A Case Study of Project Management of COVID-19 Vaccination in Japan

by

Eishi Majima

Bachelor of Engineering in Applied Physics
The University of Tokyo, 2015

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Authored by: Eishi Majima
System Design and Management Program
May 12, 2023

Certified by: Bryan R. Moser, Ph.D.
Academic Director, Senior Lecturer, System Design and Management Program
Thesis Supervisor

Accepted by: Joan Rubin
Executive Director, System Design and Management Program

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ABSTRACT

COVID-19 vaccination played a critical role in preventing the spread of the disease in the global pandemic. Research on operational mechanisms of COVID-19 vaccination projects is limited compared with the epidemiologic and socio-economic studies. Japan is a unique country with various operational information on COVID-19 vaccinations publicly available. This research evaluated vaccination trends in 49 countries and developed the model of vaccination trends in Japan to understand the operational mechanisms of national-scale projects. The international comparison revealed Japan's slow vaccine authorizations and yet the 13th earliest and 3rd fastest to achieve the achievement of 70% full vaccination coverage. Globally comparing the daily vaccination trends exhibited a slow pace in Japan's first 80 days of the vaccination project. The study found the different levels of ceiling effects of vaccine distributions on daily first-dose vaccinations by vaccine category in Japan. Based on the observations, the research developed a system dynamics model on vaccination trends with four operational factors: willing people to take vaccines, daily vaccine deliveries, vaccine stocks on sites, and human resource capacities. The model fit the actual 7-day smoothed daily vaccination trends with the R-squared of 0.943, 0.909, and 0.915 for the total, first, and second doses with Pfizer/BioNTech and Takeda/Moderna vaccines in the primary series in Japan. The simulation predicted cumulative vaccination trends with 70% coverage achievement period errors (percentage errors) of 10 days (4.24%), 12 days (5.41%), and 8 days (3.23%) for the total, first, and second doses, respectively. The developed model was applied to explore room for operational improvement in Japan for resource-saving and acceleration purposes. The experiment demonstrated the potential savings of over 20 thousand healthcare worker recruitments without vaccination delay due to vaccine supply constraints and by a modified team structure in sites with the higher nurse–doctor ratio of 3 or more. For acceleration purposes, the model estimated limited opportunities with human resource management under the vaccine supply constraints, only shortening the 70% full vaccination coverage period by 3 days. This research provides performance metrics and a simulation tool for model-based project planning and management applicable to future pandemics and public emergency responses by practitioners.

Thesis supervisor: Bryan R. Moser, Ph.D
Title: Academic Director, Senior Lecturer, System Design and Management Program

DISCLAIMERS

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Table of Contents

List of Figures

List of Tables

1. Introduction

The coronavirus disease was first detected in China in December 2019 [1] and caused 765 million cases and seven million deaths globally [2]. Various COVID-19 vaccines have been rapidly developed [3], and 13.3 billion doses have been administered in the world as of April 30, 2023 [2]. The chief of the World Health Organization announced an end to the public health emergency with COVID-19 on May 5, 2023, based on the downward trend of the pandemic with immunity increasing due to vaccines [2]. Vaccinations were critical in the fight against the COVID-19 pandemic with non-pharmaceutical interventions.

While vaccine effectiveness and epidemiologic impacts are globally studied, research on the operational mechanisms and quantitative performance evaluations of COVID-19 vaccination trends is limited. COVID-19 vaccination projects are operated by countries worldwide on a national and global scale. International comparisons and analyses on the operations of COVID-19 vaccinations can be the historical knowledge of humankind and beneficial for project managers and other practitioners.

Among the countries, Japan is a good reference for analyses because its government has released datasets of daily vaccination trends and operational information, including weekly vaccine distributions, to the public. However, the quantitative analyses of the vaccination project mechanisms are limited in Japan.

This research implements an international comparison of vaccination coverage and speed among 49 countries and develops a simulation model of the vaccination trends in Japan to understand the operational mechanisms of the national-scale project. Operational options will be explored with findings and the developed model to discuss project improvement in Japan.

Chapter 2 reviews previous research and follow-ups on the vaccination project in Japan and other countries. Chapter 3 compares the vaccination coverage, vaccine authorization dates, achievement dates of target coverages, vaccination speed, and daily vaccination trends in reference countries with Japan. The chapter also explores Japan's vaccination trends with its vaccine distribution trends and previous survey reports on vaccine hesitancy. Chapter 4 defines research questions and approaches. Chapter 5 introduces the assumptions and architecture of the vaccination trend model in Japan. Chapter 6 validates the model performance with actual vaccination trends. Chapter 7 explores room for operational improvement in Japan through the model simulation. Chapter 8 lists the research limitations and future topics. Chapter 9 concludes the overall research.

2. Previous Research on Vaccination Projects

This chapter explores previous research on the social impacts, public perceptions, self-evaluations, and socio-economic simulations of the national COVID-19 vaccination project in Japan, especially for the primary series from Chapters 2.1 to 2.4, respectively. Some examples of international comparisons and case studies of COVID-19 vaccinations are referred to in Chapter 2.5. Based on the reviews of previous research, the focus of this research is identified in the quantitative evaluations and simulations of vaccination logistics in Chapter 2.6.

2.1. Social Impacts of Vaccination Project in Japan

A report with real-world data reveals that the COVID-19 vaccination is estimated to be attributed to the aversions of 564,596 (95% confidence interval: 477,020–657,525) infectious cases and 18,622 (95% confidence interval: 6,522–33,762) deaths from March to November 2021, which are 33% and 67% reductions in total cases [4]. Another report with real-world datasets in Japan estimate that vaccine effectiveness against infection and symptomatic infection 14 days after the second dose were 83.8% (95% Confidence Interval: 75.3%–89.3%) and 89.8% (95% Confidence Interval: 80.5%–94.7%) during July 1 to December 31, 2021 [5].

Regarding side effects of vaccines, researchers in the Ministry of Health, Labour and Welfare (MHLW) and related institutes report the individual case safety reports of anaphylaxis: 4 and 1.6 cases per 1 million administrations on average with Pfizer–BioNTech's BNT162b2 and Moderna/Takeda's mRNA-1273 vaccines as of November 14, 2021 [6]. The case reports for myocarditis/pericarditis were 1.7 and 6.1 cases per 1 million vaccinations on average with those vaccines [6].

2.2. Public Perceptions on Project Operations in Japan

The citizens' perceptions of the COVID-19 vaccination project in Japan were two folds: negative opinions on the slow rollout before June 2021 and positive evaluations of catch-up after June.

Niu et al. found through their analyses of Japanese tweets between August 2020 and June 2021 that some of the major negative tweet topics were dissatisfaction with the slow vaccination process and the limited reservation capacity in the early phase of the project [7]. Another research by Kobayashi et al. on Japanese tweets correspondingly reported that booking was one of the popular topics in May 2021 [8]. Kosaka et al. pointed out the three factors of the delayed vaccine rollout: the lagged regulatory approval, vaccine procurement from foreign countries, and the limited human resources of doctors and nurses eligible to administer vaccine doses [9]. Looi shed light on the historical caution over foreign-made vaccines and the expensive administration costs with the limited human resources with regulations [10].

Liff summarized in 2022 that the Japanese government implemented countermeasures to the problems by late spring, surpassed all other G7 countries about the daily vaccination pace, and reached 75% coverage of the fully vaccinated population in 2021 [11].

2.3. Self-Evaluations and Improvement Efforts in the Government of Japan

In November 2021, the Headquarters for the Promotion of Administrative Reform Cabinet Secretariat, the Government of Japan (HPAR), held a public conference to review the COVID-19 vaccination project. HPAR and their experts valued the rapid achievement of vaccination coverage [12]; 78% of the population have received one or more doses as of November 2, 2021 [13]. At the same time, they proposed the following room for improvement in their summary comments: streamlined collaborations among the local and central governments with digital technologies, better public relationships with citizens, and installing KPI management for emergency vaccine rollouts [12].

Regarding the slow authorization process, the Japanese Cabinet submitted the Act on Pharmaceuticals and Medical Devices amendment bill to install an emergency use authorization (EUA) scheme [14]. Compared with foreign countries, the absence of the EUA scheme was attributed to the cause of delays [15]. The bill was passed in the Diet and partially enacted on May 20, 2022 [16].

In November 2022, the Ministry of Finance, the Government of Japan reported that the total expense for the COVID-19 vaccination in Fiscal Year 2021 was 2.3 Trillion Yen [17]. Compared with Influenzas and other vaccine operations, the COVID-19 vaccination project cost 50% to 90% additional expenses on the rollout logistics. The ministry also revealed room for improvement in vaccine procurement, where only 52% of procured vaccines were administered by September 2022.

In March 2023, The Board of Audit of Japan implemented an audit and reported opinions to the Diet and the Cabinet, pursuant to the provisions of Article 30-2 of the Board of Audit Act [18]. The report critically points out that:

(1) MHLW did not record the rationales for required vaccine amounts for procurement processes.
(2) MHLW did not check the payment amount from AstraZeneca on the procurement cancellation.
(3) MHLW did not continuously record the vaccine stocks.
(4) Some local governments ambiguously defined or calculated details of subsidies for vaccination operators.
(5) MHLW and Digital Agency separately developed the vaccine distribution management system (V-SYS) and record system (VRS), which caused the errors and missing information in the records.

2.4. Simulations on Vaccination Project in Japan

Academic researchers and experts have widely explored and discussed the epidemiologic impacts of vaccine coverage, vaccination pace, and prioritization strategies [19]–[24]. The governmental advisory board [25], [26] and simulation teams [27]–[33] have proposed various epidemiologic analyses and predictions with the vaccine rollout. Predictions on the economic impacts of vaccination are also implemented regarding the production losses [19], [34].

2.5. International Comparisons and Case Studies in Other Countries

The global online database “Our World in Data” of daily and cumulative vaccinations, including those in Japan, is provided by the group at the University of Oxford [35]. Vaccine coverage and association with healthcare access and quality index, socio-demographic index, and gross domestic product per capita in 192 countries are already reported [36].

Case studies of vaccine rollouts are found in Israel [37], [38], France, Germany, Sweden, Switzerland, England [39], Italy [40], Poland [41], Cambodia [42], and countries in Latin America and the Caribbean [43]. A global research group in UK and Thailand proposes a strategic road-mapping framework for disaster responses, developed based on the case study of the vaccine rollout program in the UK [44].

Modeling approaches on vaccine rollouts with epidemiological metrics are globally implemented [45], [46]. The integrated models of the vaccine rollout and non-pharmaceutical interventions are also widely recognized [47]. Simulations on the socio-economic impacts of vaccination strategies on prioritization and speed are also reported by the World Health Organization (WHO) Regional Office for Europe [48]. Detailed modeling of economic impacts with some vaccination paces and non-pharmaceutical interventions is discussed in Korea [49].

2.6. Chapter Summary

COVID-19 vaccines are considered with real-world evidence to have effectively prevented amounts of infectious cases and deaths in Japan. Though some Japanese citizens complained about the slow rollouts and limited reservation capacity by Spring in 2021, the experts in HPAR acclaimed the rapid vaccinations after July and high population coverage.

HPAR pointed out the room for improvement regarding the KPI definition and performance management. The Ministry of Finance revealed the more significant costs of the COVID-19 vaccination project compared with the other vaccine programs. The Board of Audit of Japan officially reported to the Diet and the Cabinet the need for more quantitative management of key resources for the COVID-19 vaccination project.

Academic researchers and experts in Japan have made various efforts to simulate and verify the socio-economic impacts of the vaccination project with epidemiologic datasets and models. However, the research and case studies on the quantitative performance and mechanisms of vaccination pace in Japan are limited.

Measuring comprehensive performance and understanding the mechanisms of vaccination pace are essential to extract lessons learned for better project management in future national emergency responses.

Therefore, this research focuses on the quantitative evaluations of vaccination trends and analyses of logistics mechanisms in the following chapters.

3. Review of Vaccination Project Performance

This chapter compares performance metrics on dates and speed of COVID-19 vaccinations in Japan with 48 countries. Chapter 3.1 introduces datasets for the evaluations. Chapter 3.2 reviews vaccination coverages and trends in Japan as an introduction. After defining 48 reference countries in Chapter 3.3, Chapters 3.4 to 3.6 globally compares vaccine authorization dates, achievement dates and periods of defined vaccination coverages, and average and maximum speeds, respectively. Chapter 3.7 exhibits vaccination trends in countries with the largest average–maximum speed ratios to find uniqueness in Japan. Chapter 3.8 compares daily vaccinations and vaccine distributions in Japan to discuss the potential mechanisms and bottlenecks of vaccination speed on the supply side. Chapter 3.9 reviews surveys on vaccine hesitancy and actual vaccination coverages to discuss the demand side of vaccinations.

3.1. Dataset and Data Processing Tools

This chapter quantitatively discusses the authorization date, vaccination pace, and completion date of defined vaccination coverage with publicly available datasets and evidence. The vaccination dataset was retrieved from Our World in Data (OWID) [35] on April 15, 2023, except for Japan. The data are processed with R programming language and RStudio, the integrated development environment.

The vaccination datasets of Japan are prepared with available official sources provided by the Government of Japan. Datasets on daily vaccinations from the Ministry of Health, Labour and Welfare and the Prime Minister's Office of Japan are referenced [50], [51]. The Ministry of Health, Labour and Welfare of Japan provides data collected with V-SYS platform in the time range from February 17 to April 9, 2021. This vaccination data by dose round (first or second dose) is recognized as the number with Pfizer/BioNTech vaccines because this vaccine was the only choice in that time range [52]. The Prime Minister's Office has released data collected with VRS and V-SYS platforms in the time range from April 12, 2021. The data from VRS[1] and V-SYS[2] are summed to identify all the vaccinations by dose by vaccine. This research retrieved these datasets on April 15, 2023, which covers vaccination data from February 17, 2021, to April 12, 2023.

The population, the proportion of people aged 65 and older, population density, and vaccination coverage in Japan are also prepared for the following discussions by referencing the official information on population and area by the Government of Japan [53], [54].

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[1] "初回接種_一般接種" data in "vaccination_data5" CSV file, "３回目_一般接種回数", "4 回目_一般接種回数", and "オミクロン株対応ワクチン_一般接種（５回目）" data in "allbooster_data" CSV file.

[2] "初回接種_医療従事者等" data in "vaccination_data5" CSV file.

3.2. Vaccination Coverages and Trends in Japan

This subchapter introduces the number and trend of cumulative vaccinations in Japan with the government dataset. Table 3-1 shows the number of cumulative vaccinations by dose round by vaccine as of March 31, 2023. 383 million doses of vaccines have been administered in Japan, and Pfizer/BioNTech provides the most major vaccine. Partial vaccination population coverage with only the first doses is 83.14%, and full vaccination coverage with two doses in the primary series is 82.08%. The coverage decreases as the dose round advances.

Figure 3-1 displays the vaccination trends in Japan from the earliest vaccine authorization date from February 14, 2021 [52] to March 31, 2023. Figure 3-1 (a) shows the first and second-dose vaccinations in the primary series hit ceilings in November 2021, and the ones with third doses did in June 2022. Figure 3-1 (b) shows the oscillations in two patterns: weekday (5-day) broad peaks in the first six months and Saturday peaks later. The trend with primary series also exhibits negative pulses. Corresponding calendar dates with these pulses match the national holidays on Table 3-2 except for August 12-15 and 30. The period on August 12-15 is known as a Japanese holiday season, “Obon.” Japan experienced two types of the weekday effect and the national holiday effect.

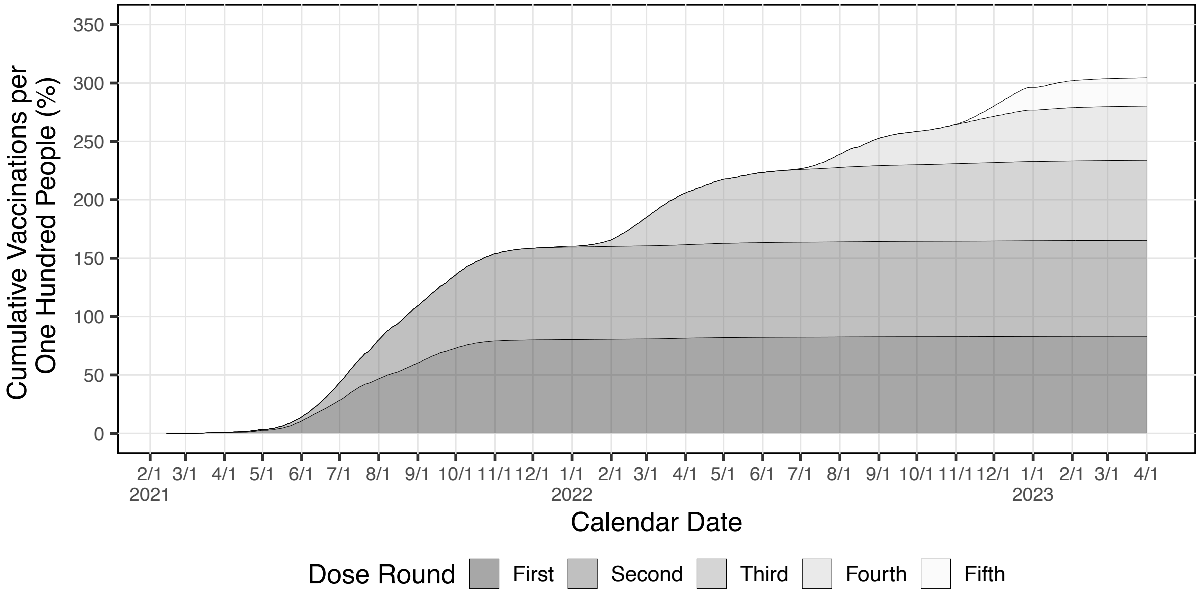
Table 3-1 Cumulative Vaccinations in Japan

The number of cumulative vaccinations by dose round by vaccine in Japan as of March 31, 2023. Columns with percentage units exhibit the cumulative numbers divided by the population in Japan.

