's logistic activities during an emergency, the distribution from the PODs must be examined. While the validity of the 24-hour timeframe for POD distribution in County X has been tested, the state's public health partner only has the results of previous simulation models and not the models themselves. Hudgeons examines and validates this output from the state's public health partner using the software RealOpt

(Hudgeons, 2018). The state's public health partner requested that this research is executed using the software RealOpt, a simulation software designed by Georgia Tech that consists of various decision support capabilities for modeling and optimizing the public health infrastructure for all hazard emergency responses (Lee, 2003). The data collected by the state's public health partner is from a series of time studies conducted in real time simulations wherein the department offered free flu vaccinations to different offices. The results from RealOpt set to maximize throughput concluded that it will take 12 hours, 15 minutes and 38 seconds plus or minus 1 minute and 42 seconds for a POD with a throughput of 11,221 people using 32 medical and 36 non-medical staff. For the POD with the maximum population of 53,707, only 42% of the population can be served with the resources designated in the simulation in the 24-hour period reserved for dispensing. State X can improve this flow to achieve a 100% throughput of the patient population by setting the Real Opt to minimize resource allocation which requires that users provide the minimum required total throughput per POD per shift (Hudgeons, 2018). Through analyses setting, Real Opt results prove that the PODs can process the population of 53,707 in 24 hours, but an additional 590 staff are required.

6.2 Travelling Salesman Model Duration

While the state's public health partner has established a general model for their service network, they requested that alternate networks be examined after the LRCs since it is not necessary to stop at two LRCs (LRCs and the CSA) for the distribution of medical countermeasures. After the LRCs, an alternate distribution model would be a travelling salesman problem, where County X's truck still drops off the supplies for the smaller counties at the LRCs, but instead of driving to the CSA to unload and reload smaller trucks, one truck would drive to the nearest POD, unload the 5-6 pallets, and continue to the next POD until all 4 PODs have their supplies. This network is pictured in Figure 4 and it would eliminate the process of reloading the smaller trucks.

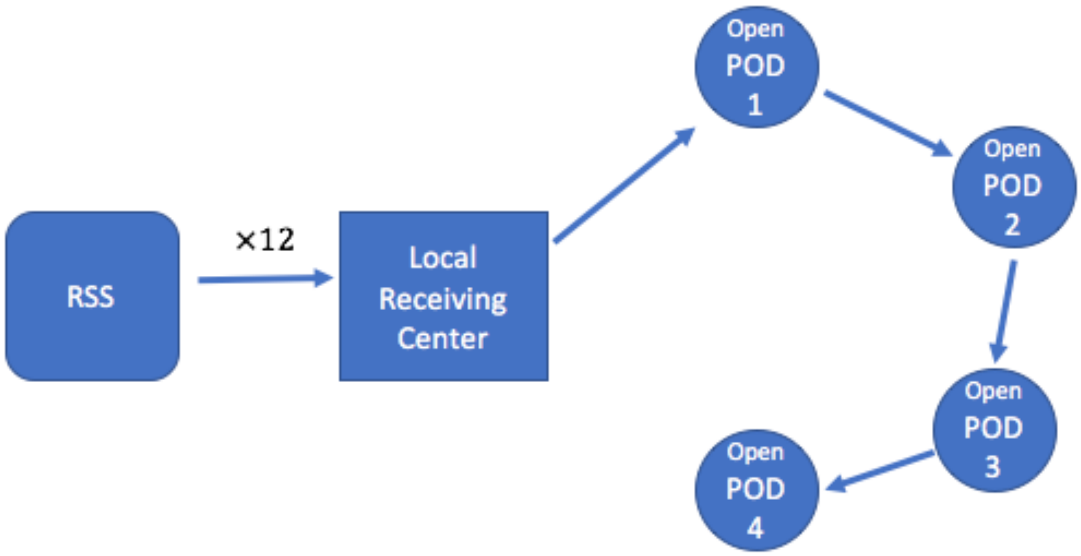

Figure 4. Travelling Salesman Service Network Design

The calculations up to unloading the smaller counties remain the same, but after they have been unloaded then the truck proceeds to first POD in the travelling salesman problem. To solve the route that would take the least amount of time starting from the LRC and stopping at every POD, the website Optimap can be used. Optimap is the fastest roundtrip solver, and it creates the fastest route for travelling salesman problems using Google maps. For this route a roundtrip is not necessary, every POD location needs to be visited once, so on the options for calculation the route should not return to the LRC after visiting every POD. The resulting route is 20.9 miles which will take 0.7 hours at 30 mph and the route is pictured in Figure 5.

Figure 5. Route for Travelling Salesman

The last process for this service network is unloading the truck at each POD. Three of the four PODs require 6 pallets which takes approximately 0.7 hours total to unload and one of the four PODs requires 5 pallets which takes 0.18 hours to load for a total of 0.88 hours of unloading (values found from bottom matrix of Figure 5). The total duration of this travelling salesman problem is summarized below in Table 4.

Table 4. Travelling Salesman Route Duration

LOGISTIC ACTIVITY	HOURS TO COMPLETE Travelling Salesman	HOURS TO COMPLETE General Model
Processing Doses in the RSS	7	7
Loading largest pop. truck with loading docks	1.5	1.5
Loading 2 trucks for LRC X	1	1
Driving to LRC	4.93	4.93
Unloading smaller counties	0.21	0.21
One truck stops at all locations (optimap)	0.7	-
Unloading the truck at each location	0.88	-
Driving to CSA	-	0.83
Unloading truck	-	0.12
Loading Ford F150s	-	0.32
Driving to furthest POD	-	0.12
Unloading	-	0.12
Total Time:	**16.22**	**16.19**

7 Results and Discussion

The 48-hour timeline is not observed in the results of this work. The 16.185 hours for the general model of the service network exceeds the 12-hour timeframe allotted for the distribution of the medical countermeasures and in 24 hours with a designated number of resources, only 42% of the POD's designated population are treated. The two different service network options for the transportation of the medical countermeasures also do not differ significantly in time, with the travelling salesman network having the same duration as the original model. For this reason, the state's public health partner can either keep their original plan to have separate truck go to each POD from the CSA or use one truck to go to all PODs depending on the resources available. It is possible for the county to attain the 48-hour timeline, since the push packages are expected to arrive to the RSS in 7 hours instead of the 12 hours allotted to this phase of the distribution as stated in Section 4.1. This would allow more than 36 hours for both the logistic activities from the RSS to the completion of dispensing. The estimate for processing 1 million doses at the RSS is 7 hours, but if this process could be completed simultaneously with loading trucks then the distribution piece would be closer to the 12-hour allotment. At 16 hours of distribution, a 20% decrease in the time from declaration of the emergency to the arrivals of the push-packages at the RSS and a 20% decrease in processing time at the RSS would allow the county to meet the guideline of 24 hours for these two phases combined. For POD dispensing however, a steep increase of 13 times the number of personnel allotted to each POD is needed to complete this phase in the 24 hours allotted to it. The population allotted to each POD includes all persons recorded in the census tract data, which means that the POD dispensing time will also be less since there will be a portion of the population receiving their medical countermeasures from Closed PODs.

Following the process of this work, other state health departments can also examine their emergency response model and whether it's possible for it to be completed in the 36 hours dedicated to logistic activities. Further research should examine more options for the service network, such as deploying a truck directly from the RSS to the PODs for counties that are large enough to fill an entire truck and therefore skip the process of the stopping at the LRCs. For smaller counties, further research could also examine whether smaller counties should be combined with each other to fill a truck from the RSS to the LRC, or if each county should have its own truck if the state's resources are available.

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