Cold Chain Planning for COVID-19 Vaccine Distribution

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Abstract

The COVID-19 vaccine will be distributed throughout the country by the government, one of which is Indonesia. COVID-19 vaccine is a perishable good. Therefore, cold chain planning is necessary for the COVID-19 vaccine distribution. This research aims to determine the priority order of Indonesia's provinces to receive vaccines and vaccine distribution alternatives. This study uses Microsoft Office Excel 2013 with the help of a solver tool for processing the Vehicle Routing Problems (VRP). The result shows that the top 7 provinces that need to be prioritized based on the frequency distribution categorization result until September 30, 2020, for vaccine distribution are DKI Jakarta, East Java, Central Java, West Java, South Sulawesi, South Kalimantan, and North Sumatra. The results of the alternative planning show that the longest total distance from alternative 1 in DKI Jakarta is 121 km for 26.03 hours, alternative 2 in DKI Jakarta is 58 km for 11.9 hours, alternative 1 in Papua is 608 km for 35.78 hours, alternative 2 in Papua is 315 km for 12.5 hours.

Keywords:
COVID-19 vaccine, cold chain planning, vaccine distribution, solver tool, Vehicle Routing Problems (VRP)

1. Introduction
Coronavirus or COVID-19 is a virus that attacks the human respiratory system and can cause death. The virus, which was first detected in Wuhan City, has been endemic since the beginning of December 2019. Since then, many scientists have tried hard to research and carry out trials to find a vaccine that can fight the COVID-19 virus. Teams of medical personnel have also begun to be deployed to deal with this new virus at each referral hospital. The COVID-19 virus has entered Indonesia since early March 2020. Since then, the Indonesian government has made several efforts and rules to prevent the transmission of the COVID-19 virus. The government has imposed large-scale social restrictions, micro-scale social restrictions, small-scale social restrictions, issuing regulations to follow health protocols and other rules. However, the number of positive and dead victims of this virus are still increasing every day until this day. The government and society still hope that the COVID-19 vaccine can be distributed immediately and ready to be used to handle this deadly virus properly. The COVID-19 vaccine has been studied since the beginning of the virus outbreak. The first COVID-19 vaccine trials began in May 2020. This vaccine will be distributed to all countries. Indonesia, which consists of 34 provinces, needs to think about ways to distribute the COVID-19 vaccine to be used in every existing province. The government is still experiencing difficulties in distributing the vaccines due to the limited facilities available in several areas. Vaccines are perishable goods or easily damaged items if the conditions are not well maintained. One of the things that can damage perishable goods is an inappropriate temperature. This condition of the environment can change the concentration of substances in the vaccine to become damaged. Therefore, an excellent way to keep vaccines from spoiling when distributed is to maintain the temperature. Therefore, the cold chain distribution system is a suitable distribution system to choose to distribute vaccines. Based on this background, the authors researched to provide several distribution alternatives that could be considered for vaccine distribution. This research focuses on cold chain planning for one province in Indonesia with the highest total cases, high-risk zone, and the average number of new cases that has cold chain facilities, and one that has no adequate cold chain facilities.

1.1 Objectives
This research aims to determine Indonesia's priority order provinces to receive vaccines and plan vaccine distribution alternatives. The research further recommends two alternatives of vaccine distribution to a province with the highest total cases, high-risk zone, and the average number of new cases that has cold chain facilities, and one province also in Indonesia but has no adequate cold chain facilities.

2. Literature Review

Vaccines are a special kind of drug, the quality of which is highly sensitive to temperature and directly related to public health (Lin, Zhao, and Lev, 2020). Vaccines can only save lives if they remain cool. Most vaccines are developed for a temperature range of 2-8°C (35-46°F), their so-called "safe range" (Comes et al. 2018). In many countries, one of the common factors limiting full and equitable access to effective immunization is the existence of gaps in cold chain and logistics (CCL) systems (Brison and LeTallec, 2017). While the focus of many in the vaccine world has been on developing new vaccines and measuring their effects on humans, failure to understand and properly address vaccine supply chain issues can greatly reduce the impact of any vaccine (Lee and Haidari, 2017). Cold chain management can enhance the quality, safety, and efficacy of an immunization program. Once the potency of a vaccine is lost, it cannot be regained or restored, and the vaccine will no longer provide protection against the target disease. Cold chain management includes the storage conditions, refrigerator maintenance, and temperature monitoring, and handling of the vaccine during immunization sessions (Chourasiya et al. 2018).

In many low-income countries, vaccine delivery systems have remained largely unchanged due to challenging contextual factors that have limited their ability to meet immunization program requirements. Structurally, the scale and geographic spread of cold chain systems have been demanding, given the need to consistently reach the whole population. Furthermore, diverse population settlements (e.g., urban, semi-urban, rural) present unique contextual challenges that test cold chain capabilities and managerial responses (Ashok et al. 2017).Vaccine cold-chain distribution system must be monitored to guarantee vaccine quality. An improper vaccine distribution system can cause damage and loss of efficacy. Therefore, the Indonesian government released some regulations to manage the vaccine cold-chain system, including the Good Distribution Practices for Pharmaceutical Products in 2012 and Regulation of the Minister of Health Number 42 in 2013 (Medisa and Nugraheni, 2018).