Dose Round	All Vaccines		Pfizer/BioNTech		Takeda/Moderna		AstraZeneca		Novavax	
	(dose)	(%)	(dose)	(%)	(dose)	(%)	(dose)	(%)	(dose)	(%)
Total	383,344,007	304.42	299,547,143	237.87	83,366,408	66.20	117,885	0.09	312,571	0.25
First	104,692,928	83.14	88,165,475	70.01	16,411,822	13.03	58,703	0.05	56,928	0.05
Second	103,364,635	82.08	87,039,281	69.12	16,211,098	12.87	59,182	0.05	55,074	0.04
Third	86,392,838	68.61	52,600,929	41.77	33,608,275	26.69	-	0	183,634	0.15
Fourth	58,401,337	46.38	42,567,642	33.80	15,816,760	12.56	-	0	16,935	0.01
Fifth	30,492,269	24.21	29,173,816	23.17	1,318,453	1.05	-	0	-	0

COVID−19 Vaccination Trends in Japan

(a) Cumulative Vaccinations by Dose Round



(b) Daily Vaccinations by Vaccine

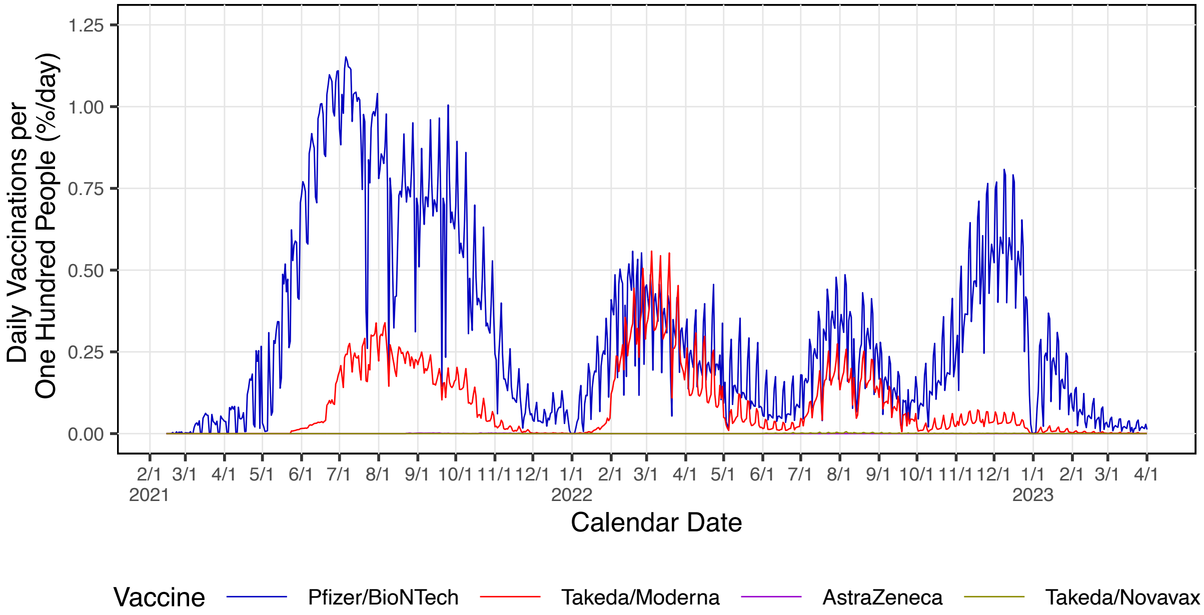


Figure 3-1 COVID-19 Vaccination Trends in Japan
(a) Trends of cumulative vaccinations per one hundred people in Japan by dose round. (b) Trends of daily vaccinations per one hundred people by vaccine.

Table 3-2 National Holidays in Japan
National holidays in Japan in 2021, 2022, and January to March 2023. The list of national holidays in Japan from the reference provided by the Government of Japan [55].

Calendar Date	National Holiday	National Holiday In Japanese	Note
1/1 every year	New Year Day	元旦	-
2021/1/11, 2022/1/10, 2023/1/9	Coming-of-Age Day	成人の日	-
2/11 every year	National Foundation Day	建国記念の日	-
2/23 every year	Emperor’s Birthday	天皇誕生日	-
2021/3/20, 2022/3/21, 2023/3/21	Spring Equinox Day	春分の日	-
4/29 every year	Showa Day	昭和の日	-
5/3 every year	Constitution Day	憲法記念日	-
5/4 every year	Greenery Day	みどりの日	-
5/5 every year	Children’s Day	こどもの日	-
2021/7/22, 2022/7/18	Anniversary-of-Ocean Day	海の日	Moved from 2021-07-19 due to the Olympics/Paralympics
2021/7/23, 2022/10/10	Sports Day	スポーツの日	Moved from 2021-10-11 due to the Olympics/Paralympics
2021/8/9, 2022/8/11	Mountain Day	山の日	Moved from 2021-08-11 to 2021-08-08 due to the Olympics/Paralympics and transferred from Sunday to Monday
2021/9/20, 2022/9/19	Respect-for-the-Aged Day	敬老の日	-
2021/9/23, 2022/9/23	Autumnal Equinox Day	秋分の日	-
11/3 every year	Culture Day	文化の日	-
11/23 every year	Labor Thanksgiving Day	勤労感謝の日	-

3.3. Reference Countries for Performance Comparison

This report compares countries selected with the following selection criteria (1)–(3) by considering WHO vaccination coverage targets, economic status, and region.

(1) Full vaccination population coverage is equal to or over 40 % by December 31, 2021
125 entities, including Japan, are extracted from the OWID's dataset.

The population target of the full vaccination population is derived from a herd immunity threshold in an objective community. The herd immunity threshold is calculated by [56]:

$$\text{Herd Immunity Threshold} = \left[1 - \frac{1}{\text{Virus Reproduction Rate}}\right] \times \frac{1}{\text{Vaccine Efficacy}}$$

Table 3-3 displays the herd immunity threshold without natural immunity after the disease recovery. The range of virus reproduction rate is set based on the meta-analysis of the basic reproduction rate by Liu et al. in early 2020: the estimated range from 1.4 to 6.49 with a mean of 3.28, a median of 2.79 and the interquartile range of 1.16 [57]. For example, the herd immunity threshold is 67%, with the virus reproduction rate of 1.5 and the vaccine efficacy of 50%. If the natural immunity after the recovery is not expected, the required vaccination population coverage equals 67% or over.

WHO has released the strategic targets of the full vaccination population coverage in October, 2021 [58]. The organization set the three targets:

- 10% full vaccination coverage in all countries by the end-September 2021
- 40% full vaccination coverage in all countries by end-2021
- 70% full vaccination coverage of the world's population by mid-2022.

40% target is set to realize the first protection for health workers, older populations, and high-risk individuals with important co-mobidities. 70% target is considered as the goal to protect people around the world from disease, maintain the health system, fully resume economic activities, restore social health, and prevent the risk of new variants.

Table 3-4 indicates the threshold of the basic reproduction rate with the WHO targets and vaccine efficacy. For example, when the average vaccine efficacy is 70%, the WHO vaccination coverage targets of 10%, 40%, and 70% could contain the disease with the basic reproduction rate of 1.08, 1.39, and 1.96. The vaccination coverage of 40% corresponds to the minimum reported value of the basic reproduction rate.

This research refers to the 40% vaccination coverage to extract the candidate reference countries for comparison from the OWID dataset. Countries where the total number of people who received all doses prescribed by the initial vaccination protocol per 100 people in the total population is equal to or over 40 by December 31, 2021, are selected for further processes.

Table 3-3 Herd Immunity Threshold
Herd immunity thresholds of the vaccination population coverage without natural immunity after disease recovery.

Virus Reproduction Rate	Vaccine Efficacy									
	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
1.0	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
1.5				83%	67%	56%	48%	42%	37%	33%
2.0					100%	83%	71%	63%	56%	50%
2.5						100%	86%	75%	67%	60%
3.0							95%	83%	74%	67%
3.5	Disease spreads.							89%	79%	71%
4.0								94%	83%	75%
4.5								97%	86%	78%
5.0								100%	89%	80%
5.5									91%	82%
6.0									93%	83%
6.5									94%	85%

Table 3-4 Threshold of Basic Reproduction Rate with WHO Vaccination Coverage Targets and Vaccine Efficacy
Thresholds of the basic reproduction rate with the WHO targets of the full vaccination population coverage and vaccine efficacy.

Vaccination Population Coverage	Vaccine Efficacy									
	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
10%	1.01	1.02	1.03	1.04	1.05	1.06	1.08	1.09	1.10	1.11
40%	1.04	1.09	1.14	1.19	1.25	1.32	1.39	1.47	1.56	1.67
70%	1.08	1.16	1.27	1.39	1.54	1.72	1.96	2.27	2.70	3.33

(2) Countries in G20, Organization for Economic Co-operation and Development (OECD), or the European Regulatory System for Medicines (ERSM)
48 entities, including Japan, are extracted from (1) cohort.

  - 18 G20 members except for South Africa and the European Union (EU) out of 20 members [59]
  - 37 OECD members except for Luxembourg out of 38 members [60]
  - 24 EU members out of 27 except for Bulgaria, Luxembourg, and Romania in addition to 3 all the EEA members, Iceland, Liechtenstein and Norway [61], [62]

(3) Singapore as an additional reference country in Asia with the (2) cohort
49 entities, including Japan, are selected in total for comparison.

Table 3-5 introduces the country list for exploration in this chapter. Figures 3-2, 3-3, 3-4, and 3-5 exhibit the relationships between full vaccination coverage and population, proportion of people aged 65 and older, population density, or Gross Domestic Product (GDP) per capita. Japan reached the 11th widest coverage of fully vaccinated people as of March 31, 2023. Japan has the 8th largest population, the largest proportion of aged people, the 8th highest population density, and the 18th highest GDP per capita in the 49 reference countries.

Table 3-5 Reference Countries for Performance Evaluation
Reference countries for the research extracted from the OWID dataset with people fully vaccinated per hundred of 40 or over as of December 31, 2021. Representations of continents, countries, and ISO country codes are based on the OWID dataset. Continents are arranged in longitudinal order from the East. Countries are placed in alphabetical order except for Japan. Values in the ERSM column indicate the membership of the countries. Each country is categorized with G20, OECD, and ERSM lists. Populations in the dataset, except for Cyprus, France, Israel, and Singapore, are referenced by OWID from the United Nations, Department of Economic and Social Affairs, Population Division, World Population Prospects 2019 Revision. OWID references populations for these four countries from official sources in each country. The years of the population are 2022, except for Cyprus, which is 2021. Proportions of people aged 65 and older are referenced by OWID from the World Bank World Development Indicators based on age/sex distributions of United Nations World Population Prospects 2017 Revision. Population densities in the dataset are referenced by OWID from the World Bank World Development Indicators, sourced from Food and Agriculture Organization and World Bank estimates. GDP per capita at purchasing power parity (constant 2011 international dollars) in the OWID dataset are referenced by OWID from the World Bank World Development Indicators, source from World Bank, International Comparison Program database. Values in the Full Vaccination Coverage column are from the maximum records of people fully vaccinated per hundred by March 31, 2023, on the OWID dataset. The population, the proportion of people aged 65 and older, population density, and full vaccination coverage in Japan are modified with the OWID dataset by referencing the official information on vaccinations, population, and area by the Government of Japan.

Continent	Country	ISO Country Code	G20	OECD	ERSM	Population (person)	Proportion of People Aged 65 and Older	Population Density (person/km^2)	GDP per Capita (dollar/person)	Full Vaccination Coverage as of Mar. 31, 2023
Asia	Japan	JPN	G20	OECD		125,927,902	28.53	333	39,002	82.08
	China	CHN	G20			1,425,887,360	10.64	148	15,309	89.54
	India	IND	G20			1,417,173,120	5.99	450	6,427	67.17
	Indonesia	IDN	G20			275,501,344	5.32	146	11,189	62.68
	Israel	ISR		OECD		9,449,000	11.73	403	33,132	65.19
	Saudi Arabia	SAU	G20			36,408,824	3.30	15	49,045	69.80
	Singapore	SGP				5,637,022	12.92	7916	85,535	90.85
	South Korea	KOR	G20	OECD		51,815,808	13.91	528	35,938	85.68
	Turkey	TUR	G20	OECD		85,341,248	8.15	105	25,129	62.31
Oceania	Australia	AUS	G20	OECD		26,177,410	15.50	3	44,649	82.72
	New Zealand	NZL		OECD		5,185,289	15.32	18	36,086	79.89
Europe	Austria	AUT		OECD	EU	8,939,617	19.20	107	45,437	74.75
	Belgium	BEL		OECD	EU	11,655,923	18.57	376	42,659	78.66
	Croatia	HRV			EU	4,030,361	19.72	74	22,670	55.86
	Cyprus	CYP			EU	896,007	13.42	128	32,415	72.11
	Czechia	CZE		OECD	EU	10,493,990	19.03	137	32,606	65.68
	Denmark	DNK		OECD	EU	5,882,259	19.68	137	46,683	80.69
	Estonia	EST		OECD	EU	1,326,064	19.45	31	29,481	64.97
	Finland	FIN		OECD	EU	5,540,745	21.23	18	40,586	78.47
	France	FRA	G20	OECD	EU	67,813,000	19.72	123	38,606	78.42
	Germany	DEU	G20	OECD	EU	83,369,840	21.45	237	45,229	76.24

	Greece	GRC		OECD	EU	10,384,972	20.40	83	24,574	73.62
	Hungary	HUN		OECD	EU	9,967,304	18.58	108	26,778	62.28
	Iceland	ISL		OECD	EEA	372,903	14.43	3	46,483	77.82
	Ireland	IRL		OECD	EU	5,023,108	13.93	70	67,335	80.86
	Italy	ITA	G20	OECD	EU	59,037,472	23.02	206	35,220	81.26
	Latvia	LVA		OECD	EU	1,850,654	19.75	31	25,064	70.57
	Liechtenstein	LIE			EEA	39,355	NA	237	NA	67.24
	Lithuania	LTU		OECD	EU	2,750,058	19.00	45	29,524	68.38
	Malta	MLT			EU	533,293	19.43	1454	36,513	88.41
	Netherlands	NLD		OECD	EU	17,564,020	18.78	509	48,473	68.08
	Norway	NOR		OECD	EEA	5,434,324	16.82	14	64,800	74.61
	Poland	POL		OECD	EU	39,857,144	16.76	124	27,216	56.82
	Portugal	PRT		OECD	EU	10,270,857	21.50	112	27,937	86.63
	Russia	RUS	G20			144,713,312	14.18	9	24,766	55.07
	Slovakia	SVK		OECD	EU	5,643,455	15.07	113	30,155	45.68
	Slovenia	SVN		OECD	EU	2,119,843	19.06	103	31,401	57.66
	Spain	ESP		OECD	EU	47,558,632	19.44	93	34,272	85.65
	Sweden	SWE		OECD	EU	10,549,349	19.98	25	46,949	71.98
	Switzerland	CHE		OECD		8,740,471	18.44	214	57,410	68.79
	United Kingdom	GBR	G20	OECD		67,508,936	18.52	273	39,753	75.19
North America	Canada	CAN	G20	OECD		38,454,328	16.98	4	44,018	82.60
	Costa Rica	CRI		OECD		5,180,836	9.47	96	15,525	83.79
	Mexico	MEX	G20	OECD		127,504,120	6.86	66	17,336	64.19
	United States	USA	G20	OECD		338,289,856	15.41	36	54,225	69.40
South America	Argentina	ARG	G20			45,510,324	11.20	16	18,934	76.61
	Brazil	BRA	G20			215,313,504	8.55	25	14,103	81.82
	Chile	CHL		OECD		19,603,736	11.09	24	22,767	90.29
	Colombia	COL		OECD		51,874,028	7.65	44	13,255	71.26

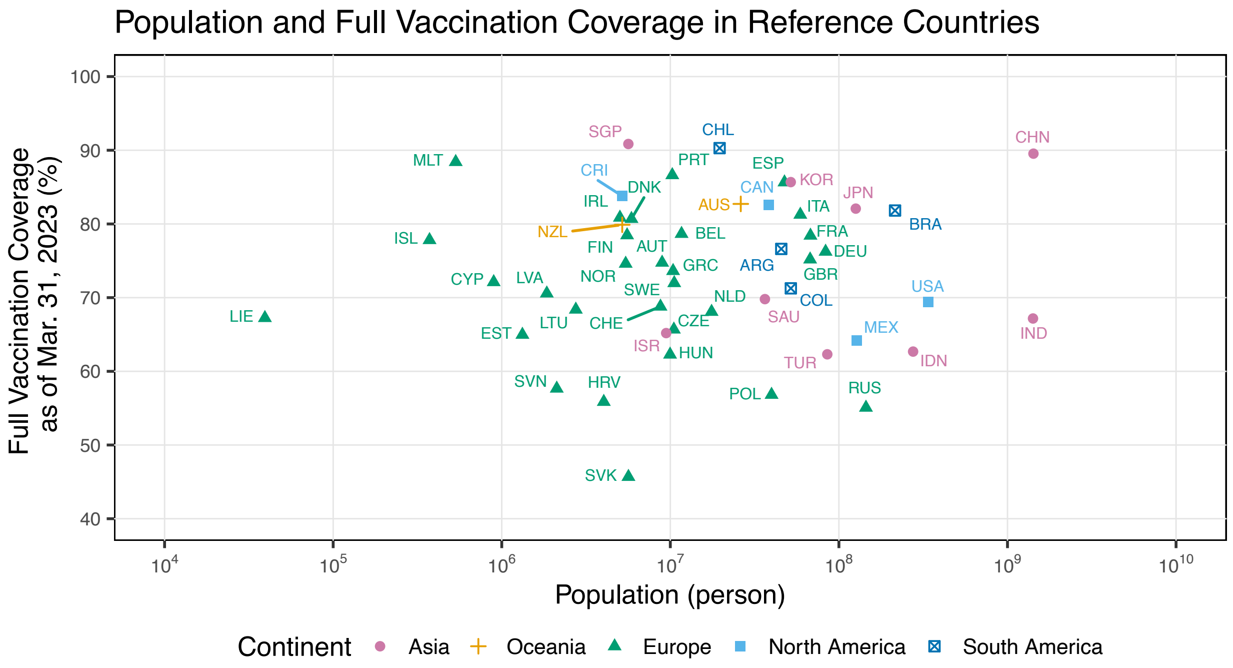


Figure 3-2 Population and Full Vaccination Coverage in Reference Countries
The scatter plot with 49 reference countries' populations and full vaccination coverages as of March 31, 2023. Labels on each plot indicate ISO country codes.

