Maximizing supply of vaccines in developed countries

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***Abstract*— Vaccination has proven to be the most effective way of combating infectious diseases. But millions of people will be unable to get the vaccine. There are several reasons such as vaccine safety issues, vaccine quality problems, Health-care deficiencies, societal obstacles, and economic restrictions. Now with the COVID-19 pandemic it is very important for the proper delivery of vaccine once it is ready. In this research we focus on problems that are related to poor structure and operation of vaccine delivery systems in developed countries like US where there will be lot of population and many hubs. Optimization and math modelling can also help tackle the covid issue and supply chain plays a crucial role when the vaccine comes up. To reach the greater number of people we keep each constraint for different coverage possibility. We propose a network design problem as a mixed integar programming by trying out various constraints. Here we examine the effects of US delivery of the COVID-19 vaccine (once it is ready). We start with a Standard problem with location of the services. In this case, we find every city in the United States a demand point, since. Citizens would need to be vaccinated and where to find distribution points let's call it is the key decision. Hubs to listen to all requests. In total we try 6 different constraints to maximize the vaccine delivery by calculating hub points for each constraint**

Keywords— Vaccine delivery, hub, Mixed integer programming, COVID, Flexibility, Network design, Supply chain

I. Introduction

In December 2019, a number of pneumonia cases of uncertain aetiology occurred in Wuhan, Hubei province , China. On 31 December 2019, 27 unexplained cases of pneumonia were recorded and found to be related to so-called 'wet markets' selling fresh meat and seafood from a variety of animals such as bats and pangolins. It was found that pneumonia was caused by a virus identified by the World Health Organization (WHO) as 'Extreme Acute Respiratory Syndrome Coronavirus 2' (SARS-CoV-2), which was subsequently referred to as Coronavirus Disease 2019 (COVID-19). The new coronavirus is thought to have originated from bats and was transmitted to humans either directly or by other animals at the end of 2019, although this was not known. There is no evidence that mutations that have occurred since the virus was discovered (changes in genetic material) have had some effect on the virus' ability to cause disease. Supply Chain Management (SCM) is the management and control of a commodity from its origin until consumption. The SCM covers content, accounting and knowledge flows. This involves design, preparation, execution, tracking, and control of the goods. The aim of this method is to minimise inventory, increase the speed of transactions and enhance the work flow with a view to benefit.

"Let's be frank here, supply chains for vaccines are far more complicated than supply chains for PPE," referring to personal protective equipment, such as surgical masks and gloves. "You can not kill EPP by leaving it for a few days on the tarmac. You are going to ruin those vaccines. We also talk of the scientific conundrum of coming forward with a functioning vaccine. In certain cases, even even more complicated is what you're just putting your finger on, which is delivery that becomes complex. None of us are safe until the vaccine is safely distributed to everyone. We are not proactively preparing to facilitate this delivery of vaccines because the different parties here do not interact. Vaccination is the most effective method of reducing morbidity and mortality caused by infectious diseases. The World Health Organization (WHO) reports that worldwide, vaccination prevents more than 2.5 million infant deaths per year. A vaccine is a biological preparation that increases immunity against a particular disease. The typical types of vaccines currently used to date are vaccines containing either dead or live-attenuated microorganisms, inactivated toxins (Toxoid), protein subunits, and antigens or conjugates containing polysaccharide. The 2019 coronavirus disease (COVID-19) pandemic resulted in 5,817,385 confirmed cases and 362,705 deaths worldwide through May 30, 2020, including 1,761,503 aggregated recorded cases and 103,700 deaths in the United States. Previous February – early April 2020 analyses revealed that age-approximately 65 years and underlying health conditions were correlated with a higher risk for serious outcomes.

By taking advantage of technology many vaccines have low-cost mass production.Take chance. Maintaining low-cost vaccines however remains one of the big challenges for Supply Chain Managers of Vaccines. Some of the vaccines must be held inside a Narrow temperature range to the use of the immunisation session, termed as "cold chain," and it plays important role for the delivery of vaccines.And with the support of foreign organisations and emerging technical innovations Vaccines can now be purchased at low cost and in bulk. Yet packing, logistics and logistics

Delivery of vaccines cost-effectively thus ensuring that vaccines are available in a safe manner

This remains a big problem for end-users. For several developed countries , in particular, the vaccines Generally spread across a legacy hierarchical medical network with locations and shipping routes Also determined by political boundaries and history of this network

A mixed-integer programming (MIP) problem is one where, at the optimal solution, some of the decision variables are restricted to be integer values (i.e. whole numbers like -1, 0, 1, 2, etc.) Using integer variables significantly expands the scope of useful problem optimization you can define and solve. A major special case is an X1 decision variable which must be either 0 or 1 at the solution.. However, integer variables make the problem of optimization non-convex, and therefore much more difficult to solve.