Vehicle Routing Problem (VRP) is one of the important issues that exist in a transportation system. This is a well-known combinatorial optimization problem that consists of a customer population with deterministic demands and a central depot that acts as the base of a homogeneous fleet of vehicles. The objective is to design a set of vehicle routes starting and terminating at the central depot, such that the demand of customers is totally satisfied, each customer is visited once by a single vehicle, the total demand of the customers assigned to a route does not exceed vehicle capacity, and to minimize the overall travel cost, taking into account various operational constraints (Juliandri, 2018). The Nearest Neighbor Algorithm is a procedure where the route of the vehicle starts from the customer closest to the depot. Then the next route is the customer closest to the first customer who has been visited. This procedure will be repeated until all customers enter the route. The steps carried out in the process using the Sequential Insertion Algorithm are as follows (Fitriani et al. 2021).

1. Starting from the depot, then looking for unvisited customers who have the shortest distance from the depot as the first location.
2. Go to another customer that has the closest distance from the previously selected customers, and the number of shipments does not exceed the capacity of the vehicle.
   (a) If there is a customer-selected as the next customer and there is a remaining vehicle capacity, then go back to step 2.
   (b) If the vehicle does not have the remaining capacity, return to step 1.
   (c) If there is no selected location because the number of shipments exceeds the capacity of the vehicle, then return to step 1. Start again from the depot and visit the closest unvisited customers.
3. If all of the customers have been visited exactly once, then the algorithm ends.

VRP is a vital problem and a crucial link in reducing the total cost of distribution of cold-chain logistic distribution (Wang et al. 2017). Supply Network Design represents one of the high-impact strategic decisions in competitiveness for companies. The Supply Network Design (SND) represents the impact of strategic decisions on the competitiveness of an organization, defining the number, location, and capacity of the warehouses and manufacturing plants or the flow of material along with the logistics network (Buritica, 2018).

3. Methods

Data processing for the province priority based on COVID-19 cases is carried out in several stages, including COVID-19 cases data tabulation and sort them according to the highest number of cases. The next stage is giving a score for each category. This study uses three categories: the number of COVID-19 total cases, risk zoning, and the average number of new COVID-19 cases per day. The range of scores based on total cases and the average number of new cases per day is 1 to 34, while the risk zone is 33 to 34. The scores for the total cases are given by ordering the total

cases from highest to lowest. Provinces with the highest total cases scored 34, while provinces with the lowest total cases scored 1. The average number of new cases per day category is scored in the same way. Provinces with the highest average number of new cases per day scored 34, while the lowest scored 1. The way of assessing the risk zone is different from the two previous categories. This assessment was carried out by giving a score of 34 for all provinces that have cities/regencies with high-risk zones and 33 for all cities/regencies that do not have cities/regencies with high-risk zones.

Cold chain activities identification is carried out for each distribution point. This identification uses the basic science of the supply chain to differentiate the activities that need to be carried out by each distribution point. Cold chain activities need to be carried out by cold chain actors to maintain the quality of distributed goods, starting from supplier to spoke. Mapping the location of supplier, hub, and spoke is carried out to visually determine the extent of distribution coverage in each province, which in this study are Jakarta and Papua. This mapping is done by plotting the coordinate point data from the supplier, hub, and spoke obtained into Google My Maps. The icons are given for the supplier, hub, and spoke are different. The colors given for each city/district are also different. Both of these are done to clarify the process of identifying the area, which is also assisted by the legends on the map.

Distribution alternative planning is done by processing distribution constraint data to obtain the number of trucks needed to carry out the distribution. After the required number of trucks has been obtained, the division of areas is carried out based on the coordinate points on the map that has been made. Forming a distribution route for each alternative is made using the solver tool in Microsoft Office Excel. This processing is carried out to obtain a distribution channel that can be proposed as an alternative distribution of the COVID-19 vaccine in the selected provinces. The final stage of this processing is to process the data to get the total travel time using mileage and vehicle speed that is influenced by loading and unloading times which are assumed to be 30 minutes. The total length of unloading time is also influenced by the number of health units targeted. The more health units targeted, the more unloading processes will be carried out, so the time needed will also be longer.

4. Data Collection

Data collection is done by collecting information in the form of data needed for this research. The data used in this research consisted of primary data and secondary data. Primary data was collected using Google My Maps. Some of the primary data obtained in this research are:

- Coordinate points of suppliers, hubs, and spokes in DKI Jakarta and Papua. The coordinates of Marina Pier in North Jakarta, Husein Sastranegara Airport in Bandung, as well as several airports used in Papua have also been collected. These coordinate points are obtained by using Google Maps.
- Distance data from each planned alternative.