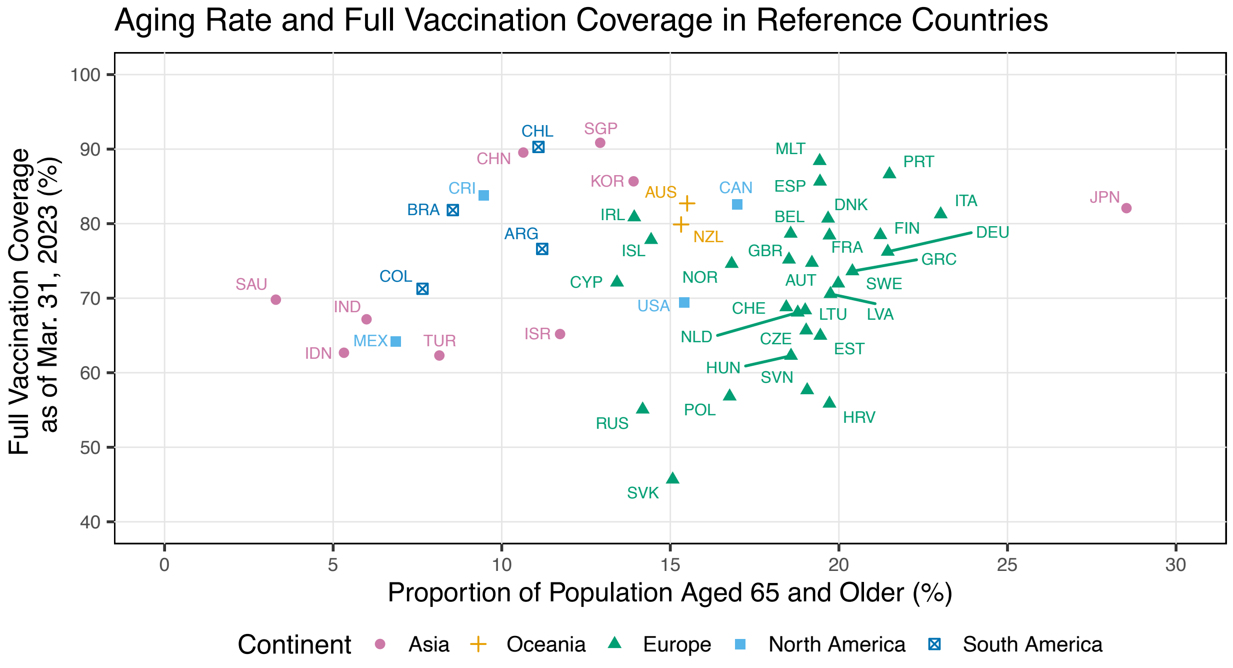


Figure 3-3 Aging Rate and Full Vaccination Coverage in Reference Countries
The scatter plot with 48 reference countries' aging rate and full vaccination coverages as of March 31, 2023. Labels on each plot indicate ISO country codes. This figure does not include Liechtenstein due to the data limitation.

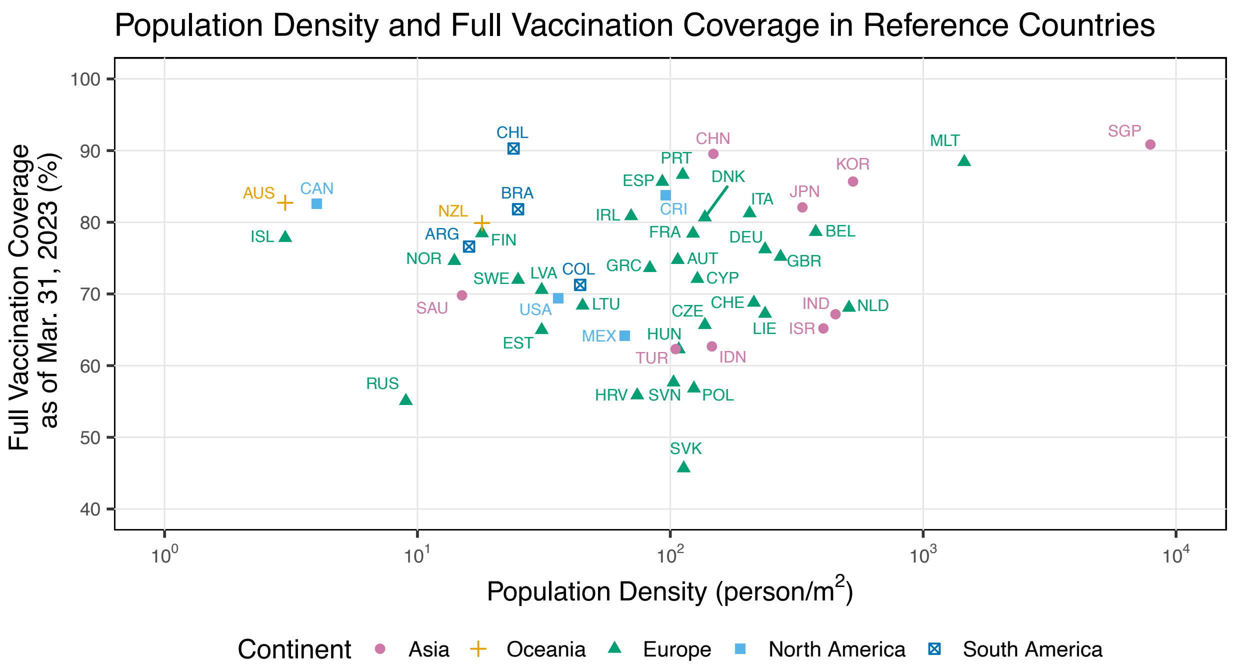


Figure 3-4 Population Density and Full Vaccination Coverage in Reference Countries
The scatter plot with 49 reference countries' population and full vaccination coverages as of March 31, 2023. Labels on each plot indicate ISO country codes.

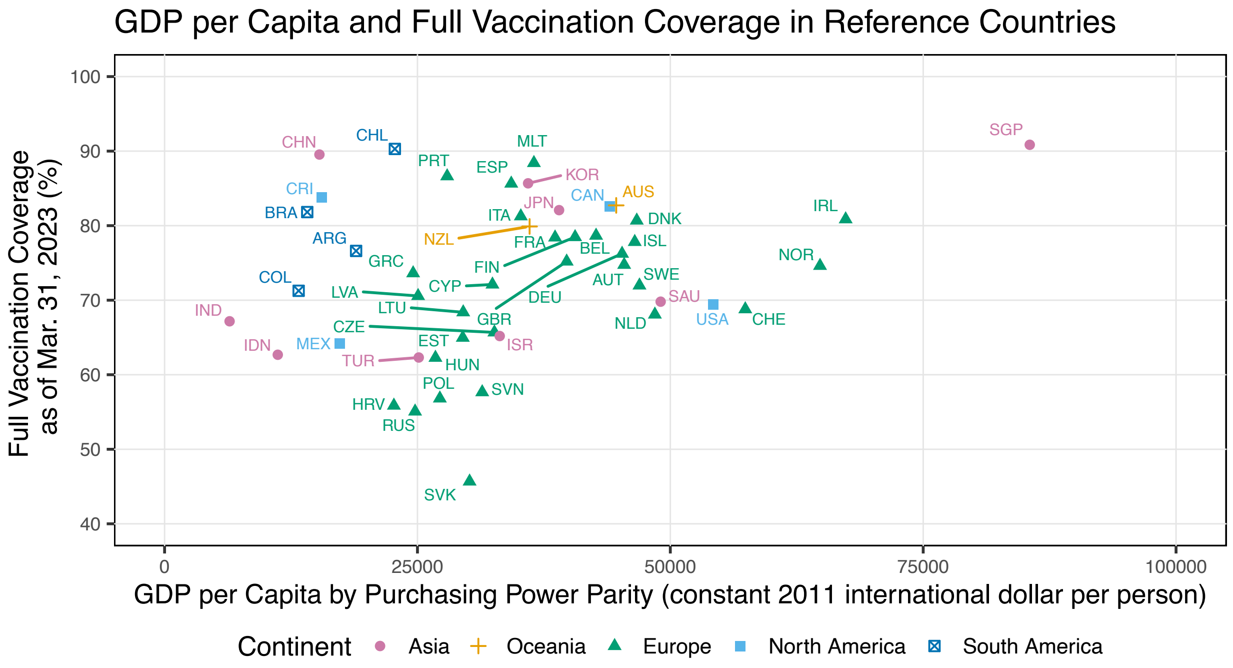


Figure 3-5 GDP per Capita and Full Vaccination Coverage in Reference Countries
The scatter plot with 48 reference countries' GDP product per and full vaccination coverages as of March 31, 2023. Labels on each plot indicate ISO country codes. This figure does not include Liechtenstein due to the data limitation.

3.4. Vaccine Authorization Dates

The authorization dates of vaccines for primary vaccination in the 49 reference countries are listed through the following processes.

(1) Reference the authorization information of COVID-19 by technical platforms and country by Chen et al. in 2022.

Chen et al. provide the country lists and use status of authorized vaccines as of February 8, 2022, in the supplementary material for the article published in BMC Medicine in 2022 [36].

(2) Explore the official information as of February 11, 2023, on the lists of authorized vaccines for primary vaccination by country.

(1) list and official sources are compared to identify the vaccine lists to search authorization dates.

(3) Search references on the authorization dates of vaccines for primary vaccination.

Regarding the countries in the European Regulatory System for Medicines, the centralized marketing authorization is valid in the EU Member States and three EEA countries, Iceland, Liechtenstein, and Norway [62]. This report identifies most of the vaccine authorization dates in the ERSM members by referencing the European Medicines Agency's official website [63].

Table 3-6 shows the characteristics of authorized vaccines by the reference countries. Table 3-7 lists the authorization dates of vaccines in the reference countries. Due to the data limitation on authorized vaccines, Liechtenstein is omitted from the reference cohort for the following discussions.

Table 3-6 Authorized Vaccines for Primary Vaccinations
The list of vaccines authorized for primary vaccination by the reference countries. This list is arranged in alphabetical order of vaccine platforms.

Vaccine Platform	Developer (Abbreviation)	Vaccine Name	No. of Doses	Schedule	References
DNA based vaccine	Zydus Cadila	nCov vaccine, Zycov-d	3	Day 0 + 28 + 56	[3]
Inactivated virus	Bharat Biotech	BBV152 vaccine COVAXIN	2	Day 0 + 14	[3]
	Beijing Institute of Biological Products, Sinopharm (Sinopharm-Beijing)	BBIBP-CorV Covilo	2	Day 0 + 21	[3], [64]
	Chumakov Federal Scientific Center for Research and Development of Immune-and-Biological Products (Chumakov Center)	CoviVac	2	Day 0 + 14	[3]
	Erciyes University and the Health Institutes of Turkey (E. Univ. and TUSEB)	TURKOVAC	2	Day 0 + 21	[3]
	Institute of Medical Biology and Chinese Academy of Medical Sciences (IMBCAMS)	SARS-CoV-2 vaccine	2	Day 0 + 28	[3], [64]
	Shenzhen Kangtai Biological Products	KCONVAC	2	Day 0 + 28	[3], [65]
	Wuhan Institute of Biological Products, Sinopharm (Sinopharm-Wuhan)	WBIP-CorV	2	Day 0 + 21	[3], [64]
	Sinovac	CoronaVac	2	Day 0 + 14	[3]
	Valneva	VLA2001	2	Day 0 + 21	[3]
Protein subunit	Anhui Zhifei Longcom Biopharmaceutical and Institute of Microbiology, Chinese Academy of Sciences (Anhui Zhifei Longcom and IMCAS)	ZF2001, Zifivax	2-3	Day 0 + 28 or Day 0 + 28 + 56	[3]
	Biological E. Limited	BECOV2, Corbevax	2	Day 0 + 28	[3]
	Novavax	NVX-CoV2373, Nuvaxovid, Covovax	2	Day 0 + 21	[3], [66]
	Serum Institute of India/Novavax	NVX-CoV2373, Covovax	2	Day 0 + 21	[3], [67]
	Takeda Pharmaceutical Company Ltd (Takeda/Novavax)	NVX-CoV2373, TAK-019	2	Day 0 + 21	[3], [68]
	PT Bio Farma (Indovac)	Indovac	2	Day 0 + 28	[3], [69]

	PT Bio Farma (Inavac)	Inavac	2	Day 0 + 28	[3], [70]
	Russian Federal Budgetary Research Institution State Research Center of Virology and Biotechnology "Vector" (Vector Center (EpiVacCorona))	EpiVacCorona	2	Day 0 + 21	[3]
	Russian Federal Budgetary Research Institution State Research Center of Virology and Biotechnology "Vector" (Vector Center (EpiVacCorona-N))	EpiVacCorona-N, AURORA-Covid-19	2	Day 0 + 14	[3]
	SK Bioscience	GBP510, SKYCovione	2	Day 0 + 28	[3], [71]
	Gennova Biopharmaceuticals Limited	GEMCOVAC-19	2	Day 0 + 28	[3]
RNA based vaccine	Moderna	mRNA-1273, Spikevax	2	Day 0 + 28	[3]
	Takeda Pharmaceutical Company Ltd (Takeda/Moderna)	mRNA-1273, TAK-919	2	Day 0 + 28	[3], [72]
	Pfizer/BioNTech	BNT162b2, Comirnaty	2	Day 0 + 21	[3]
	Walvax Biotechnology; Shanghai RNACure Biopharma (Walvax Biotechnology)	RQ3013, AWcorna	1	Day 0	[3], [73]
Viral vector (Non-replicating)	AstraZeneca/University of Oxford (AstraZeneca/Univ. Oxford)	AZD1222, ChAdOx1-S, Vaxzevria	1-2	Day 0 + 28	[3]
	Serum Institute of India/AstraZeneca	AZD1222, ChAdOx1-S CoviShield	1-2	Day 0 + 28	[3], [74]
	CanSino Biologics	Convidecia	2	Day 0 + 21	[3]
	Bharat Biotech International Limited	BBV154, iNCOVACC	1	Day 0	[3], [75]
	Gamaleya Research Institute (Sputnik V)	Gam-COVID-Vac Sputnik V	2	Day 0 + 21	[3]
	Gamaleya Research Institute (Sputnik M)	Gam-COVID-Vac, Sputnik M	2	-	[3]
	Gamaleya Research Institute (Sputnik Light)	Sputnik Light	1	-	[76]
	Janssen, Johnson & Johnson	Ad26.COV2.S Jcovden	1-2	Day 0 or Day 0 +56	[3], [77]
Virus like particle	Medicago	CoVLP COVIFENZ	2	Day 0 + 21	[3], [78]

Table 3-7 Authorization Dates of COVID-19 Vaccines by Country

Authorization dates for primary vaccination in the reference countries. Continents are arranged in longitudinal order from the East. Countries are placed in alphabetical order except for Japan. Vaccines are represented by the abbreviated developer names based on Table 3-6. Ref (1), Ref (2), and Ref (3) columns indicate evidence referred to in the exploration processes of authorization dates introduced in Chapter 3.4.

Continent	Country	ISO Country Code	ERSM	Vaccine	Authorization Date	Ref (1)	Ref (2)	Ref (3)
Asia	Japan	JPN	-	Pfizer/BioNTech	2021-02-14	[36]	[52]	[52]
				Takeda/Moderna	2021-05-21	[36]	[52]	[79]
				AstraZeneca/University of Oxford	2021-05-21	[36]	[52]	[52]
				Takeda/Novavax	2022-04-19	-	[52]	[80]
				Janssen, Johnson & Johnson	2022-06-20	-	[52]	[52]
	China	CHN	-	Sinopharm-Beijing	2020-12-29	[36]	-	[81]
				Sinovac	2021-02-06	[36]	-	[82]
				CanSino Biologics	2021-02-25	[36]	-	[83]
				Sinopharm-Wuhan	2021-02-25	[36]	-	[83]
				Anhui Zhifei Longcom and IMCAS	2021-03-15	[36]	-	[84]
				Shenzhen Kangtai Biological Products	2021-05-14	[36]	-	[85]
				IMBCAMS	2021-06-09	[36]	-	[86]
	India	IND	-	AstraZeneca/University of Oxford	2021-01-02	[36]	-	[87]
				Serum Institute of India/AstraZeneca	2021-01-02	[36]	-	[87]
				Bharat Biotech	2021-01-02	-	-	[87]
				Gamaleya Research Institute (Sputnik V)	2021-04-13	[36]	-	[88]
				Moderna	2021-06-29	[36]	-	[89]
				Janssen, Johnson & Johnson	2021-08-07	[36]	-	[90]
				Zydus Cadila	2021-08-20	[36]	-	[91]
				Serum Institute of India/Novavax	2021-12-28	-	-	[92]
				Biological E. Limited	2021-12-28	-	-	[93]
				Gamaleya Research Institute (Sputnik Light)	2022-02-06	-	-	[94]
				Gennova Biopharmaceuticals Limited	2022-06-29	-	-	[95]
				Bharat Biotech International Limited	2022-09-06	-	-	[75]
	Indonesia	IDN	-	Sinovac	2021-01-11	[36]	-	[96]
				AstraZeneca/University of Oxford	2021-03-09	[36]	-	[97]
				Sinopharm-Beijing	2021-04-30	[36]	-	[98]
				Moderna	2021-07-02	[36]	-	[99]
				Pfizer/BioNTech	2021-07-15	[36]	-	[100]

				Gamaleya Research Institute (Sputnik V)	2021-08-25	-	-	[101]
				CanSino Biologics	2021-09-07	[36]	-	[102]
				Janssen, Johnson & Johnson	2021-09-07	[36]	-	[102]
				Anhui Zhifei Longcom and IMCAS	2021-10-07	[36]	-	[103]
				Novavax	2021-11-01	[36]	-	[67]
				Serum Institute of India/Novavax	2021-11-01	-	-	[67]
				Shenzhen Kangtai Biological Products	2021-11-03	-	-	[104]
				PT Bio Farma (Indovac)	2022-09-28	-	-	[69]
				Walvax Biotechnology	2022-09-30	-	-	[73]
				PT Bio Farma (Inavac)	2022-11-04	-	-	[70]
	Israel	ISR	-	Pfizer/BioNTech	2020-12-06	[36]	[105]	[106]
				Moderna	2021-01-04	[36]	[105]	[107]
				AstraZeneca/University of Oxford	2021-10-21	[36]	[105]	[108]
				Novavax	2022-09-16	-	[105]	[109]
	Saudi Arabia	SAU	-	Pfizer/BioNTech	2020-12-10	[36]	-	[110]
				AstraZeneca/University of Oxford	2021-02-18	[36]	-	[111]
				Moderna	2021-07-09	[36]	-	[112]
				Sinopharm-Beijing	2021-08-24	[36]	-	[113]
				Sinovac	2021-08-24	-	-	[113]
				Janssen, Johnson & Johnson	Not Found	[36]	-	-
	Singapore	SGP	-	Pfizer/BioNTech	2020-12-14	[36]	-	[114]
				Moderna	2021-02-03	[36]	-	[115]
				Sinovac	2021-10-23	[36]	-	[116]
				Novavax	2022-02-03	-	-	[117]
				Sinopharm-Beijing	Not Found	[36]	-	-
	South Korea	KOR	-	Pfizer/BioNTech	2021-02-03	[36]	-	[118]
				AstraZeneca/University of Oxford	2021-02-10	-	-	[119]
				Janssen, Johnson & Johnson	2021-04-07	[36]	-	[120]
				Moderna	2021-05-21	[36]	-	[121]
				Novavax	2022-01-12	[36]	-	[122]
				SK Bioscience	2022-06-29	-	-	[71]
				Serum Institute of India/AstraZeneca	Not Found	[36]	-	-
	Turkey	TUR	-	Sinovac	2021-01-13	[36]	-	[123]
				Pfizer/BioNTech	2021-04-02	[36]	-	[124]
				Gamaleya Research Institute (Sputnik V)	2021-04-30	-	-	[125]
				E. Univ. and TUSEB	2021-12-22	[36]	-	[126]
Oceania	Australia	AUS	-	Pfizer/BioNTech	2021-01-25	[36]	[127]	[128]