Alternative methods, such as genetic and evolutionary algorithms, generate candidate solutions randomly which satisfy the constraints of the integer. These initial solutions are typically far from optimal, but these methods then turn existing solutions into new candidate solutions, by means of methods such as integer- or permutation-preserving mutation and crossover, which still meet the constraints of the integer but may have better objective values. This cycle is repeated until there is a "optimal solution" The formatter will need to create these components, incorporating the applicable criteria that follow.

II. Literature Survey

In this section, we are considering four types of models for optimising outreach coverage. In all We assign our models to several locations which can be chosen. We commence with a simple A model similar to the MCLP model in binary form. The second model extends that by drawing From the GMCLP method, coverage being a step-by-step and diminishing distance feature. The third model consists of a new generalisation of the cooperative cover scheme: not linear, Part coverage accumulation is part coverage of the area. Basically The model is a broader one that could be considered to generalise all of the first three ones. More analysis is Particularly for rural areas with relatively low population densities; Models for urban environment coverage are likely to be much more complex. Since most are Urban areas continue to have health posts or hospitals on a regular basis, and general access is provided Centered on farmland. In fact, we assume that the social planner isn't biased by Information plans where the journey is smoother or quicker [1]

Firstly, universal access is the WHO's target and That is directly captured by the constraints of our model. Secondly, our platform draws on the current model Hubs buildings, as opposed to modern ones. Third, Operational Simplicity in most LMICs Is a driving necessity since resources are very small, and finding Skilled logisticians and qualified staff, capable of dealing with numerous suppliers and various Equipment Forms. In prototype, Vaccines flow from the national centre (source node) to the clinic (sink nodes) usually through one or more clinics Further intermediate hubs (the nodes of transhipment). Though there are several vaccines (usually 6 to 8) Transportation and storage capacities treated in the cold chain are influenced only by the sum Needed room. And we just find the overall number of delivered or deposited vaccines. Current locations of legacy intermediate nodes (regional or district) are chosen Center) and while we maintain monthly or quarterly replenishment options as per WHO Guidelines, we allow the hub to pick either option freely [2]

The decision variables for the integer programming model are all either non-negative integers or binary (0–1). A set of binary decision variables is defined for each month in which a particular vaccine can be administered, where a value of one indicates that the vaccine combination should (not) be administered in that month As indicated This may result in substantial cost savings from the outcomes of the pilot test, because the cost of clinical visits is the most important Dominant contribution of vaccine administration. Usage of in nature Research into activities in this new area has potential To redefine the manner in which immunisation in public health The programmes are planned , implemented in the United States, And appraised [3].

Since the interrelationship between participating companies is seen as crucial Success factor in creating a more competitive integrated supply chain Manufacturing, it suggests an interrelation correlation. Besides this relation, Consideration of sustainable development of the supply chain which is connected to Economic and environmental gains face a joint challenge. Future work is required to investigate the different types of Practical problems related to integrated development processes and sustainability in Supply chains of which this structure refers. Secondly, the social factors and their effects. They are not evaluated in this context, because this assessment goes beyond our emphasis on discipline. This critical dimension will however be dealt with in the future through a cross-disciplinary approach group research [7]

III. Implementation

Here we analyze the impact of COVID-19 vaccine distribution in US (once it is ready). We start with a standard facility location problem. We consider in this case every US city as a demand point since people will have to be vaccinated and main decision is where to locate distribution points (let's call it hubs) to attend all the demand. The problem can be formalized as following: given n cities and m possible distribution points we define continuous variables $x_{ij} \geq 0$ as the amount of vaccines serviced from hub j to city i, and binary variables $y_j = 1$ if a hub is established at location j, 0 otherwise. An integer-optimization model for the capacitated facility location problem can now be specified as follows:

$$Minimize \sum_j f_j y_j + \sum_i \sum_j c_{ij} x_{ij}$$

Subject to

$$\sum_j x_{ij} = d_i \qquad \forall i \ in \ N$$

$$\sum_i x_{ij} \leq M_j y_j \qquad \forall j \ in \ M$$

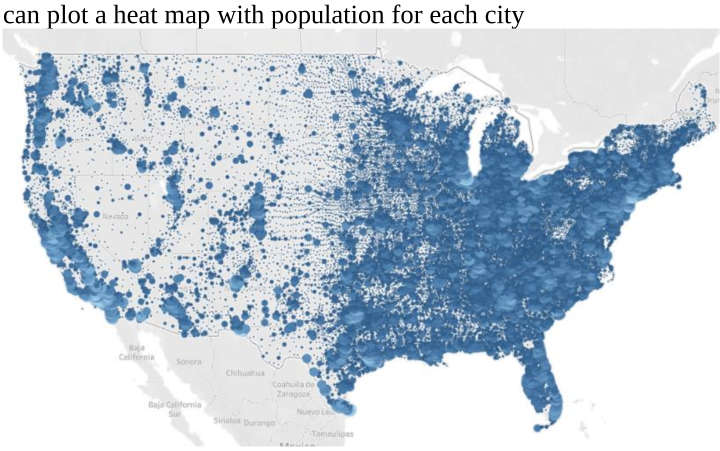
$$x_{ij} \leq d_i y_j \qquad \forall i \ in \ N \ \forall j \ in \ M$$

$$x_{ij} \geq 0 \qquad \forall i \ in \ N \ \forall j \ in \ M$$

$$y_j \in \{0,1\} \qquad \forall j \ in \ M$$

Where d_i is the population of city, M_j the capacity of each hub, c_{ij} *and* f_j as variable and fixed cost respectively. We'll consider variable cost as distance and fixed cost as 1000, for now. Every city can serve as a hub.

The first task is to collect all the population data from census [5] for each of the 32637 cities in the US. With this data we can plot a heat map with population for each city



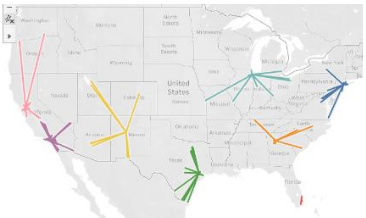
It can be seen that east coast has a higher population density and will require more vaccines. To avoid model explosion we'll consider only the top 250 cities population wise.

The first analysis will be how to split these hubs minimizing only distance to final demand point (city) if we want to build 3, 15 or 30 hubs. So we'll add the constraint:

$$\sum_j y_j = k$$

Where k will be 3

Where k will be 8



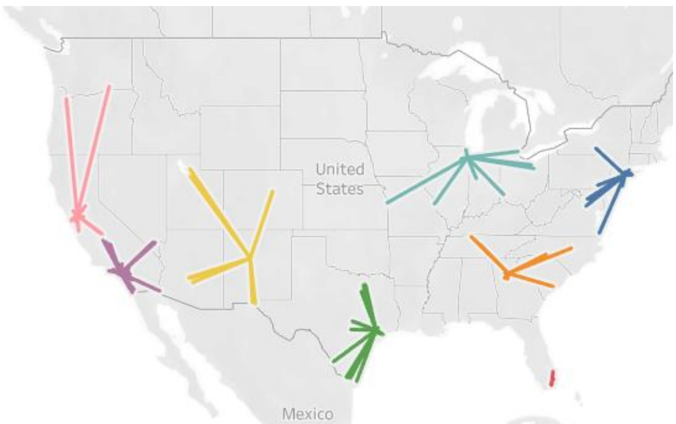
Where k will be 15

We'll now add a different constraint and change the objective function: a city is served by a hib within 500km distance and we want to minimize the number of hub points used. The model will be modified as following:

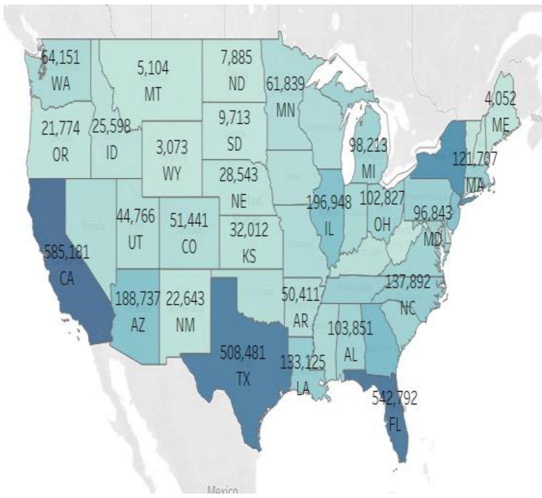
$$Minimize \sum_j y_j$$

$$\sum_i x_{ij} = 0 \qquad \forall j \; in \; M: dist_{ij} \geq 500$$

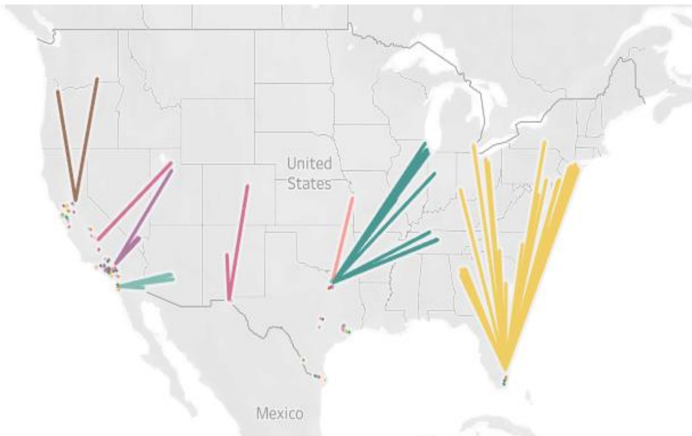
The optimal number of hubs are 8



Introducing the COVID context we'll collect data on number of covid cases habitants for each state in the US [4]



We'll add a constraint that a hub needs to be built in a state where we have more than 500.000 cases



$$Minimize \sum_j f_j y_j + \sum_i \sum_j c_{ij} x_{ij}$$

We use 6 different constraints for maximizing the vaccine delivery we calculate hub points individually for each constraint below.

Analysis 1: -> minimizing distance + fixed cost with open number of hubs

Analysis 2: -> minimizing distance + fixed cost with open number of hubs (3 hubs fixed)

Analysis 3:-> minimizing distance + fixed cost with open number of hubs (8 hubs fixed)

Analysis 4: -> minimizing distance + fixed cost with open number of hubs (15 hubs fixed)

Analysis 5:-> minimizing distance + fixed cost with extra constraint that state with more than 500k cases needs a hub built in it

Analysis6:->minimizing distance + fixed cost with maximum distance between hub and city as 500km

IV. Results And Discussions

All the population data is collected from the census [5], with these data a heat map is plotted for each city. These two tables represent input data.

Input:

Table 1: First ten rows of census.xslx

Latitude	Longitude	City	State ID	Population	County	3-digit ZIP
41.78	-87.71	Chicago	IL	113916	Cook	606
31.78	-106.30	El Paso	TX	111086	El Paso	799
40.75	-73.85	Corona	NY	109931	Queens	113
33.91	-118.08	Norwalk	CA	105549	Los Angeles	906
34.01	-118.26	Los Angeles	CA	103892	Los Angeles	900
34.26	-118.42	Pacoima	CA	103689	Los Angeles	913
40.65	-73.96	Brooklyn	NY	101572	Kings	112
33.97	-118.17	Bell Gardens	CA	101279	Los Angeles	902
40.74	-73.88	Elmhurst	NY	100820	Queens	113

The above table represents population data of US

Table 2: First ten rows of covid.xslx

State	Cases
AL	103851.00
AK	3821.00
AZ	188737.00
AR	50411.00
CA	585181.00
CO	51441.00
CT	50684.00
DE	15699.00
DC	12896.00

The above table represents number of Covid cases for each city.Then the cases in each city are placed in a heat map and with population more in east coast we further divide the hubs for vaccine delivery with some fixed number K. We fix the value of k by testing.

Output:
Table 3: First six rows of flow.csv

Origin	Destination	Flow
75002	60629	113916
79936	79936	111086
33411	11368	109931
90650	90650	105549
90011	90011	103892

The above table represents quantity of vaccines shipped between two different cities.

Table 4:

Hub	Used
60629	1
79936	0
11368	0
90650	0
90011	0
91331	0

The above table represents the if a hub is used or not by representing in a binary value

We will pass the csv files to Tableu to get the pictorial representation of results

V. Conclusion And Future Works

The vaccine delivery is maximized by using the various constraints under mixed integer programming where it will be useful under current COVID Pandemic in developed countries like USA. Future works includes considering the herd immunization where not all people should be vaccinated. Another goal is to expand it on the global scale and add third echelon in supply chain to reflect the distribution centers.

VI. References

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