Secondary data is obtained from various sources, such as news, official websites, journals, reports, and several other sources. Some of the secondary data obtained in this study are:

- Data on COVID-19 cases, risk zoning, and the average number of new COVID-19 cases per day in all provinces in Indonesia. The data has been collected from March 2, 2020, to September 30, 2020, on the official website of the Satgas Penanganan COVID-19. Data on the availability of cold chain facilities in Indonesia is also sought and obtained through news reported by Bisnis.com.
- Things to be done on cold chain activities. This data was collected from the Regulation of the Badan Penanganan Obat dan Makanan Number 6 the Year 2020 concerning Amendments to the Regulation of the Badan Pengawas Obat dan Makanan Number 9 of 2019 concerning Technical Guidelines for a Well Drug Distribution.
- Refrigerated warehouses and health units such as hospitals and health centers in DKI Jakarta and Papua were taken from the official website of Asosiasi Rantai Pendingin Indonesia (ARPI) and Badan Penanganan Obat dan Makanan (BPOM). This data was obtained from the official website of the Satgas Penanganan COVID-19, while health centers in DKI Jakarta and Papua were obtained from files published by the Ministry of Health (2020). The health centers taken were only those considered active by the Ministry of Health through the published file.
- Vehicle capacity, vaccine weight, and population data are used for initial data on distribution flow planning. Vehicle capacity data was obtained from logistics news, while vaccine weight was obtained from the official website of SGD-Pharma, which displays several sizes of injection vials. The COVID-19 vaccine is packaged in an injection bottle with a capacity of 5 ml (equivalent to 5 grams). The injection bottle with a capacity of 5 ml weighs 14 grams. Therefore, it can be concluded that the COVID-19 vaccine weighs 19 grams. Data on the number of residents in each city/district is sought and obtained from the official website of the Badan Pusat Statistik.

- Limit size data in the form of vaccine weight, container weight, capacity of trucks, planes, and ships, as well as the number of stages of distribution. These limits are used to process truck requirements that affect each alternative's distribution lines, mileage, and travel time. Vehicle speed data of trucks, planes and ships are also carried out for processing to obtain the required travel time data for each alternative.

5. Results and Discussion

5.1 Province Priority

Prioritizing provinces in Indonesia for receiving the COVID-19 vaccine is done by giving a score for some categories. Data categories that have been collected are COVID-19 total cases, risk zone, and the average number of new cases per day for all provinces in Indonesia. Table 1 shows the data collected from data from March 2, 2020, to September 30, 2020, on the official website of the Satgas Penanganan COVID-19 (2020).

Table 1. Number of COVID-19 cases in the provinces of Indonesia

Province	Number of …		
	Total case	High risk	New cases
Jakarta	73,736	4	342
East Java	43,744	4	222
Central Java	22,435	5	114
West Java	22,205	5	104
South Sulawesi	15,579	2	80
South Kalimantan	10,348	2	56
North Sumatra	10,313	6	52
Bali	8,878	2	48
East Kalimantan	8,651	3	43
Riau	7,622	5	41
Papua	6,321	4	33
West Sumatera	6,281	6	33
South Sumatera	6,095	0	33
Banten	5,643	4	27
Aceh	4,554	4	24
North Sulawesi	4,487	0	24
Central Kalimantan	3,645	0	19
West Nusa Tenggara	3,316	0	18
Gorontalo	2,753	1	16
Southeast Sulawesi	2,862	1	14
Maluku	2,815	1	15
Special Region of Yogyakarta	2,643	0	13
Riau Islands	2,243	0	12
West Papua	2,135	2	11
North Maluku	2,065	0	11
West Kalimantan	982	0	5
Lampung	894	0	5
West Sulawesi	794	0	4
Bengkulu	693	1	4
North Kalimantan	577	0	3
Jambi	513	0	3
East Nusa Tenggara	424	0	2
Central Sulawesi	410	0	2
Bangka Belitung Islands	361	0	2

The three provinces with the highest number of COVID-19 total cases as of September 30, 2020, are Jakarta with a total of 73,736 cases (25.7%), East Java with a total of 43,744 cases (15.2%), and Central Java with a total of 22,435 cases (7.8%). Gugus Tugas Percepatan Penanganan COVID-19 has also shown the zones of each city/district in each province. Referring to Detiknews (2020), there are 15 public health indicators used by the government to determine corona zoning consisting of 11 epidemiological indicators, two public health surveillance indicators, and two health services. Data up to September 30, 2020, shows that the three provinces that previously occupied as the top three highest number of COVID-19 total cases also have some red zone or high-risk provinces. Jakarta has four cities/regencies with red zone status out of a total of six cities/regencies, East Java has four cities/districts with red

zone status out of a total of 38 cities/regencies, and Central Java was having five cities/regencies with red zone status out of a total of 35 cities/regencies. Gugus Tugas Percepatan Penanganan COVID-19 has also shown a graph of the increase in COVID-19 cases. The three provinces with the highest average number of new cases up to September 30, 2020, are occupied by Jakarta with an average of 342 people per day, East Java with an average of 222 people per day, West Java with 104 people per day.

The scoring process is done to see the order of risk for COVID-19 cases in Indonesia. The scoring is carried out in three categories: based on the total cases, whether or not there is a high-risk zone, and the increase in transmission cases. The range of values given based on total cases and increment of cases is 1 to 34, while the risk zone is 33 to 34. Table 2 shows the scoring that has been done to see the province priority to receive the COVID-19 vaccine.