				AstraZeneca/University of Oxford	2021-02-15	[36]	[127]	[129]
				Janssen, Johnson & Johnson	2021-06-25	-	-	[130]
				Moderna	2021-08-09	[36]	[127]	[131]
				Novavax	2022-01-20	[36]	[127]	[132]
	New Zealand	NZL	-	Pfizer/BioNTech	2021-02-03	[36]	[133]	[134]
				Janssen, Johnson & Johnson	2021-07-07	[36]	[133]	[135]
				AstraZeneca/University of Oxford	2021-07-29	[36]	[133]	[136]
				Novavax	2022-02-04	-	[133]	[137]
				Moderna	2022-06-17	-	[133]	[138]
Europe	Austria	AUT	EU	Pfizer/BioNTech	2020-12-21	[36]	-	[63]
				Moderna	2021-01-06	[36]	-	[63]
				AstraZeneca/University of Oxford	2021-01-29	[36]	-	[63]
				Janssen, Johnson & Johnson	2021-03-11	[36]	-	[63]
				Novavax	2021-12-20	[36]	-	[63]
				Valneva	2022-06-24	-	-	[63]
	Belgium	BEL	EU	Pfizer/BioNTech	2020-12-21	[36]	[139]	[63]
				Moderna	2021-01-06	[36]	[139]	[63]
				Janssen, Johnson & Johnson	2021-03-11	[36]	[139]	[63]
				Novavax	2021-12-20	[36]	[139]	[63]
				AstraZeneca/University of Oxford	2021-01-29	[36]	-	[63]
	Croatia	HRV	EU	Pfizer/BioNTech	2020-12-21	[36]	-	[63]
				Moderna	2021-01-06	[36]	-	[63]
				AstraZeneca/University of Oxford	2021-01-29	[36]	-	[63]
				Janssen, Johnson & Johnson	2021-03-11	[36]	-	[63]
	Cyprus	CYP	EU	Pfizer/BioNTech	2020-12-21	[36]	-	[63]
				Moderna	2021-01-06	[36]	-	[63]
				AstraZeneca/University of Oxford	2021-01-29	[36]	-	[63]
				Janssen, Johnson & Johnson	2021-03-11	[36]	-	[63]
	Czechia	CZE	EU	Pfizer/BioNTech	2020-12-21	[36]	[140]	[63]
				Moderna	2021-01-06	[36]	[140]	[63]
				AstraZeneca/University of Oxford	2021-01-29	[36]	[140]	[63]
				Janssen, Johnson & Johnson	2021-03-11	[36]	[140]	[63]
				Novavax	2021-12-20	[36]	[140]	[63]
	Denmark	DNK	EU	Pfizer/BioNTech	2020-12-21	[36]	[141]	[63]
				Moderna	2021-01-06	[36]	[141]	[63]
				AstraZeneca/University of Oxford	2021-01-29	[36]	[141]	[63]
				Janssen, Johnson & Johnson	2021-03-11	[36]	[141]	[63]

Estonia	EST	EU	Pfizer/BioNTech	2020-12-21	[36]	[142]	[63]
			Moderna	2021-01-06	[36]	[142]	[63]
			AstraZeneca/University of Oxford	2021-01-29	[36]	[142]	[63]
			Janssen, Johnson & Johnson	2021-03-11	[36]	[142]	[63]
			Novavax	2021-12-20	[36]	[142]	[63]
Finland	FIN	EU	Pfizer/BioNTech	2020-12-21	[36]	[143]	[63]
			Moderna	2021-01-06	[36]	[143]	[63]
			Janssen, Johnson & Johnson	2021-03-11	[36]	[143]	[63]
			Novavax	2021-12-20	-	[143]	[63]
			Valneva	2022-06-24	-	[143]	[63]
			AstraZeneca/University of Oxford	2021-01-29	[36]	-	[63]
France	FRA	EU	Pfizer/BioNTech	2020-12-21	[36]	-	[63]
			Moderna	2021-01-06	[36]	-	[63]
			AstraZeneca/University of Oxford	2021-01-29	[36]	-	[63]
			Janssen, Johnson & Johnson	2021-03-11	[36]	-	[63]
			Novavax	2021-12-20	[36]	-	[63]
Germany	DEU	EU	Pfizer/BioNTech	2020-12-21	[36]	[144]	[63]
			Moderna	2021-01-06	[36]	[144]	[63]
			Janssen, Johnson & Johnson	2021-03-11	[36]	[144]	[63]
			Novavax	2021-12-20	-	[144]	[63]
			Valneva	2022-06-24	-	[144]	[63]
			AstraZeneca/University of Oxford	2021-01-29	[36]	-	[63]
Greece	GRC	EU	Pfizer/BioNTech	2020-12-21	[36]	-	[63]
			Moderna	2021-01-06	[36]	-	[63]
			AstraZeneca/University of Oxford	2021-01-29	[36]	-	[63]
			Janssen, Johnson & Johnson	2021-03-11	[36]	-	[63]
Hungary	HUN	EU	Pfizer/BioNTech	2020-12-21	[36]	-	[63]
			Moderna	2021-01-06	[36]	-	[63]
			Gamaleya Research Institute (Sputnik V)	2021-01-21	[36]	-	[145]
			AstraZeneca/University of Oxford	2021-01-29	[36]	-	[63]
			Sinopharm-Beijing	2021-01-29	[36]	-	[146]
			Janssen, Johnson & Johnson	2021-03-11	[36]	-	[63]
			CanSino Biologics	2021-03-22	-	-	[147]
			Serum Institute of India/AstraZeneca	2021-03-22	-	-	[147]
Iceland	ISL	EEA	Pfizer/BioNTech	2020-12-21	[36]	[148]	[63]
			Moderna	2021-01-06	[36]	[148]	[63]
			AstraZeneca/University of Oxford	2021-01-29	[36]	[148]	[63]

			Janssen, Johnson & Johnson	2021-03-11	[36]	[148]	[63]
			Novavax	2021-12-20	-	[148]	[63]
Ireland	IRL	EU	Pfizer/BioNTech	2020-12-21	[36]	[149]	[63]
			Moderna	2021-01-06	[36]	[149]	[63]
			AstraZeneca/University of Oxford	2021-01-29	[36]	-	[63]
			Janssen, Johnson & Johnson	2021-03-11	[36]	[149]	[63]
			Novavax	2021-12-20	-	[149]	[63]
Italy	ITA	EU	Pfizer/BioNTech	2020-12-21	[36]	-	[63]
			Moderna	2021-01-06	[36]	-	[63]
			AstraZeneca/University of Oxford	2021-01-29	[36]	-	[63]
			Janssen, Johnson & Johnson	2021-03-11	[36]	-	[63]
			Novavax	2021-12-20	[36]	-	[63]
Latvia	LVA	EU	Pfizer/BioNTech	2020-12-21	[36]	-	[63]
			Moderna	2021-01-06	[36]	-	[63]
			AstraZeneca/University of Oxford	2021-01-29	[36]	-	[63]
			Janssen, Johnson & Johnson	2021-03-11	[36]	-	[63]
Liechtenstein	LIE	EEA	-	-	-	-	-
Lithuania	LTU	EU	Pfizer/BioNTech	2020-12-21	[36]	-	[63]
			Moderna	2021-01-06	[36]	-	[63]
			AstraZeneca/University of Oxford	2021-01-29	[36]	-	[63]
			Janssen, Johnson & Johnson	2021-03-11	[36]	-	[63]
			Novavax	2021-12-20	-	-	[63]
Malta	MLT	EU	Pfizer/BioNTech	2020-12-21	[36]	-	[63]
			Moderna	2021-01-06	[36]	-	[63]
			AstraZeneca/University of Oxford	2021-01-29	[36]	-	[63]
			Janssen, Johnson & Johnson	2021-03-11	[36]	-	[63]
			Novavax	2021-12-20	-	-	[63]
Netherlands	NLD	EU	Pfizer/BioNTech	2020-12-21	[36]	[150]	[63]
			Moderna	2021-01-06	[36]	[150]	[63]
			Janssen, Johnson & Johnson	2021-03-11	[36]	[150]	[63]
			Novavax	2021-12-20	-	[150]	[63]
			AstraZeneca/University of Oxford	2021-01-29	[36]	-	[63]
Norway	NOR	EEA	Pfizer/BioNTech	2020-12-21	[36]	[151]	[63]
			Moderna	2021-01-06	[36]	[151]	[63]
			AstraZeneca/University of Oxford	2021-01-29	[36]	[151]	[63]
			Janssen, Johnson & Johnson	2021-03-11	[36]	[151]	[63]
			Novavax	2021-12-20	-	[151]	[63]

Poland	POL	EU	Pfizer/BioNTech	2020-12-21	[36]	-	[63]
			Moderna	2021-01-06	[36]	-	[63]
			AstraZeneca/University of Oxford	2021-01-29	[36]	-	[63]
			Janssen, Johnson & Johnson	2021-03-11	[36]	-	[63]
Portugal	PRT	EU	Pfizer/BioNTech	2020-12-21	[36]	-	[63]
			Moderna	2021-01-06	[36]	-	[63]
			AstraZeneca/University of Oxford	2021-01-29	[36]	-	[63]
			Janssen, Johnson & Johnson	2021-03-11	[36]	-	[63]
Russia	RUS	-	Gamaleya Research Institute (Sputnik V)	2020-08-11	[36]	-	[152]
			Vector Center (EpiVacCorona)	2020-10-14	[36]	-	[153]
			Chumakov Center	2021-02-20	[36]	-	[154]
			Gamaleya Research Institute (Sputnik Light)	2021-05-06	[36]	-	[155]
			Vector Center (EpiVacCorona-N)	2021-08-26	[36]	-	[156]
			Gamaleya Research Institute (Sputnik M)	2021-11-14	[36]	-	[157]
			CanSino Biologics	Not found	[36]	-	-
Slovakia	SVK	EU	Pfizer/BioNTech	2020-12-21	[36]	-	[63]
			Moderna	2021-01-06	[36]	-	[63]
			AstraZeneca/University of Oxford	2021-01-29	[36]	-	[63]
			Gamaleya Research Institute (Sputnik V)	2021-03-01	[36]	-	[158]
			Janssen, Johnson & Johnson	2021-03-11	[36]	-	[63]
Slovenia	SVN	EU	Pfizer/BioNTech	2020-12-21	[36]	-	[63]
			Moderna	2021-01-06	[36]	-	[63]
			AstraZeneca/University of Oxford	2021-01-29	[36]	-	[63]
			Janssen, Johnson & Johnson	2021-03-11	[36]	-	[63]
Spain	ESP	EU	Pfizer/BioNTech	2020-12-21	[36]	-	[63]
			Moderna	2021-01-06	[36]	-	[63]
			AstraZeneca/University of Oxford	2021-01-29	[36]	-	[63]
			Janssen, Johnson & Johnson	2021-03-11	[36]	-	[63]
Sweden	SWE	EU	Pfizer/BioNTech	2020-12-21	[36]	-	[63]
			Moderna	2021-01-06	[36]	-	[63]
			AstraZeneca/University of Oxford	2021-01-29	[36]	-	[63]
			Janssen, Johnson & Johnson	2021-03-11	[36]	-	[63]
			Novavax	2021-12-20	[36]	-	[63]
Switzerland	CHE	-	Pfizer/BioNTech	2020-12-19	[36]	[159]	[159]
			Moderna	2021-01-12	[36]	[159]	[159]
			Janssen, Johnson & Johnson	2021-03-22	[36]	[159]	[159]
			Novavax	2022-04-12	-	[159]	[159]

	United Kingdom	GBR	-	Pfizer/BioNTech	2020-12-02	[36]	[160]	[161]
				AstraZeneca/University of Oxford	2020-12-30	[36]	[160]	[162]
				Moderna	2021-01-08	[36]	[160]	[163]
				Janssen, Johnson & Johnson	2021-05-28	[36]	[160]	[164]
				Novavax	2022-02-03	-	[160]	[165]
				Valneva	2022-04-14	-	[160]	[166]
North America	Canada	CAN	-	Pfizer/BioNTech	2020-12-09	[36]	[167]	[168]
				Moderna	2020-12-23	[36]	[167]	[169]
				AstraZeneca/University of Oxford	2021-02-26	[36]	[167]	[170]
				Serum Institute of India/AstraZeneca	2021-02-26	[36]	-	[171]
				Janssen, Johnson & Johnson	2021-03-05	[36]	[167]	[172]
				Novavax	2022-02-17	-	[167]	[173]
				Medicago	2022-02-24	-	[167]	[174]
	Costa Rica	CRI	-	Pfizer/BioNTech	2020-12-15	[36]	[43]	[175]
				AstraZeneca/University of Oxford	2021-04-07	[36]	[43]	[176]
	Mexico	MEX	-	Pfizer/BioNTech	2020-12-11	[36]	[177]	[177]
				Serum Institute of India/AstraZeneca	2021-01-04	[36]	[177]	[177]
				AstraZeneca/University of Oxford	2021-01-04	[36]	[177]	[177]
				CanSino Biologics	2021-02-08	[36]	[177]	[177]
				Gamaleya Research Institute (Sputnik V)	2021-02-09	[36]	[177]	[177]
				Sinovac	2021-02-09	[36]	[177]	[177]
				Bharat Biotech	2021-04-06	[36]	[177]	[177]
				Janssen, Johnson & Johnson	2021-05-27	[36]	[177]	[177]
				Moderna	2021-08-17	[36]	[177]	[177]
				Sinopharm-Beijing	2021-08-25	-	[177]	[177]
	United States	USA	-	Pfizer/BioNTech	2020-12-11	[36]	[178]	[179]
				Moderna	2020-12-18	[36]	[178]	[180]
				Janssen, Johnson & Johnson	2021-02-27	[36]	[178]	[181]
				Novavax	2022-07-13	-	[178]	[182]
South America	Argentina	ARG	-	Pfizer/BioNTech	2020-12-22	[36]	[183]	[184]
				Gamaleya Research Institute (Sputnik V)	2020-12-24	[36]	[183]	[184]
				AstraZeneca/University of Oxford	2020-12-30	[36]	[183]	[184]
				Serum Institute of India/AstraZeneca	2021-02-09	[36]	[183]	[184]
				Sinopharm-Beijing	2021-02-22	[36]	[183]	[184]
				Sinovac	2021-03-05	-	-	[185]
				CanSino Biologics	2021-06-12	[36]	[183]	[184]
				Moderna	2021-10-04	[36]	[183]	[186]

				Gamaleya Research Institute (Sputnik Light)	2021-12-06	-	-	[187]
	Brazil	BRA	-	Serum Institute of India/AstraZeneca	2021-01-17	[36]	-	[188]
				AstraZeneca/University of Oxford	2021-01-17	[36]	-	[188]
				Sinovac	2021-01-17	[36]	-	[188]
				Pfizer/BioNTech	2021-02-23	[36]	-	[189]
				Janssen, Johnson & Johnson	2021-03-31	[36]	-	[190]
				Sinopharm-Beijing	2021-05-07	-	-	[191]
				Gamaleya Research Institute (Sputnik V)	2021-06-04	-	-	[192]
	Chile	CHL	-	Pfizer/BioNTech	2020-12-16	[36]	-	[193]
				Sinovac	2021-01-20	[36]	-	[194]
				AstraZeneca/University of Oxford	2021-01-27	[36]	-	[195]
				CanSino Biologics	2021-04-07	[36]	-	[196]
				Janssen, Johnson & Johnson	2021-06-10	[36]	-	[197]
				Gamaleya Research Institute (Sputnik V)	2021-07-21	-	-	[198]
				Moderna	2022-02-02	-	-	[199]
	Colombia	COL	-	Pfizer/BioNTech	2021-01-05	[36]	-	[200]
				Sinovac	2021-02-03	[36]	-	[201]
				AstraZeneca/University of Oxford	2021-02-23	[36]	-	[202]
				Janssen, Johnson & Johnson	2021-03-25	[36]	-	[203]
				Moderna	2021-06-24	[36]	-	[204]
				Anhui Zhifei Longcom and IMCAS	2022-01-27	-	-	[205]

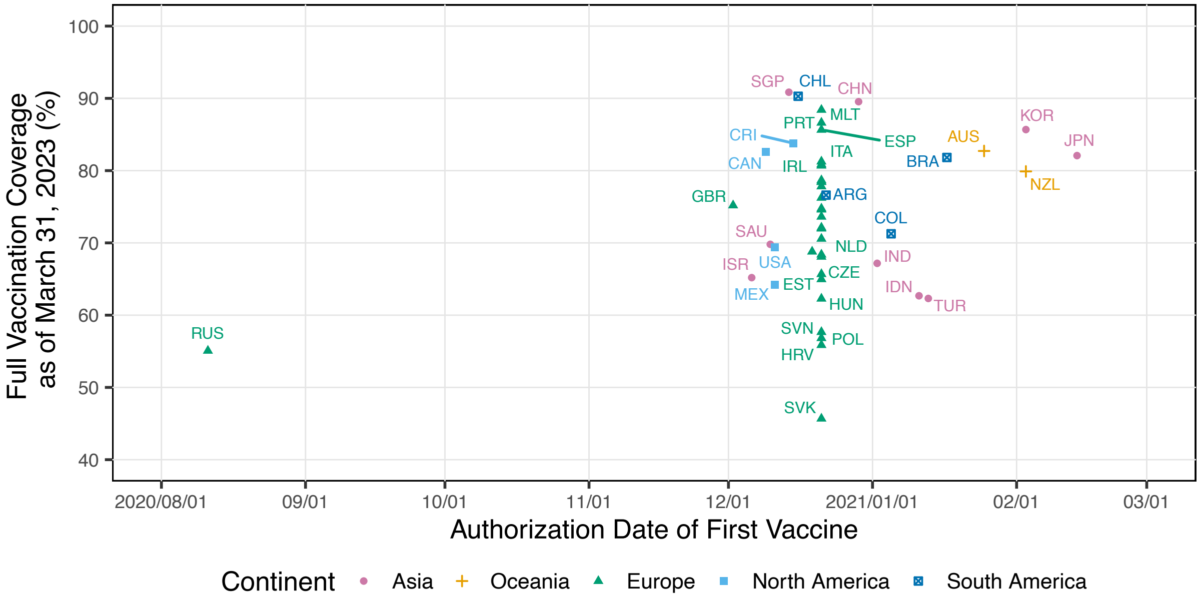
Figure 3-6 displays the authorization dates of the first vaccines in the reference countries. Figure 3-6 (a) reveals that countries in North America and Europe achieved early authorizations on average, compared with Asia, Oceania, and South America. Figure 3-6 (b) reveals that Pfizer/BioNTech vaccine was globally the dominant choice for initial authorizations: the vaccine was authorized in 42 countries out of 48. Sinovac was authorized first in three countries, and AstraZeneca/University of Oxford with Serum Institute of India was in two countries. Baharat Biotech's COVAXIN, Gamaleya Research Institute's Sputnik V, and Sinopharm's BBIBP-CorV were the first authorized vaccines in one country each. Russia was the earliest country to authorize its first vaccine, Sputnik V, on August 11, 2020. The United Kingdom was the second country, with Pfizer/BioNTech on December 2, 2020. Japan was the latest country to authorize its first vaccine among the 48 reference countries. Japan authorized the Pfizer/BioNTech vaccine as its first option on February 14, 2021.