Table 2. Scoring for COVID-19 cases in the provinces of Indonesia

Province	Score			Total Score
	Total case	High risk	New cases	
Jakarta	34	34	34	102.00
East Java	33	34	33	100.00
Central Java	32	34	32	98.00
West Java	31	34	31	96.00
South Sulawesi	30	34	30	94.00
South Kalimantan	29	34	29	92.00
North Sumatra	28	34	28	90.00
Bali	27	34	27	88.00
East Kalimantan	26	34	26	86.00
Riau	25	34	25	84.00
Papua	24	34	23	81.00
West Sumatera	23	34	24	81.00
South Sumatera	22	33	22	77.00
Banten	21	34	21	76.00
Aceh	20	34	19	73.00
North Sulawesi	19	33	20	72.00
Central Kalimantan	18	33	18	69.00
West Nusa Tenggara	17	33	17	67.00
Gorontalo	14	34	16	64.00
Southeast Sulawesi	16	34	14	64.00
Maluku	15	34	15	64.00
Special Region of Yogyakarta	13	33	13	59.00
Riau Islands	12	33	12	57.00
West Papua	11	34	11	56.00
North Maluku	10	33	10	53.00
West Kalimantan	9	33	9	51.00
Lampung	8	33	8	49.00
West Sulawesi	7	33	7	47.00
Bengkulu	6	34	6	46.00
North Kalimantan	5	33	5	43.00
Jambi	4	33	4	41.00
East Nusa Tenggara	3	33	3	39.00
Central Sulawesi	2	33	2	37.00
Bangka Belitung Islands	1	33	1	35.00

Referring to Bisnis.com (2020), Chairperson of the Asosiasi Rantai Pendingin Indonesia (ARPI) Hasanuddin Yasin said that all provinces in Java and Bali have qualified cooling chain facilities. Apart from that, there are also North Sumatra, South Sumatra, Lampung, Riau, South Kalimantan, East Kalimantan, South Sulawesi, Southeast Sulawesi, Central Sulawesi and West Nusa Tenggara. Jakarta has the highest total cases, high-risk zone, and average of new cases with cold chain facilities. Meanwhile, Papua has the highest total cases, high-risk zone, and average of new cases with no adequate cold chain facilities. The selected provinces to be discussed in this research are Jakarta and Papua.

5.2 Supplier, Hub, and Spoke Location Mapping

The location mapping was done by plotting the coordinate point of all suppliers, hubs, and spokes into Google My Maps. Cold storage warehouse data in Jakarta and Papua is taken from the official website of the Asosiasi Rantai Pendingin Indonesia (ARPI) (2020) and the Badan Pengawas Obat dan Makanan (BPOM) (2020). Health unit data such as hospitals and public health centers in DKI Jakarta and Papua are also searched. This data is obtained from the official website of Satgas Penanganan COVID-19 (2020), while the health centers in Jakarta and Papua are obtained from files published by the Ministry of Health. The selected health centers are only those considered active by the Ministry of Health through the published files. The supplier for the distribution of the COVID-19 vaccine is PT Bio Farma. Figure 1 shows the map of the supplier, hubs, and spokes location for Jakarta. Jakarta has 326 health units (spoke) that are served by six hubs. Figure 2 shows the map of the supplier, hub, and spoke location for Papua. Papua has 264 health units that are served by nine hubs. There is one dock involved in this research, while the airports involved are ten airports.

Figure 1. Map of supplier, hub, and spoke location for Jakarta

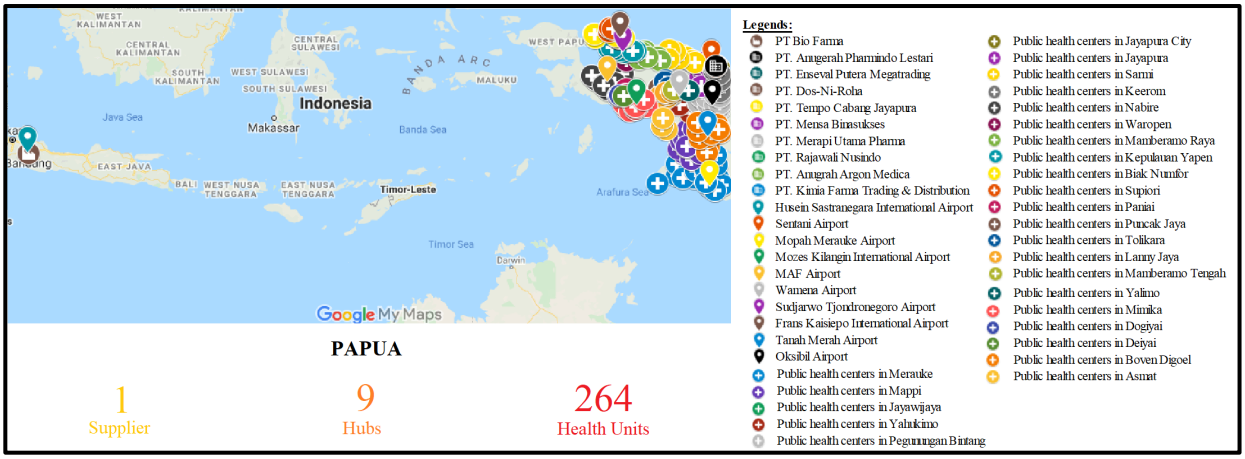

Figure 2. Map of supplier, hub, and spoke location for Papua

The proposed plans for the distribution in Jakarta and Papua are different. Every hub in Jakarta is assigned to serve one city/regency. Meanwhile, every hub in Papua is assigned to serve several cities/regencies with the reference of the airport. One hub gets one airport and serves several cities/regencies around the airport. The proposed plan is that when the vaccines arrive at Sentani Airport, all hubs take the amount of vaccine according to their share, then bring the vaccine back to the cold storage of each hub for further processing before distribution. A few days before the distribution process took place, the required number of trucks left for the city/regency where the airport assigned to them is located. The truck takes the vaccine from the airport when the vaccine has arrived and can be distributed directly to all health units in the city/district served by each hub. However, this does not apply to PT Enseval Putera Megatrading, which serves cities/regencies around Sentani Airport so that the distribution can be made directly from

their cold storage. Several cities/districts with a small population or health units are combined with other cities/districts that are also have a similar condition.

5.3 Cold Chain Process

Cold Supply Chain consists of three distribution points starting from the supplier (Sr), hub (H) and spoke (Sp). Each distribution point has its activities. In general, there are four activities that need to be carried out, namely production, receiving, storage, and delivery. These activities are regulated in the Badan Pengawas Obat dan Makanan Regulation Number 6 of 2020. Table 3 shows the activities that need to be carried out at each distribution point.

Table 3. Cold chain process

Distribution Points			Activity	Details
Sr	H	Sp		
√			Production	COVID-19 vaccine supplier qualification for materials owned and distribution facilities in accordance with statutory regulations and license ownership and applying the principles and guidelines of CDOB.
√	√	√	Receiving	Ensure that the shipment comes from an approved party. Check the specifications, quality and accuracy of the COVID-19 vaccine. Take note of the batch number and expiration date. Record the number of vaccines that have been received.
√	√	√	Storage	Clean the vaccine once received. Storing vaccines for a while has been cleaned in compliance with statutory regulations and according to the vaccine category. Control stock rotation according to First Expired First Out (FEFO) rules. Check and control the temperature of the storage warehouse and the quality of vaccines periodically according to recommendations from the producer.
√	√		Delivery	Pack in the appropriate packaging to maintain the condition and quality of the vaccine. Ensure that the recipient is the rightful or authorized party. Include the identity document for the vaccine that is sent. Check and monitor all documents and shipping activities. Make deliveries directly to the address listed and must be received by the person in charge of the facility.
All activities must be documented.				
Legends (Sr = Supplier; H = Hub; Sp = Spoke)				

Production activity is only carried out at the supplier distribution point because the supplier is the one who produces the vaccine, while the other distribution points are the liaison and the destination party. Receiving activities are carried out by suppliers, hubs, and spoke. These three points are involved in receiving activities when receiving vaccines from previous parties. PT Bio Farma (supplier) will also receive some vaccines from another country, so the supplier will also do the receiving activity. Once the vaccines are ready to be distributed, the supplier delivers the vaccine to every hub in the provinces, and then the hub will receive the vaccines from the supplier. The final delivery is the delivery from the hub to all spokes that have been assigned. Storage activities are carried out by supplier, hub, and spoke. Based on the detailed activity, the cold storage temperature must be monitored to maintain the quality of the vaccine. Cold chain facilities such as freezers, thermometers, trained workers, and other facilities are needed to maintain the vaccine quality.

5.4 Distribution Alternatives

This research plans two distribution alternatives. The first alternative is planned to maximize the trucks' capacity, which is 10 tons or the equivalent of 10,000,000 grams. The second alternative is planned by shortening the delivery time to approximately 12 hours for each truck. Table 4 shows the truck needed to distribute the COVID-19 vaccine from the supplier, PT Bio Farma, to all hubs in Jakarta, assuming that the number of vaccines needed at each stage is the same. This table is also used for the distribution from the hub to the spoke. Delivery to East Jakarta that needs three trucks is the most number of trucks needed per stage. The mileage and time traveled by the delivery truck from PT Bio Farma to all hubs in Jakarta can be seen in Table 5.

Table 4. Truck needed for the distribution to Jakarta

City / Regency	Total population	Vaccine weight (grams)	Vaccine total weight (grams)	Truck capacity (grams)	Stages	Truck needed per stage
South Jakarta	2,264,699	19	86,058,562	10,000,000	5	2
Central Jakarta	928,109	19	35,268,142	10,000,000	5	1
West Jakarta	2,589,933	19	98,417,454	10,000,000	5	2
East Jakarta	2,937,859	19	111,638,642	10,000,000	5	3
Kepulauan Seribu	24,295	19	923,210	10,000,000	5	1
North Jakarta	1,812,915	19	68,890,770	10,000,000	5	2

Table 5. Mileage and travel time for the distribution to Jakarta

From	To	Mileage (km)	Travel time (hours)
PT Bio Farma	PT Prima Prospek Indonesia	153	5.1
PT Bio Farma	PT Halal Logistic Multi Terminal	150	5
PT Bio Farma	PT Citra Bhakti Sejahtera	140	4.7
PT Bio Farma	PT Lima Satria Pratama	154	5.1
PT Bio Farma	PT Kimia Farma	141	4.7
PT Bio Farma	PT Indomaguro Tunas Unggul	161	5.4

The COVID-19 vaccine distribution to Papua is planned to be done by using a cargo plane. Table 6 shows the cargo plane needed for the distribution, while the mileage and time traveled for the distribution to Papua can be seen in Table 7.