Figure 3-7 displays the authorization dates of each vaccine in Japan and the other reference countries. Japan authorized the following vaccines:

Pfizer/BioNTech	42nd in 45 reference countries
Takeda/Moderna	33rd in 43 reference countries
AstraZeneca/University of Oxford	40th in 42 reference countries
Takeda/Novavax	24th in 26 reference countries
Janssen vaccines	40th in 40 reference countries.

First Authorization Dates and Full Vaccination Coverages in Reference Countries

(a) By Continent



(b) By Vaccine Developer

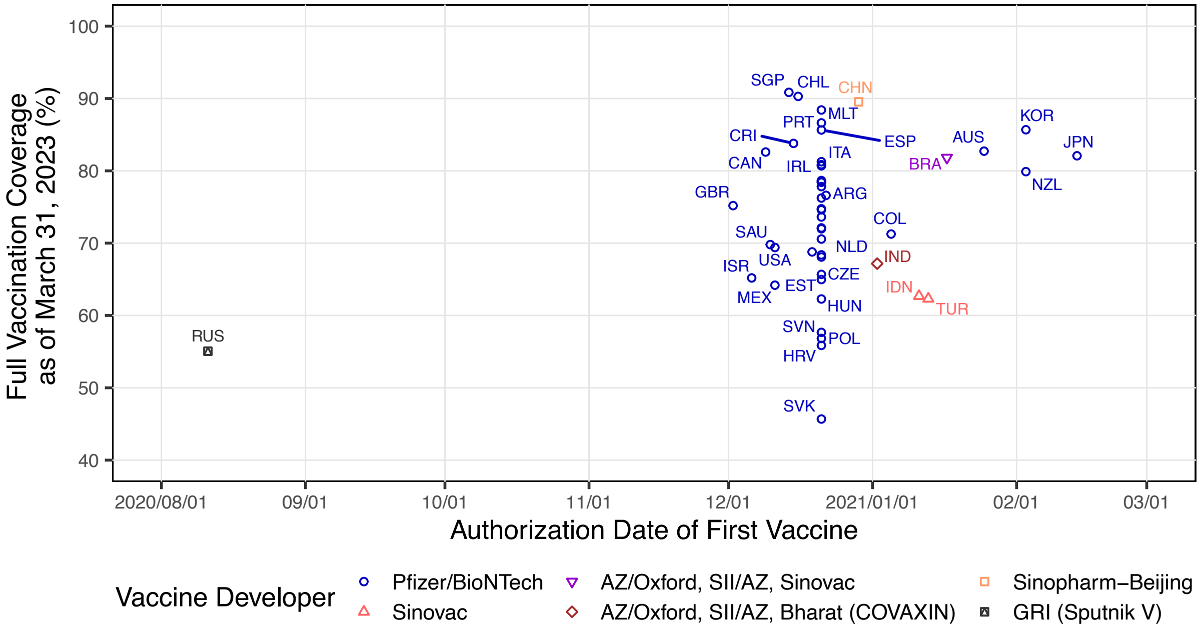


Figure 3-6 First Authorization Dates and Full Vaccination Coverages in Reference Countries
The scatter plot with the first vaccine authorization dates for primary administration and full vaccination coverages in the reference countries. Labels on each plot indicate ISO country codes. Some labels are omitted to avoid overlaps. Figure (a) is colored and shaped by continent where the countries exist. Figure (b) is colored and shaped by the vaccine developer of the first vaccine in each country. "AZ" stands for AstraZeneca, and "GRI" does for Gamaleya Research Institute.

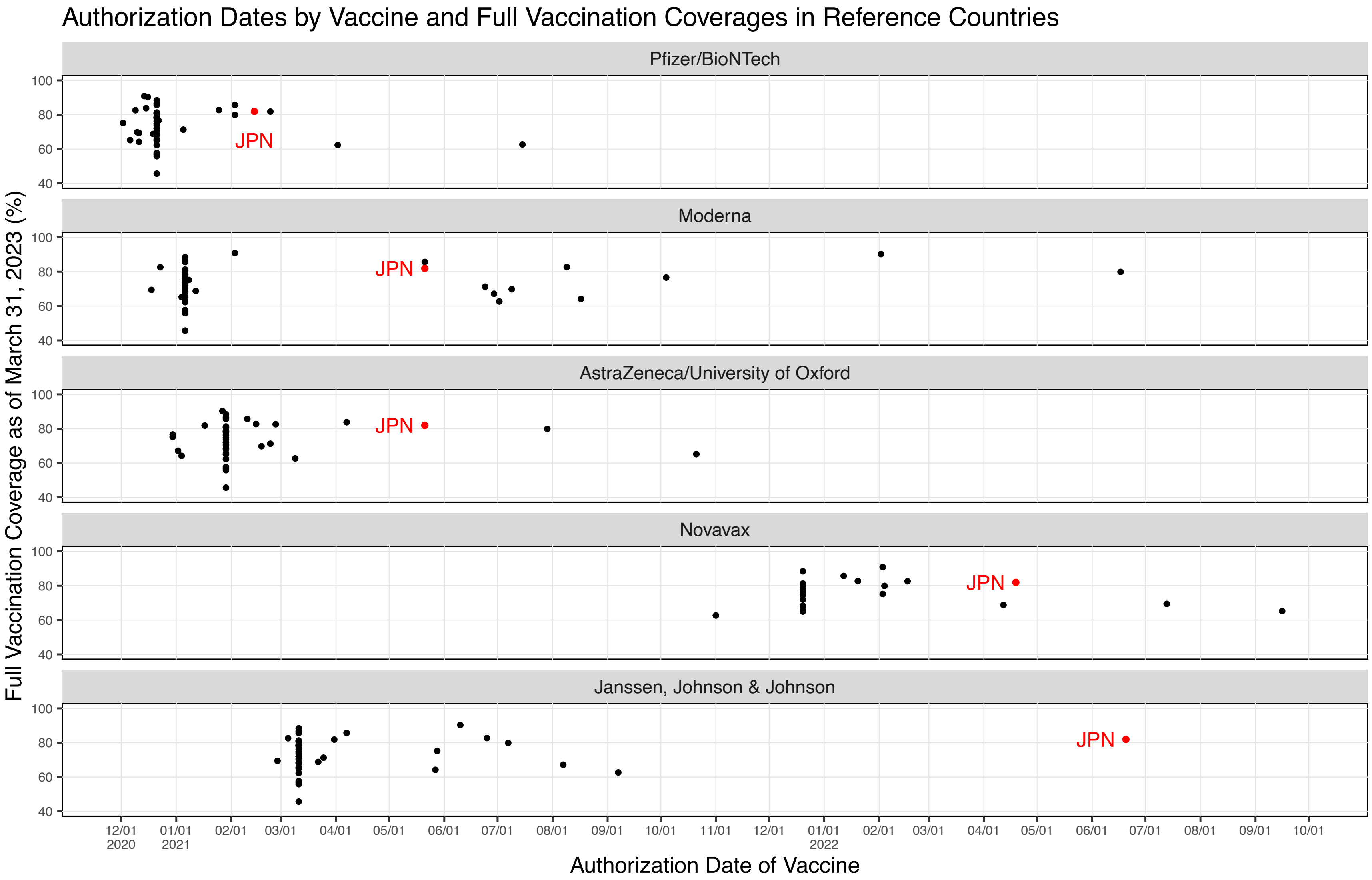


Figure 3-7 Authorization Dates by Vaccine and Full Vaccination Coverages in Reference Countries
The scatter plot with the authorization dates by vaccine and full vaccination coverage and full vaccination coverages in the reference countries. The data on Takeda/Moderna and Takeda/Novavax vaccines in Japan are classified in the Moderna and Novavax facets. Plots with "JPN" labels indicate the authorization dates in Japan.

3.5. Achievement Dates and Periods of Vaccination Coverage Targets

This subchapter compares achievement dates of vaccination coverage targets and achievement periods in reference countries. The following results and discussions refer to the three WHO vaccination coverage target of 10%, 40%, and 70% by September 2021, December 2021, and June 2022 each.

An achievement period is defined as the days from the authorization date of the first vaccine and the achievement date of the vaccination coverage target. Authorization dates of the first vaccines in the reference countries are extracted from Table 3-7, and the achievement dates of vaccination coverage targets are from the Japanese government dataset and the OWID dataset.

Figure 3-8 displays the achievement dates of three vaccination coverage targets in reference countries. All the countries achieved 10% and 40% full vaccination coverages by the target date of September and December 2021. 29 countries reached coverage of 70% and over by June 2022, and Colombia did on July 29, 2022. The top 3 earliest countries with 10% and 40% coverage are Israel, the United States, and Chile. Regarding the 70% coverage, the top 3 earliest countries are Malta, Singapore, and Iceland. Israel and the United States hit the ceilings of vaccination coverage below 70%. Japan accomplished 10%, 40%, and 70% full vaccination coverages on June 22, August 13, and October 18, 2021: 39th, 31st, and 13th in 48, 48, and 30 reference countries.

Figure 3-9 exhibits the periods of achievement with three vaccination coverage targets in reference countries. The top 3 countries with the shortest achievement periods of 10% and 40% coverages are Israel, the United States, and Chile, the same as the ranking of the earliest countries. Regarding the period of 70% coverage, the top 3 countries are Malta, Singapore, and Japan. Japan achieved 129, 181, and 247 days for 10%, 40%, and 70% full vaccination coverages: 9th, 7th, and 3rd in 48, 48, and 30 reference countries.

Table 3-8 summarizes the country rankings by authorization dates of first vaccines, achievement dates, and periods with three full vaccination coverages. The table implies that Japan caught up with other countries after the late start by accelerating its vaccination pace.

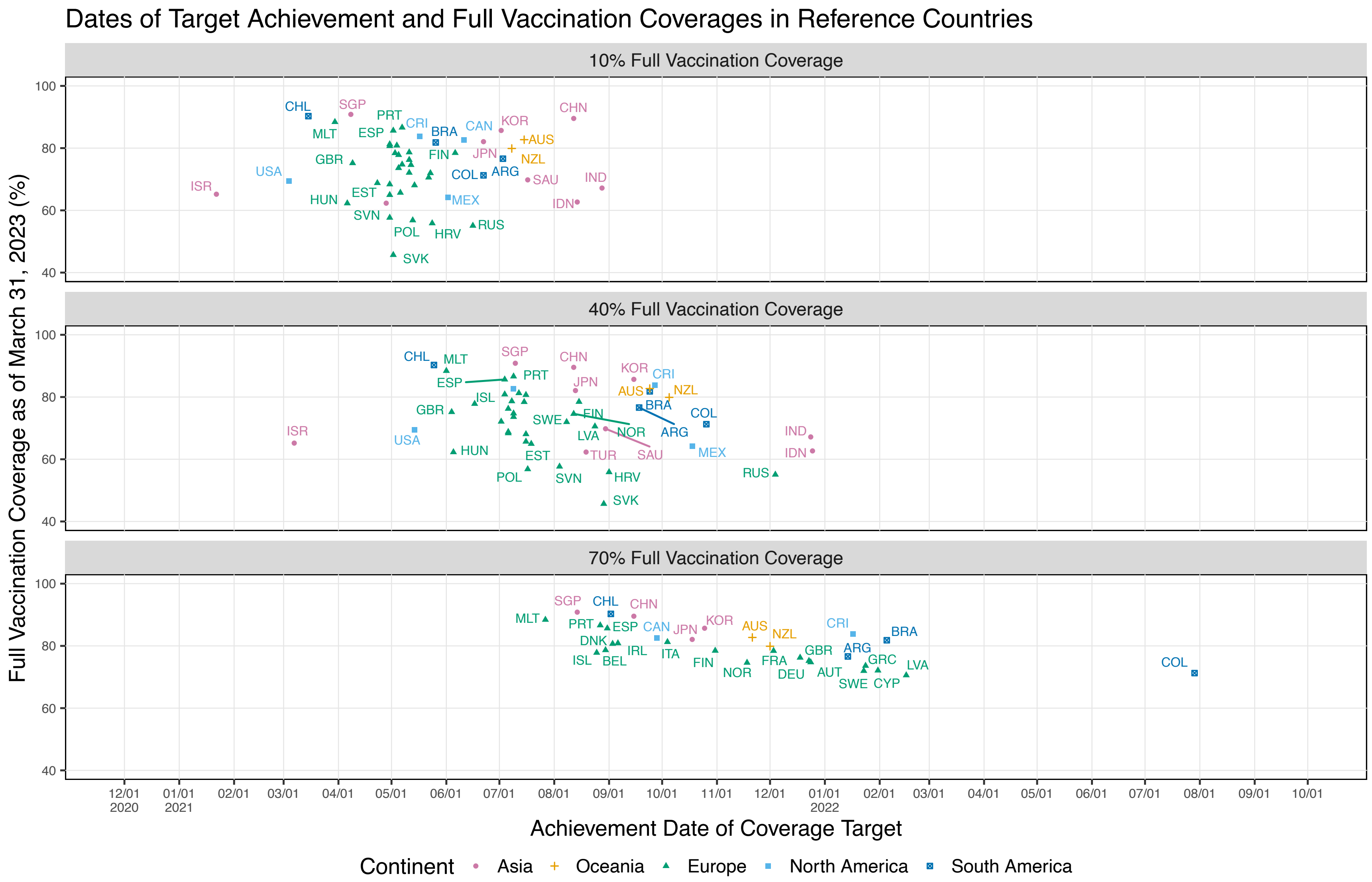


Figure 3-8 Dates of Target Achievement and Full Vaccination Coverages in Reference Countries

The scatter plot with achievement date of vaccination coverage targets and full vaccination coverages in the reference countries. The facet of 70% coverage displays 30 countries that achieved the target coverage. Labels on each plot indicate ISO country codes. Some labels are omitted to avoid overlaps. The 10% and 40% achievement dates in China are the date with 54.5% full vaccination coverage due to the data limitation.

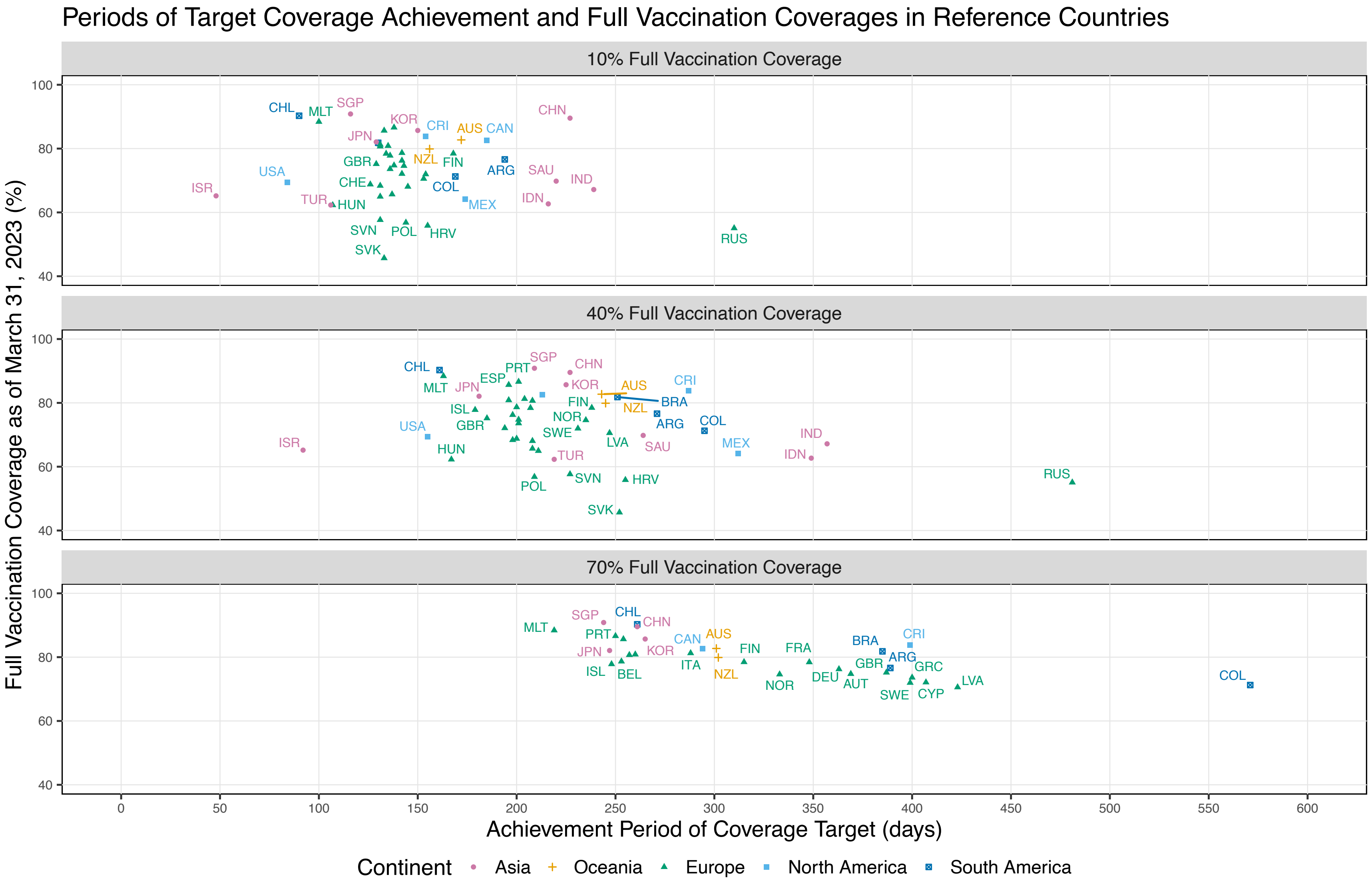


Figure 3-9 Periods of Target Achievement and Full Vaccination Coverages in Reference Countries

The scatter plot with achievement periods of vaccination coverage targets and full vaccination coverages in the reference countries. The facet of 70% coverage displays 30 countries that achieved the target coverage. Labels on each plot indicate ISO country codes. Some labels are omitted to avoid overlaps. The 10% and 40% achievement periods in China are based on the date with 54.5% full vaccination coverage due to the data limitation.