Table 6. Plane needed for the distribution to Papua

Province	Vaccine total weight (grams)	Container weight (grams)	Transportation capacity (grams)	Stages	Plane needed per stage
Papua	128,413,476	1,323,000	18,000,000	5	2

Table 7. Mileage and travel time for the distribution to Papua

From	To	Mileage (km)	Time travel (hours)
PT Bio Farma	Husein Sastranegara Int. Airport	3.2	0.1
Husein Sastranegara Int. Airport	Sentani Airport	4,200	14
Total		4,203.2	14.1

The use of cargo planes is not only applied for the distribution from PT Bio Farma to Papua but also applied for the distribution from Sentani Airport at Jayapura City to another airport in Papua. Table 8 shows the number of cargo planes needed to distribute the vaccine, while Table 9 shows the mileage and travel time to distribute the vaccine from Sentani Airport to each airport. Once the vaccine arrived at every airport listed in Table 8, the truck of the corresponding hub will pick the vaccine and distribute it to the health units. Table 10 shows the truck needed for the distribution in Papua.

Table 8. Plane needed for the distribution to each airport

Airports	Provinces served	Vaccine total weight (grams)	Plane capacity (grams)	Stage	Plane needed per stage
MAF	Nabire, Waropen + Mamberamo Raya, Dogiyai + Paniai + Deiyai	21,067,922	18,000,000	5	1
Sentani	Jayapura, Sarmi, Kota Jayapura	17,955,342	18,000,000	5	1
Sudjarwo Tjondronegoro	Kepulauan Yapen	3,845,752	18,000,000	5	1
Frans Kaisiepo International	Biak Numfor, Supiori	6,578,218	18,000,000	5	1

Mozes Kilangin International	Mimika	8,348,182	18,000,000	5	1
Mopah Merauke	Merauke	8,641,618	18,000,000	5	1
Wamena	Jayawijaya + Mamberamo Tengah, Yahukimo + Yalimo, Tolikara, Lanny Jaya + Puncak Jaya	36,745,468	18,000,000	5	1
Oksibil	Pegunungan Bintang, Keerom	5,049,744	18,000,000	5	1
Tanah Merah	Boven Digoel, Mappi, Asmat	10,259,734	18,000,000	5	1

Table 9. Mileage and travel time for the distribution to each airport

From	To	Mileage (km)	Travel time (hours)
Sentani Airport	Mopah Merauke Airport	350	1.2
Sentani Airport	Mozes Kilangin International Airport	300	1.0
Sentani Airport	MAF Airport	450	1.5
Sentani Airport	Wamena Airport	150	0.5
Sentani Airport	Sudjarwo Tjondronegoro Airport	400	1.3
Sentani Airport	Frans Kaisiepo International Airport	350	1.2
Sentani Airport	Tanah Merah Airport	300	1.0
Sentani Airport	Oksibil Airport	225	0.8

Table 10. Truck needed for the distribution to Jakarta

City / Regency	Total population	Vaccine weight (grams)	Vaccine total weight (grams)	Truck capacity (grams)	Stages	Truck needed per stage
Jayawijaya + Mamberamo Tengah	266,088	19	10,111,344	10,000,000	5	1
Jayapura	131,802	19	5,008,476	10,000,000	5	1
Dogiyai + Paniai + Deiyai	348,511	19	13,243,418	10,000,000	5	1
Kota Jayapura	300,192	19	11,407,296	10,000,000	5	1
Yahukimo + Yalimo	253,492	19	9,632,696	10,000,000	5	1
Mappi	103,292	19	3,925,096	10,000,000	5	1
Nabire	150,308	19	5,711,704	10,000,000	5	1
Mimika	219,689	19	8,348,182	10,000,000	5	1
Boven Digoel	69,211	19	2,630,018	10,000,000	5	1
Merauke	227,411	19	8,641,618	10,000,000	5	1
Kepulauan Yapen	101,204	19	3,845,752	10,000,000	5	1
Tolikara	139,111	19	5,286,218	10,000,000	5	1
Waropen + Mamberamo Raya	55,600	19	2,112,800	10,000,000	5	1
Biak Numfor + Supiori	173,111	19	6,578,218	10,000,000	5	1
Sarmi	40,515	19	1,539,570	10,000,000	5	1
Keerom	57,100	19	2,169,800	10,000,000	5	1
Pegunungan Bintang	75,788	19	2,879,944	10,000,000	5	1
Asmat	97,490	19	3,704,620	10,000,000	5	1
Lanny Jaya + Puncak Jaya	308,295	19	11,715,210	10,000,000	5	1

Alternative 1

The number of trucks needed for this alternative is using the data from Table 4 and Table 10. Table 11 shows the calculation example for the distribution route in Jakarta using Microsoft Office Excel solver tool. This channel is a distribution channel carried out after the vaccine is received at PT Citra Bhakti Sejahtera from PT Bio Farma. This distribution will also be carried out after the process at the hub has been completed. This example is taken from the distribution channel traversed by the PT. Citra Bhakti Sejahtera's truck 1 headed to the health units in South Jakarta with the assumption that the number of vaccines needed for all health units is the same.

Table 11. South Jakarta truck 1 distribution route calculation

Truck 1	1	2	3	…	41	42	43	44
1	106.9892092	106.8965656	106.8977554	…	0.081486391	0.043513578	0.094989392	0.035104601
2	106.9273978	106.8347494	106.8359454	…	0.126883685	0.108083258	0.139454711	0.106266525
3	106.9339605	106.8413133	106.8425078	…	0.11650843	0.100861166	0.128614019	0.100055499
…	…	…	…	…	…	…	…	…
41	0.081486391	0.126883685	0.11650843	…	0	0.038307533	0.014133859	0.047161163
42	0.043513578	0.108083258	0.100861166	…	0.038307533	0	0.051531991	0.008904125
43	0.094989392	0.139454711	0.128614019	…	0.014133859	0.051531991	0	0.060234827
44	0.035104601	0.106266525	0.100055499	…	0.047161163	0.008904125	0.060234827	0

Route	1	33	34	…	39	37	40	35

Mileage (km): 121
Travel time (hours): 26.03

Table 12 shows an example of the calculation for the distribution route in Papua using the Microsoft Office Excel solver tool. The distribution process in Papua begins with receiving vaccines at Sentani Airport by PT Anugrah Argon Medica from Husein Sastranegara International Airport by PT Bio Farma. PT Anugrah Argon Medica then brought the vaccine to its cold storage. A few days before the distribution, PT Anugrah Argon Medica sent several trucks as needed to Oksibil Airport. Distribution begins with PT Anugrah Argon Medica delivering vaccines from Sentani Airport to Oksibil Airport. This route is a distribution route carried out after the vaccine is received at Oksibil Airport from Sentani Airport. This distribution will also be carried out after the process at the hub has been completed. This example is taken from the distribution channel traversed by trucks going to the health units in Pegunungan Bintang with the assumption that the number of vaccines needed for all health units is the same.

Table 12. Pegunungan Bintang truck distribution route calculation

	1	2	3	…	27	28	29	30
1	0	0.618041436	0.526381965	…	0.189149909	0.404119932	0.596319806	0.60889035
2	0.618041436	0	0.332843619	…	0.696446387	0.748331364	1.160915709	1.083187354
3	0.526381965	0.332843619	0	…	0.681053407	0.824583454	1.122599502	1.11171475
…	…	…	…	…	…	…	…	…
27	0.189149909	0.696446387	0.681053407	…	0	0.226819833	0.465211488	0.431902599
28	0.404119932	0.748331364	0.824583454	…	0.226819833	0	0.486685693	0.343530263
29	0.596319806	1.160915709	1.122599502	…	0.465211488	0.486685693	0	0.229245469
30	0.60889035	1.083187354	1.11171475	…	0.431902599	0.343530263	0.229245469	0

Route	1	17	19	…	25	23	22	24

Mileage (km): 608.54
Travel time (hours): 35.78

Alternative 2

This alternative is planned by specifying that each truck distributes the vaccine for approximately 12 hours. All routes in alternative 1 that have met this criterion have the same path, mileage, and travel time. Lines that already have less than or equal to 12 hours of travel time are the Thousand Islands, North Jakarta 2 trucks, Dogiyai-Paniai-Deiyai, Yahukimo-Yalimo, and Jayapura City. Table 13 shows an example of the calculation for the distribution route in DKI Jakarta using the Microsoft Office Excel solver tool. This channel is a distribution channel carried out after the vaccine is received at PT Kimia Farma (Persero), Tbk from PT Bio Farma. This distribution will also be carried out after the process at the hub has been completed. This example is taken from the distribution channel that PT Kimia Farma (Persero), Tbk passes to the health units in East Jakarta with the assumption that the number of vaccines needed for all health units is the same.

Table 14 shows an example of the calculation for the distribution route in Papua using the Microsoft Office Excel solver tool. The distribution process in Papua begins with receiving the vaccine at Sentani Airport by PT Enseval Putera Megatrading from Husein Sastranegara International Airport by PT Bio Farma. PT Enseval Putera Megatrading then brought the vaccines to its cold storage. This distribution is carried out after the process at the hub has been completed. This example is taken from the distribution channel that is traversed by trucks going to the health unit in Sarmi.