Table 3-8 Rankings of Reference Countries by Authorization Dates, Achievement Dates, and Periods
Rankings of 48 reference countries by authorization dates of first vaccines, achievement dates and periods. The "10%", "40%", and "70%" columns indicate associated full vaccination coverages. The 10% and 40% achievement dates and periods in China are based on the date with 54.5% full vaccination coverage due to the data limitation. Vertically merged cells indicate tied ranks. "GBR" stands for the United Kingdom.

Rank	Authorization Date	Date of Coverage Achievement			Period of Coverage Achievement		
		10%	40%	70%	10%	40%	70%
1	Russia	Israel	Israel	Malta	Israel	Israel	Malta
2	GBR	United States	United States	Singapore	United States	United States	Singapore
3	Israel	Chile	Chile	Iceland	Chile	Chile	Japan
4	Canada	Malta	Malta	Portugal	Malta	Malta	Iceland
5	Saudi Arabia	Hungary	GBR	Belgium	Turkey	Hungary	Portugal
6	United States Mexico	Singapore	Hungary	Spain	Hungary	Iceland	Belgium
7		GBR	Iceland	Chile	Singapore	Japan	Spain
8	Singapore	Switzerland	Cyprus	Denmark	Switzerland	GBR	Denmark
9	Costa Rica	Turkey	Spain Ireland	Ireland	Japan GBR	Cyprus	Ireland
10	Chile	Denmark Estonia Italy Lithuania Slovenia		China		Spain Ireland	Chile China
11	Switzerland		Germany Lithuania Switzerland	Canada	Brazil		
12	Malta Hungary Denmark Estonia Italy Lithuania Slovenia Slovakia Spain France Ireland Greece Iceland Czechia Austria Portugal Belgium Cyprus Germany Norway Poland Netherlands Latvia Sweden Croatia Finland			Italy	Denmark Italy Lithuania Estonia Slovenia	Lithuania Germany	South Korea
13				Japan			Italy
14			Belgium	South Korea		Switzerland Belgium	Canada
15		Slovakia Spain	Portugal Canada Austria Greece	Finland			Australia
16				Norway		Greece Portugal Austria	New Zealand
17		France		Australia	Spain Slovakia		Finland
18		Ireland		New Zealand			Norway
19		Greece Iceland	Singapore	France	France	Italy	France
20			Italy	Germany	Ireland	France	Germany
21		Czechia	France	GBR	Iceland Greece	Denmark Czechia Netherlands	Austria
22		Austria Portugal	Denmark Czechia Netherlands	Austria			Brazil
23				Argentina	Czechia		GBR
24		Belgium Cyprus Germany		Costa Rica	Portugal Austria	Singapore Poland	Argentina
25			Poland	Sweden			Sweden Costa Rica
26			Estonia	Greece	Belgium Germany Cyprus	Estonia	
27		Norway	Slovenia	Cyprus		Canada	Greece
28		Poland	Sweden	Brazil		Turkey	Cyprus
29		Netherlands	China Norway	Latvia	Norway	South Korea	Latvia
30		Costa Rica		Colombia	Poland	Slovenia China	Colombia
31		Latvia	Japan	-	Netherlands		-
32		Sweden	Finland	-	South Korea	Sweden	-
33		Croatia	Turkey	-	Latvia	Norway	-
34		Brazil	Latvia	-	Costa Rica Sweden	Finland	-
35		Mexico	Slovakia	-		Australia	-
36		Finland	Saudi Arabia	-	Croatia	New Zealand	-
37		Canada	Croatia	-	New Zealand	Latvia	-
38	Argentina	Russia	South Korea	-	Finland	Brazil	-
39	China	Colombia Japan	Argentina	-	Colombia	Slovakia	-
40	India		Australia Brazil	-	Australia	Croatia	-
41	Colombia	South Korea		-	Mexico	Saudi Arabia	-
42	Indonesia	Argentina	Costa Rica	-	Canada	Argentina	-
43	Turkey	New Zealand	New Zealand	-	Argentina	Costa Rica	-
44	Brazil	Australia	Mexico	-	Indonesia	Colombia	-
45	Australia	Saudi Arabia	Colombia	-	Saudi Arabia	Mexico	-
46	South Korea New Zealand	China	Russia	-	China	Indonesia	-
47		Indonesia	India	-	India	India	-
48	Japan	India	Indonesia	-	Russia	Russia	-

3.6. Vaccination Speed

This subchapter compares vaccination speeds in the 48 reference countries with average and top speed metrics. Average vaccination speed is defined as the cumulative new vaccinations as of the achievement date of 40% full vaccination coverage divided by the corresponding achievement period. Maximum vaccination speed is defined as the maximum daily new vaccinations in the achievement period. The standardized average and maximum speed are the average and maximum vaccination speed per one hundred people, respectively. The vaccination data is extracted from the Government of Japan sources for Japan and the OWID dataset for other countries.

The average and maximum speed ratio can be regarded as an efficiency metric of vaccination logistics. A country with a large average–maximum speed ratio is considered to reach a target vaccination coverage with a small effort on peak logistics.

Figure 3-10 displays the combination of standardized maximum speeds and standardized average speeds in the 40 reference countries. Japan achieved the standardized maximum speed of 1.40 %/day (1,757,237 doses/day) and the standardized average speed of 0.51 %/day (638,434 doses/day). 10 countries over the solid red line, Italy, United Kingdom, United States, Israel, Greece, Argentina, Malta, Czechia, Singapore, and France, realized larger average–maximum speed ratios than that in Japan of 0.363.

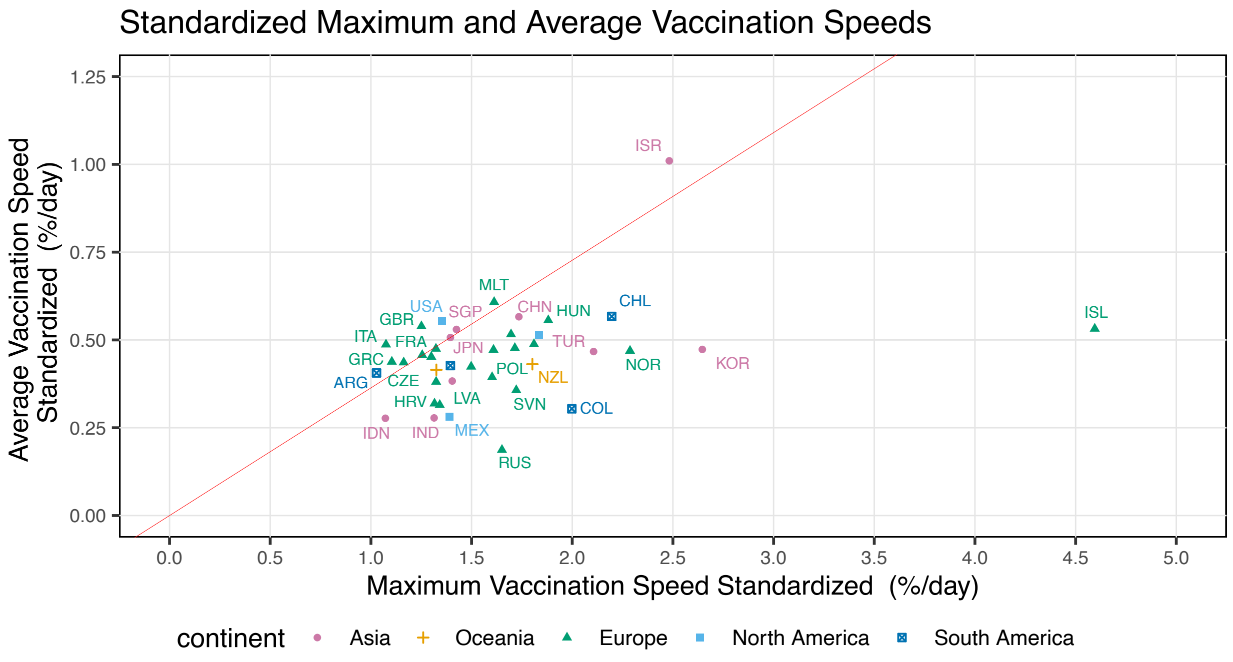


Figure 3-10 Standardized Maximum and Average Vaccination Speeds
The scatter plot with standardized maximum speeds and standardized average speeds by the achievement date of the 40% full vaccination coverages in each reference country. A solid red line passes through Japan's point and has the slope of average–maximum speed ratio in Japan. Austria, Denmark, Finland, Netherlands, Portugal, Slovakia, Sweden, and Costa Rica are excluded due to data constraints. Labels on each plot indicate ISO country codes. Some labels are omitted to avoid overlaps.

3.7. Trends of Daily Vaccinations

This subchapter compares trends of daily vaccinations for primary series in 11 reference countries with the highest average–maximum speed ratios. The data of raw and 7-day smoothed daily vaccinations are extracted from the OWID dataset. Daily vaccinations per one hundred citizens are calculated with the population data.

Figure 3-11 displays the 7-day smoothed trends of daily vaccinations per one hundred people in the 11 reference countries. Japan administered vaccinations at low speed in the first 80 days by early May, compared with other countries. After that period, Japan steeply accelerated vaccinations, achieving the 3rd fastest maximum smoothed speed (1.34 %/day) and 4th shortest period of the 40% full vaccination coverage (181 days) in the 11 reference countries.

Figure 3-12 exhibits the trends of not-smoothed daily vaccinations per one hundred people in the 11 reference countries. The trends have periodic oscillations with around a 7-day period. Japan, Singapore, Greece, and Italy have smaller amplitudes than other countries. A small amplitude enables a high average vaccination speed by limiting maximum speed.

The high maximum speed and small weekday amplitude in Japan can be attributed to the large financial expenses on vaccinations. To accelerate the daily vaccinations for the primary series in 2021, the Government of Japan offered financial incentives for the preparations and administration of vaccination sites with fast vaccination paces [17]. Besides, the government increased payments per dose by 35% and 103% for overtime work and holiday work [17]. Two key factors of rapid vaccinations, high maximum speed and minimized weekday amplitudes, are accompanied by late vaccine authorization and slow initiation in the first months, which cost large physical and financial resources to Japan.

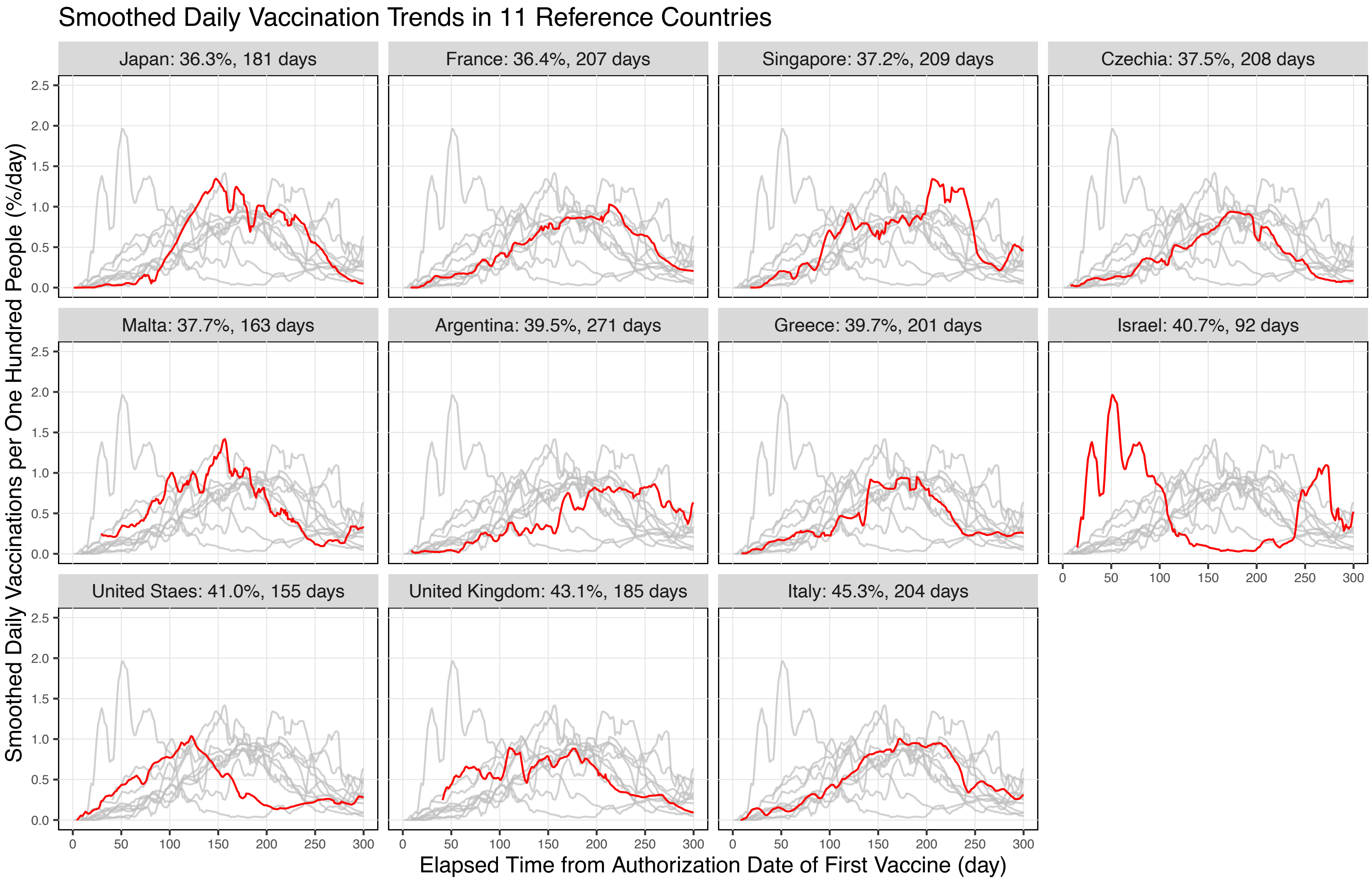


Figure 3-11 Smoothed Daily Vaccination Trends in 11 Reference Countries

Trends of 7-day smoothed daily vaccinations per one hundred people in 11 reference countries with the highest average–maximum speed ratios. X-axes are the elapsed days from the authorization dates of the first vaccines in each country. Each facet title displays a country name, average–maximum speed ratio, and 40% full vaccination coverage period.

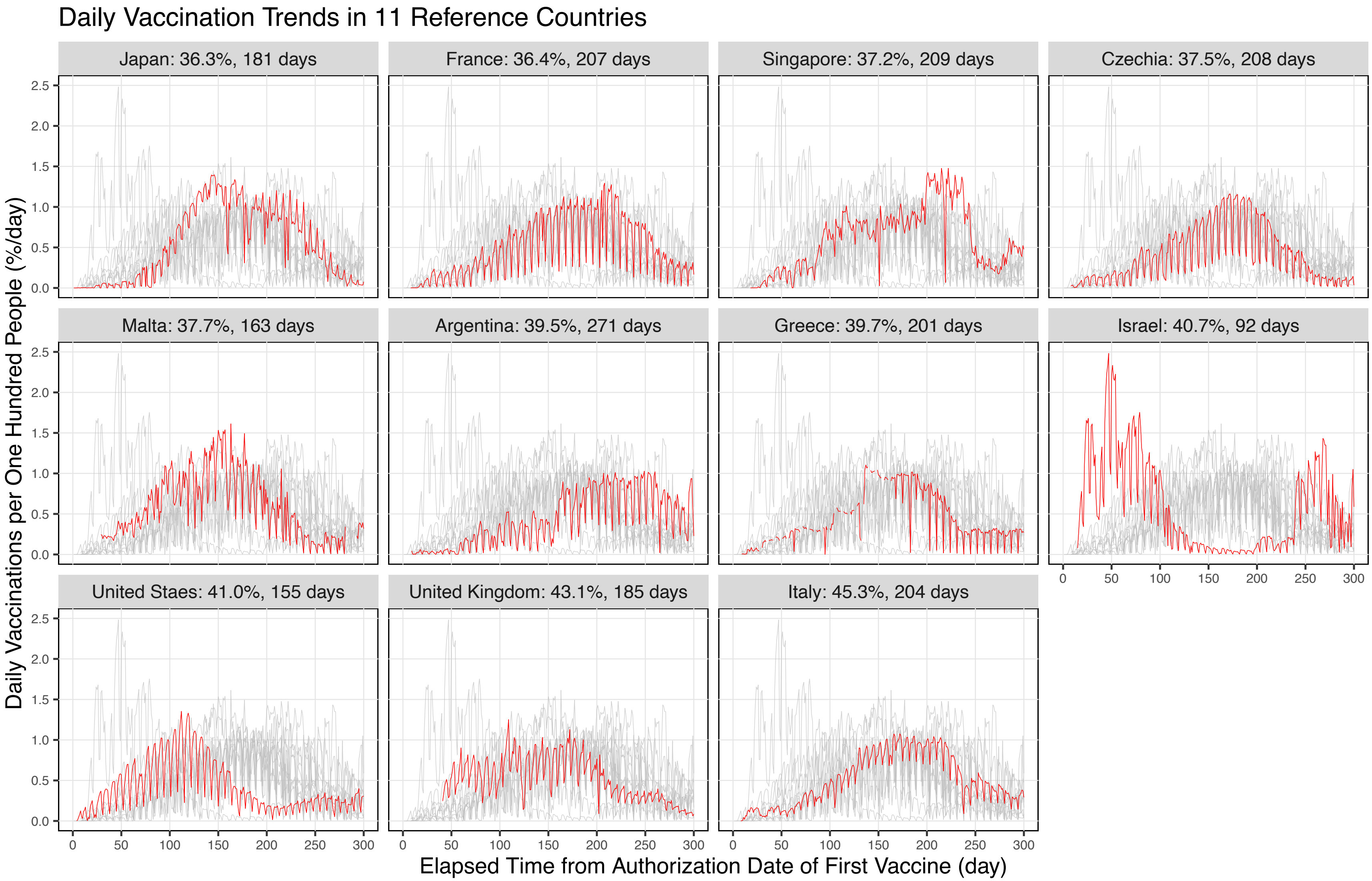


Figure 3-12 Daily Vaccination Trends in 11 Reference Countries

Trends of daily vaccinations per one hundred people in 11 reference countries with the highest average–maximum speed ratios. X-axes are the elapsed days from the authorization dates of the first vaccines in each country. Each facet title displays a country name, average–maximum speed ratio, and 40% full vaccination coverage period.

3.8. Vaccine Supply in Japan

3.8.1. Datasets

The determinants of daily vaccinations are classified into supply and demand sides. Regarding the supply side, this subchapter compares trends of vaccination and vaccine distribution from the national government in Japan.

The amounts of bi-weekly and weekly distributions of Pfizer/BioNTech and Takeda/Moderna vaccines for primary series from the Government of Japan to vaccination sites by September 2021 are available [206], [207]. The daily distribution dataset of vaccines is developed by dividing bi-weekly and weekly distributions by 14 and 7 days each. The dataset of daily vaccinations is derived from the Japanese government sources introduced in Chapter 3.1.

The time range for comparison of daily vaccinations and distributions is from the authorization date of the first vaccine, Pfizer/BioNTech one, on February 14, 2021, to the day before initiating the third shot on November 30, 2021 [208].

The available distribution dataset introduces 201 million vaccines distributed in total, decomposed into 173.47 million Pfizer/BioNTech vaccines and 27.94 million Takeda/Moderna vaccines supplied from February to October 2021. The vaccinations dataset shows 199.54 million administered in total, decomposed into 167.21 million Pfizer/BioNTech vaccines, and 32.33 million Takeda/Moderna vaccines are administered for first and second doses from February to November 2021. One note is that the excess number of vaccination compared with the distribution of Takeda/Moderna vaccines is 4.39 million doses, which means that Takeda/Moderna vaccines had been distributed at least 4.39 million doses from mid-September to November 2021 in addition to the available data.

In the objective period, the AstraZeneca vaccine was available. However, this research focuses on Pfizer/BioNTech and Takeda/Moderna vaccines due to the limitation of distribution datasets. The omission impact of the AstraZeneca vaccine can be small because this vaccine only covers 0.06 % of the cumulative vaccinations of all the available vaccines from February 14 to November 30, 2021, in Japan.

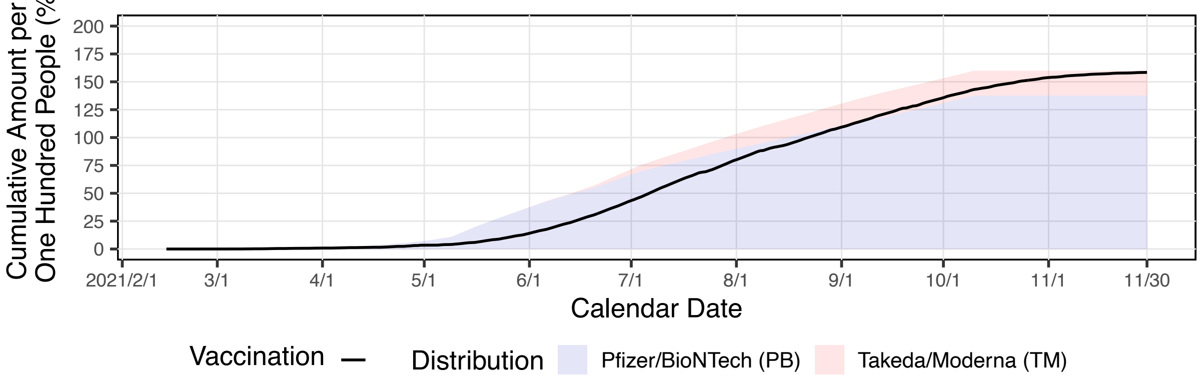
3.8.2. Ceiling Effect of Vaccine Distribution on Vaccination Speed

Figure 3-13 shows the trends of vaccine distribution and vaccinations for the primary series in Japan. Figure 3-13 (a) indicates that the ramp of vaccinations had a three to four-week lag from the distributions. The lag was largest around June 2021.

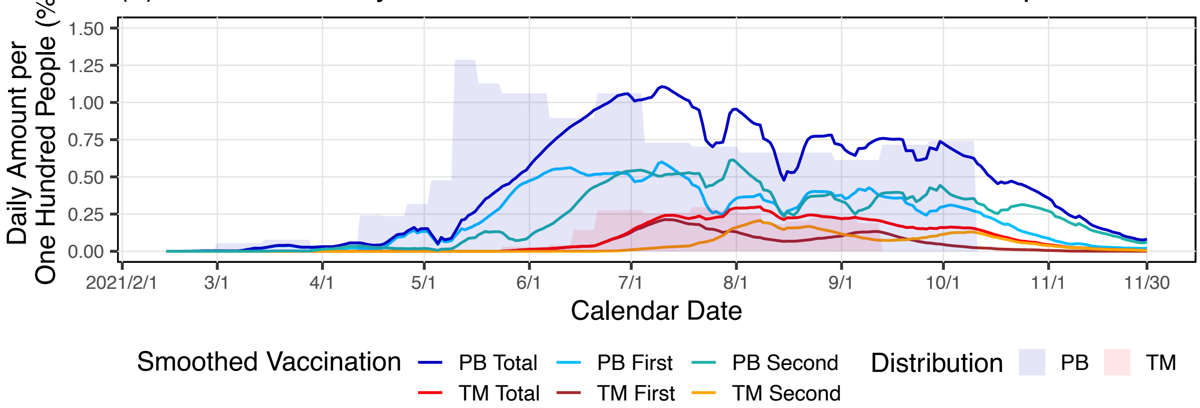
Figure 3-13 (b) reveals that the daily distribution–vaccination gap got largest in mid-May. The distribution of Pfizer/BioNTech vaccines had been limited until mid-April, and the distribution pace steeply increased in early May. The trends on Pfizer/BioNTech vaccines around April to June reveal that there is a one to four-week interval from the shipment of vaccines to vaccinations on sites.

Vaccination and Vaccine Distribution Trends of Primary Series in Japan

(a) Cumulative Vaccinations and Vaccine Distributions in Japa



(b) Smoothed Daily Vaccinations and Vaccine Distributions in Japan



(c) Daily Vaccinations and Vaccine Distributions in Japan

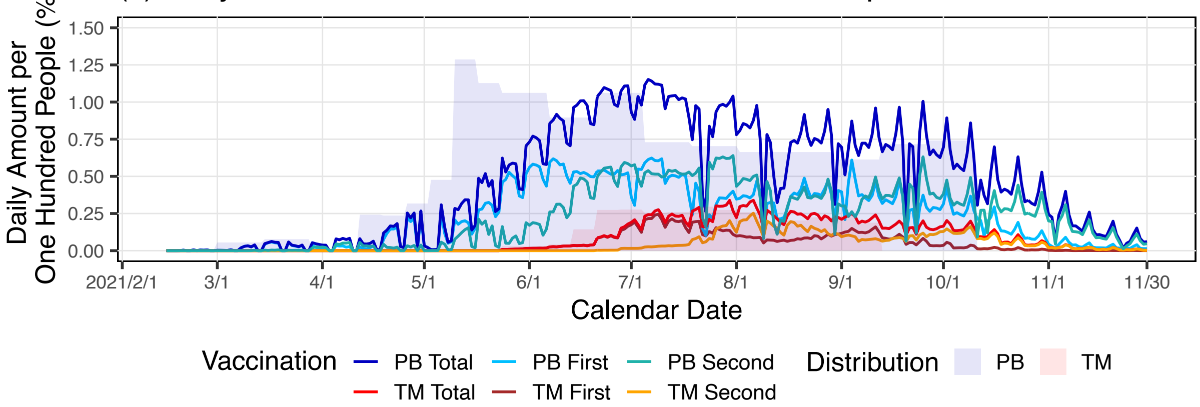


Figure 3-13 Vaccination and Vaccine Distribution Trends of Primary Series in Japan
Vaccine distributions and vaccinations per one hundred people in Japan from the earliest vaccine authorization date to the day before initiating the third dose. Area plots indicate vaccine distributions, and lines do vaccinations. (a) Cumulative amount trends. (b) Smoothed daily amount trends by vaccine by dose round. (c) Not-smoothed daily amount trends. “PB” and “TM” stand for the Pfizer/BioNTech and Takeda/Moderna vaccines, respectively.

The gap between Pfizer/BioNTech vaccine distribution and total vaccinations shrinks after mid-June. At that time, the daily second-dose vaccination ramped up and caught up with the pace of first doses. Figure 3-13 (b) exhibits that the peak of smoothed first-dose vaccinations with Pfizer/BioNTech vaccines in early June is 43.67% of the distribution peak in mid-May. Figure 3-13 (c) shows that the corresponding peak of not-smoothed first-dose vaccinations with Pfizer/BioNTech vaccines in early June is 48.03% of the distribution peak in mid-May. These trends of first-dose, second-dose, and total vaccinations imply that the daily vaccinations of first doses had a 50% ceiling with daily distributions to reserve vaccines for promised second doses. This phenomenon can be attributed to the scheduled doses of two with the interval of three weeks with Pfizer/BioNTech's primary series (c.f. Table 3-6).

In contrast, Figure 3-13 (b) shows that the first-dose vaccinations with Takeda/Moderna vaccines hit the level of daily distributions in July. The peak of smoothed first-dose vaccinations with Takeda/Moderna vaccines in early July is 77.03% of the distribution peak in late June. Figure 3-13 (c) shows that the peak of not-smoothed first-dose vaccinations with Takeda/Moderna vaccines in early July is 88.76% of the distribution peak in late June. The results imply that the operators on each vaccination site might not have reserved Moderna vaccines for future second doses, though Takeda/Moderna proposes two doses for its primary series. This behavior means that the operators could have optimistic attitudes on future vaccine supplies from the national government in the administrations with Takeda/Moderna vaccines.

Publicly available information introduces the following operational differences among Pfizer/BioNTech and Moderna vaccines: shipment frequency, vaccine order protocol, and operator cohort.

The shipment frequency with Pfizer/BioNTech vaccines was 14 days, while that with Takeda/Moderna vaccines was 7 days [206]. The order confirmation of Pfizer/BioNTech vaccines required two-week coordination processes among clinics, municipal governments, prefectural governments, and the national government. In contrast, the national government simplified the order protocol with Moderna vaccines and promised a second shipment in one week without repetitive coordination processes.

The vaccination sites with Pfizer/BioNTech vaccines were managed by local governments with hospitals and clinics [206]. On the other hand, most Moderna vaccines were administered by private companies, universities, and other cooperative organizations at their workplaces and large vaccination sites [206], [207]. 63% of Moderna vaccines were distributed to workplaces by mid-September 2021 [207]. Some parts of the rest vaccines were administered at large vaccination sites operated by the Japan Self Defense Force (JSDF) [206].

All these differences in vaccination operations could be potential determinants of the lag and ceiling level of daily vaccinations under the distribution constraints. If the predictability of vaccine distribution is high, and an operator has an optimistic mindset or confidence in its operation, the ceiling level gets high and, the lag decreases.

However, one caution is that if local governments stopped reserving vaccines for second doses and raised their ceiling level, the national government was predicted to halve its distribution pace with Pfizer/BioNTech vaccines to prevent undesired future cancellations with second doses due to the supply shortage, as long as operators strictly comply with the interval of first and second doses.

3.8.3. Interval from First to Second Dose

Figure 3-13 (b) exhibits that both the Pfizer/BioNTech and Takeda/Moderna curves of second vaccinations fit well with shifted first-dose curves with lags. The observed intervals among two doses are around three weeks and four weeks on Pfizer/BioNTech and Takeda/Moderna vaccines each. These values are in accordance with the standard intervals, 21 days and 28 days, for each vaccine (c.f. Table 3-6).

3.8.4. Candidates of Vaccination Bottleneck

Considering the ceiling effect of distribution, the slow vaccination speed in the first 80 days by early May could be attributed to the limited vaccine distributions from the national government to vaccination sites. There could be various possible root causes of the distribution bottleneck, not only the vaccine procurement in a national scale [9], [11], but also the procurement of needles, syringes, and freezers for vaccine storage [206], and other resource or operational factors. Regarding the freezers, Pfizer/BioNTech vaccines required a -90 to -60 °C environment to store over one month in the early phase of the vaccination project in Japan [209]. The national government had to supply 7,000 and more ultra-deep freezers and dry ice to vaccination sites before administering Pfizer/BioNTech vaccines [206]. Takeda/Moderna vaccines needed to be stored in a -20 °C environment for 6 months [209]. The national government also supplied freezers to administer Takeda/Moderna vaccines [206].

On the other hand, the ramp-up pace of daily vaccinations in mid to late May was below the 50% level of daily distributions. The vaccination bottleneck in this period could be associated with other supply or demand factors: human resources for administration [9]–[11], facilities for vaccination sites, reservation management [7], [8] on the supply side, citizens’ vaccine hesitancy [10] and accessibility to vaccination sites on the demand side, for example.

3.9. Vaccine Hesitancy and Demands in Japan

This subchapter lists references on vaccine hesitancy and compares them with the actual vaccination coverage in Japan to explore the possible bottleneck of daily vaccinations from the demand side.

Table 3-9 lists the surveys on vaccine willingness/intention/trust with Japanese respondents conducted from September 2020 to May 2021. References show willing respondents of 65.7% in September 2020, respondents with intention of 62.1% in January 2021, 56.1% and 88.7% in February 2021, and people with trust in COVID-19 vaccines of 47% in May 2021, with corresponding cohorts in each survey.

The actual full vaccination coverage as of March 31, 2023, is 82.08% of the total population in Japan (c.f. Table 3-5). 10%, 40%, and 70% full vaccination coverages were achieved on June 22, August 13, and October 18, 2021 (c.f. Chapter 3-5). Despite the citizens' historical concerns about vaccines, more Japanese citizens fully received COVID-19 vaccines in the primary series than the willingness surveys found before the first vaccine was authorized on February 14, 2021.

These references and results on vaccination coverages imply that the citizens' vaccine hesitancy/willingness was less likely to be the factor of the lagged ramp-up of daily vaccinations from the distribution in mid to late May.

Table 3-9 References on Vaccine Willingness in Japan

References on willingness/intention/trust on COVID-19 in Japan from September 2020 to May 2021. “M,” “F,” “O,” and “y.o. in the Considered Respondent Characteristics column stand for “Male,” “Female,” “Others,” and “years old.”

Survey Period	Respondent Size	Considered Respondent Characteristics	Metric	Value		Reference
September 2020	1,100	Gender: M 53.1%, F 46.9% Age: Under 19 to Over 70 Average 44.8 y.o. Chronic condition Place of residence	Respondents with willingness/ uncertainty/ unwillingness to vaccinate	All respondents - Willingness - Uncertainty - Unwillingness	 65.7% 22.0% 12.3%	Yoda and Katsuyama, *Vaccines*, Jan. 2021 [210]
January 14–18, 2021	2,956	Sex: M 49.3%, F 50.7% Age: 20–79 y.o. Underlying diseases Marital status Employment status Residential area Living arrangement Educational attainment Annual personal income	Participants highly likely/ unlikely to get a COVID-19 vaccine	All participants - Highly likely - Unlikely	 62.1% 37.9%	Machida et al., *Vaccines*, Mar. 2021 [211]
February 8–26 2021	23,142	Sex: M 51.8%, F 49.2% Age: 15–79 y.o. Annual income Marital status Occupation Educational level Use of combustible cigarettes or heated tobacco product Alcohol use Comorbidity (present) Personal history of COVID-19 infection etc.	COVID-19 vaccine intention	All participants - Intend - Hesitant	 88.7% 11.3%	Okubo et al., *Vaccines*, June 2021 [212]
February 26– March 4, 2021	30,053	Gender: M 51.9%, F 47.9%, O 0.2% Prefecture Highest educational level Occupation type Annual household income Household size Marital size To what extent did the COVID-19 pandemic affect your life, within the past year?	COVID-19 vaccine intention	All participants - Yes - Not sure - No	 56.1% 32.9% 11.0%	Nomura et al., *The Lancet Regional Health – Western Pacific,* July 2021 [213]
March 8– May 16, 2021	2,505	Age: 18 to 39, 40 to 65, 65 and older	Trust COVID-19 Believe their health authorities will provide them with an effective COVID-19 vaccine	- -	47% 47%	Institute of Global health Innovation, Imperial College London, May 2021 [214]

3.10. Chapter Summary

This chapter quantitatively evaluated the performance of the COVID-19 vaccination project for the primary series in Japan with international comparisons: the latest full vaccination population coverage with 49 developed countries, authorization dates by vaccine, achievement dates of 10%, 40%, and 70% full vaccination coverages, average and maximum vaccination speeds with 48 countries, trends of daily vaccinations with 11 countries which realized the highest average–maximum speed ratio in the reference countries including Japan.

Japan achieved the 11th widest full vaccination coverage, 82.08%, in the research cohort as of March 31, 2023. Despite the latest authorization of its first vaccine on February 14, 2021, Japan became the 13th earliest country achieving 70% full vaccination coverage on October 18, 2021, by the 3rd shortest period from the initial vaccine authorization to the achievement date of 70% full vaccination coverage, 247 days. The country ranked 11th with the average–maximum speed ratio of 0.363 with the small oscillation amplitude of the daily vaccinations, which can be associated with the additional government expenses on overwork and holiday administration. The international comparison of the daily vaccination trends identified Japan's slow pace in the first 80 days from mid-February to early May.

Trends of daily vaccinations by dose round (first or second dose) by vaccine (Pfizer/BioNTech or Takeda/Moderna) on primary series in Japan were analyzed with vaccine distribution data. This research found the different levels of the daily distribution ceiling effect on daily vaccinations with Pfizer/BioNTech and Takeda/Moderna vaccines: the 48.03% and 88.76% ceiling of daily distributions each.

The analyses identified the vaccination bottleneck in the first 80 days was the vaccine supply from the national government to vaccination sites, and there could be another dominant constraint in mid to late May 2021. The demand-side discussions on vaccine hesitancy and achieved vaccination coverages in the real world implied the possible existence of bottlenecks on the supply side in mid to late May 2021.

4. Problem Definitions and Research Approach

This research sets two purposes to explore (1) the critical determinants of COVID-19 vaccination trends on the primary series in Japan and (2) the improvement room of vaccination operations by the Government of Japan.

The literature review in Chapter 2 revealed a limited number of comprehensive and quantitative works on the mechanisms of vaccination trends in Japan. Quantitative evaluations of vaccination coverages and speeds with international comparisons in Chapter 3 identified the low vaccination speed in the first 80 days. Comparing vaccine distributions and administrations exhibits the different ceiling levels of vaccine distribution speed and another potential bottleneck on the supply side with the low vaccination speed.

Identifying operational mechanisms and improvement options on vaccine rollouts is beneficial to prepare for future pandemics effectively and efficiently.

The research assumes that the potential core determinants of vaccination speed are willing populations to take vaccine shots, vaccine deliveries, vaccine stocks at vaccination sites, and human resource capacities. The assumptions are tested by fitting actual vaccination trends in Japan with a system dynamics simulation model.

Once the assumptions are validated, operational options on the vaccination project are explored with the validated vaccination model.