Table 13. East Jakarta truck 5 distribution route calculation

Truck 5	1	2	3	…	17	18	19	20
1	0	0.12148644	0.10192566	…	0.14992406	0.1053885	0.15726217	0.14931781
2	0.12148644	0	0.02727974	…	0.07531889	0.05511729	0.08488045	0.08279345
3	0.10192566	0.02727974	0	…	0.06460526	0.03107808	0.0742239	0.06960838
…	…	…	…	…	…	…	…	…
17	0.14992406	0.07531889	0.06460526	…	0	0.04502213	0.00973097	0.00968871
18	0.1053885	0.05511729	0.03107808	…	0.04502213	0	0.0532698	0.04632008
19	0.15726217	0.08488045	0.0742239	…	0.00973097	0.0532698	0	0.008692
20	0.14931781	0.08279345	0.06960838	…	0.00968871	0.04632008	0.008692	0
Route	1	8	3	…	19	20	16	17
Mileage (km):	58							
Time travel (hours):	11.9							

The delivery time shortening in alternative 2 is increasing the truck needed for the distribution. The truck needed for the distribution is increased because of the time limitation, while the hub still needs to distribute the vaccine with the same number of spoke. Figure 3 shows the additional number of trucks needed for the distribution in alternative 2.

Table 14. Sarmi truck 2 distribution route calculation

Truck 2	1	2	3	4
1	0	2.09672	2.35806	2.54597
2	2.09672	0	0.263	0.50043
3	2.35806	0.263	0	0.27536
4	2.54597	0.50043	0.27536	0
Route	1	2	3	4
Mileage (km):	315			
Time travel (hours):	12.50			

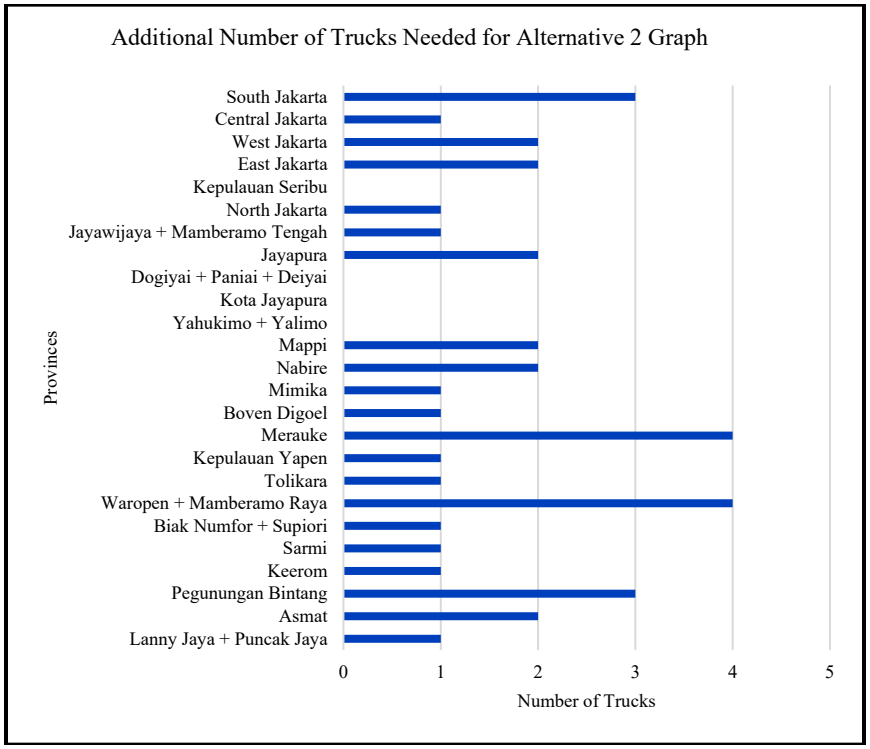

Figure 3. Additional number of trucks needed for alternative 2

6. Conclusion

This research presents the province's priority to receive the COVID-19 vaccine, the supplier, hubs, and spokes location map, cold chain activities that need to be carried out, and distribution alternatives. The results show that Jakarta, East Java, Central Java, West Java, South Sulawesi, South Kalimantan, North Sumatra, Bali, East Kalimantan, and Riau are the ten highest provinces that need to be prioritized in vaccine distribution based on the total cases, risk zone, and the average number of new cases per day. However, this province's priority may have a slight difference with today's condition as this research is only used the data up to September 30, 2020. The results and discussion of the cold chain process in this study indicate that PT Bio Farma carries out the production activities as a supplier. Receiving and storage activities are carried out by PT Bio Farma, all hubs in Jakarta and Papua, as well as all spoke which are health units in Jakarta and Papua. Delivery activities are carried out by PT Bio Farma and all hubs in Jakarta and Papua. The results of the first alternative show that the longest travel time for Jakarta is 26.03 hours with a mileage of 121 km, and Papua for 35.78 hours with a mileage of 608 km. The travel time and mileage obtained in this research are high due to the maximum capacity objective function. The maximum capacity function will use a few trucks but will traverse a high mileage and travel time. Meanwhile, the process can traverse an appropriate travel time and mileage but will need additional transportation to distribute the vaccine. The results of the second distribution alternative show that the longest travel time for Jakarta is 11.9 hours with a distance of 58 km, and Papua for 12.5 hours with a distance of 315 km. The highest additional truck needed for the second alternative is four trucks that occurred for Merauke and the combination of Waropen and Mamberamo Raya.

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