5. Model Development on Vaccination Trends

This chapter introduces a system dynamics approach to simulate vaccination trends in Japan. Chapters 5.1 and 5.2 shows the model overview with a time frame. Chapters 5.3 to 5.4 exhibit stocks and flows of populations and vaccines. Chapters 5.5 to 5.7 discusses key algorithms and assumptions for demand-supply balancing mechanism with resource constraints. Chapter 5.8 summarizes the system dynamics architecture. Chapters 5.9 and 5.10 list variables and algorithms in detail for implementation. Chapter 5.11 introduces evaluation metrics for fitting.

5.1. Modeling Approach

The vaccination trends in Japan are simulated with a system dynamics model of the population and vaccines with R programming language and RStudio. Vaccination trends are time series. A key research purpose is to dissect mechanisms behind vaccination trends, which demands explainability on the model. The system dynamics approach can simulate time series behaviors by explicitly assuming interactions of variables with differential equations.

Figure 5-1 exhibits the model overview. Inputs are categorized into six components: age-stratified populations, authorization of vaccines and initiation of vaccinations, vaccine characteristics, vaccine deliveries and stocks, human resources, and other operational factors. The model consists of stocks and flows of populations and vaccines, and causal loops of human resource increase and population/vaccine depletions with daily time steps for the primary-series time range. Key outputs are the population trends of partially and fully vaccinated people to predict the socio-economic impacts of the vaccination project in further research.

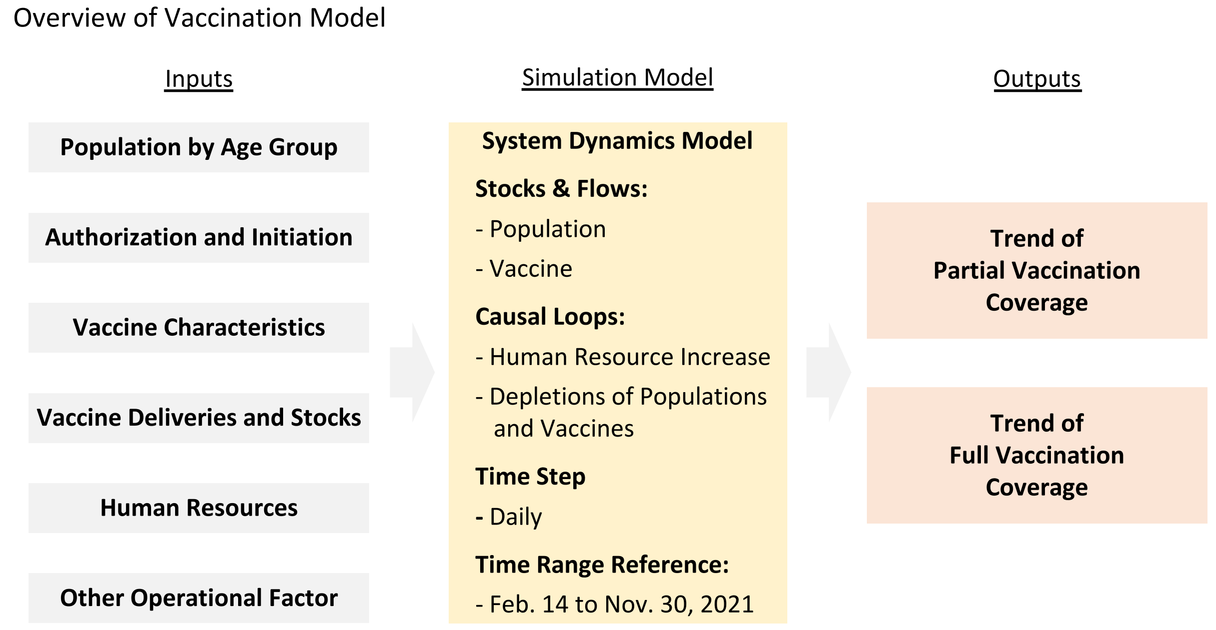


Figure 5-1 Overview of Vaccination Model
Schematic of vaccination model to simulate the trends of partial and full vaccination coverages.

5.2. Time Step and Range

The model adopts daily time steps for the simulation of the vaccinated population trends. The time range of simulation in a base case is from February 14, 2021, the authorization date of the Pfizer/BioNTech vaccine, to November 30, 2021, the day before the initiation of the third dose. The simulation program has 445 time steps as the available simulation time range, which corresponds to from December 1, 2020, to February 28, 2022, in the real world.

5.3. Population Stocks and Flows

The model assumes stocks and flows of the population by occupational category by age group based on the operations in Japan as Figure 5-2. The changes in the total population and occupational/age structures are not considered in the model.

5.3.1. Authorization of Vaccines and Initiation of Vaccinations

First, citizens in each country are classified in the stock of population not eligible for vaccines p_n. There is the population flows $pflow_{\mathrm{autho}}$ with corresponding age groups moving from p_{n} to p_{e}, the compartment for the eligible population [206] on the earliest dates among the first vaccine authorization dates for each age group or the day before the earliest initiation dates minus reservation interval. There is the population flow $pflow_{\mathrm{init}}$ with people in corresponding priority order moving from p_{e} [206] on the day before the earliest initiation dates of vaccinations minus reservation interval based on priority order with occupation and age group. The population in $pflow_{\mathrm{init}}$ is divided into the willing and unwilling population, p_{w} and p_{u}, with the willing proportion to take first dose w_1.

5.3.2. Willingness Filter of First Dose

Willing people make reservations of their first shots under the reservation capacity [206], which corresponds to the population flow $pflow_{\mathrm{rsv1}}$ to the population compartment p_{rsv1}. After passing a reservation interval, people in p_{rsv1}receive or cancel their first doses. Cancellation might occur due to changing minds and physical conditions [206]. The vaccination and cancellation flow of the first dose are represented by $pflow_{\mathrm{d1}}$ and $pflow_{\mathrm{cncl1}}$, respectively. People taking first doses are classified in the compartment p_{d1}, the population partially vaccinated but not completing the immunity development interval. The population in $pflow_{\mathrm{cncl1}}$ is divided into the willing and unwilling population, p_{w} and p_{u}, with the willing proportion to take the first dose w_1.

5.3.3. Partially Vaccinated Population

After passing the immunity development interval with the first dose, the population of $pflow_{\mathrm{i1}}$ is divided into the willing and unwilling population, p_{i1} and p_{i1fin}, with the willing proportion to take the second dose w_2. The population stock p_{i1} stands for the population who have immunity with the partial fulfillment of the primary series and want to take second doses. The compartment p_{i1fin} stands for the population who have immunity with the partial fulfillment of the primary series, do not want to take the second dose, and end the vaccination processes.

5.3.4. Interval from First to Second Dose

This model assumes that people in p_{i1} make reservations to take second doses according to the standard intervals from the first to second dose by vaccine. The population flow with second dose reservations is $pflow_{\mathrm{rsv2}}$ to the population compartment p_{rsv2}. After passing a reservation interval, people in p_{rsv2} receive or cancel their second doses. Cancellation might occur due to changing mind, physical conditions, and reservation by mistake [206]. The vaccination and cancellation flows of second doses are represented by $pflow_{\mathrm{d2}}$ and $pflow_{\mathrm{cncl2}}$, respectively.

5.3.5. Fully Vaccinated Population

People taking second doses are moved to the compartment p_{d2}, the population fully vaccinated in the primary series but not completing immunity development interval with second doses. The population in $pflow_{\mathrm{cncl2}}$ is divided into the willing and unwilling population, p_{i1} and p_{i1fin}, with the willing proportion to take the second dose w_2. After passing the immunity development interval with the second dose, the population in p_{d2} moves with $pflow_{\mathrm{i2}}$ to the compartment p_{i2}, the stock of people fully immunized.

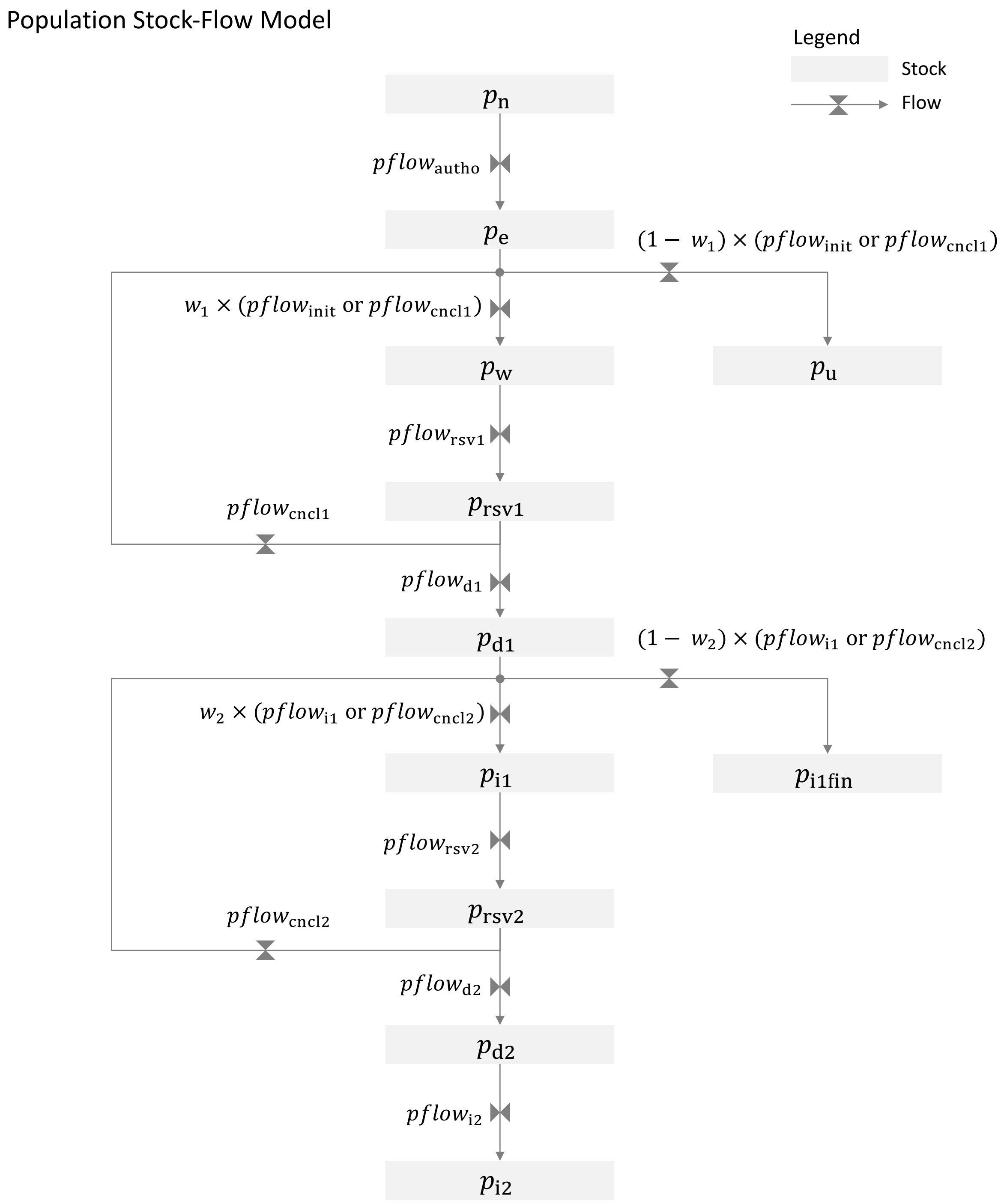


Figure 5-2 Population Stock-Flow Model
Stocks and flows with people's vaccination processes in the primary series assumed for simulation.

5.4. Vaccine Stocks and Flows

This research assumes stocks and flows of vaccines by vaccine developer based on the logistics in Japan, as Figure 5-3 exhibits. Other resource supplies, needles, syringes, freezers, etc., are not explicitly considered and assumed to be sufficient for vaccine supplies in the model.

5.4.1. Vaccine Distribution and Reservation

First, the amounts of procured vaccines are set in the stock v_{procured}. The national government officially announces future vaccine delivery and confirms orders from vaccination site operators by vaccine distribution category [206]. The vaccine flow $vflow_{\mathrm{order}}$ stands for order confirmations by the national government. The ordered vaccines at the national storages and on the way to vaccination sites are represented by v_{ordered}.

The model assumes that operators start receiving citizens' reservations with delivered vaccines on each vaccination site to avoid cancellations due to supply-side operations. The delivery flows of vaccines from the national storage to vaccination sites are represented by $vflow_{\mathrm{deliver}}$. The delivered vaccines are stored in stock v_{site} without reservations. Once operators receive reservations, vaccines in v_{site} move to $v_{\mathrm{site\_rsv1}}$ and $v_{\mathrm{site\_rsv2}}$ with reservations for first and second doses on vaccination sites, respectively. The vaccine flows $vflow_{\mathrm{rsv1}}$ and $vflow_{\mathrm{rsv2}}$ stand for the reservations of vaccines for first and second doses, respectively.

5.4.2. Vaccination and Cancellation

The vaccination and cancellation flow of the first and second doses are represented by $vflow_{\mathrm{d1}}$, $vflow_{\mathrm{d2}}$, $vflow_{\mathrm{cncl1}}$, and $vflow_{\mathrm{cncl2}}$, respectively. The vaccines in $vflow_{\mathrm{d1}}$ and $vflow_{\mathrm{d2}}$ move to the stock of administered vaccines $v_{\mathrm{admn1}}$and v_{admn2}, respectively, and end transitions. The vaccines with cancellations return to the on-site vaccine stock v_{site} and are allocated new reservations.

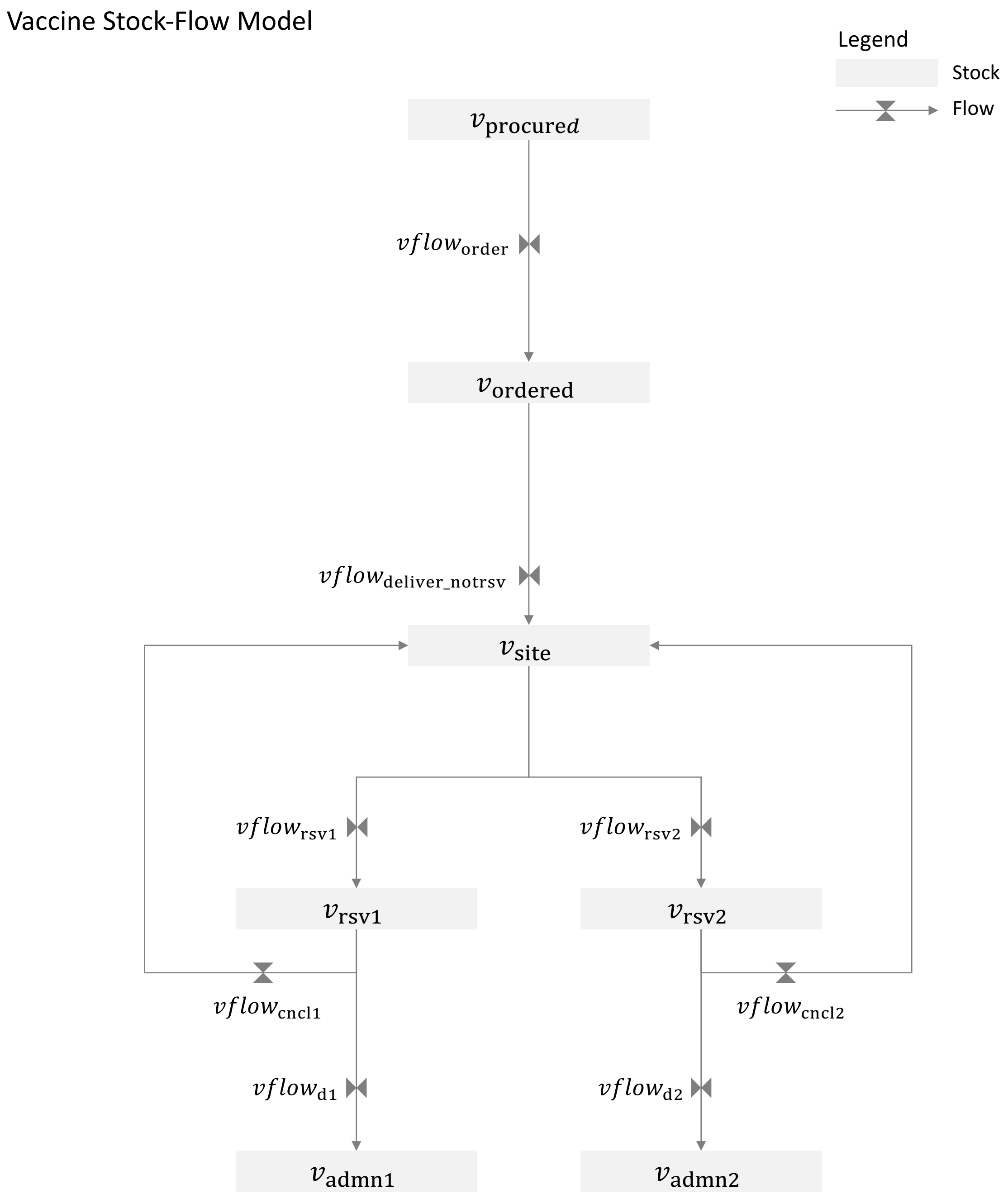


Figure 5-3 Vaccine Stock-Flow Model
Assumed stocks and flows of vaccines in the primary series assumed for simulation.

5.5. Demand-Supply Balancing for Reservations

The model fits the actual daily vaccination trend with vaccination demand and supply parameters. Reservation is the leading indicator of vaccination. Therefore, the model considers the national-scale demand-supply balancing on vaccinations to simulate the number of reservations $pflow_{\mathrm{rsv1}}$, $pflow_{\mathrm{rsv2}}$ and accompanied vaccine reservations $vflow_{\mathrm{rsv1}}$and $vflow_{\mathrm{rsv2}}$ each time step.

On the demand side, the sum of unvaccinated people willing to take the first doses p_{w} and partially vaccinated people willing to take the second doses p_{i1} is the total demand. The model prioritizes second doses for resource allocation to comply with the scheduled intervals among first and second doses by vaccine. This assumption can be aligned with the observed vaccination trends in Japan discussed in Chapter 3.8.

On the supply side, the model assumes the maximum vaccination capacity with the smaller factor among vaccine capacity discussed and cooperative healthcare workers for vaccinations discussed in the following chapters. The assumptions of vaccine and human resource constraints are based on the ceiling effect of vaccine distributions observed with the real-world datasets in Japan in Chapter 3.8. Considering the gap between daily vaccinations and vaccine distributions in mid and late May 2021, Figure 3-13 (b) implies that there could be other bottlenecks besides vaccine supplies. Previous studies [9]–[11] qualitatively point out the influence of human resource constraints.

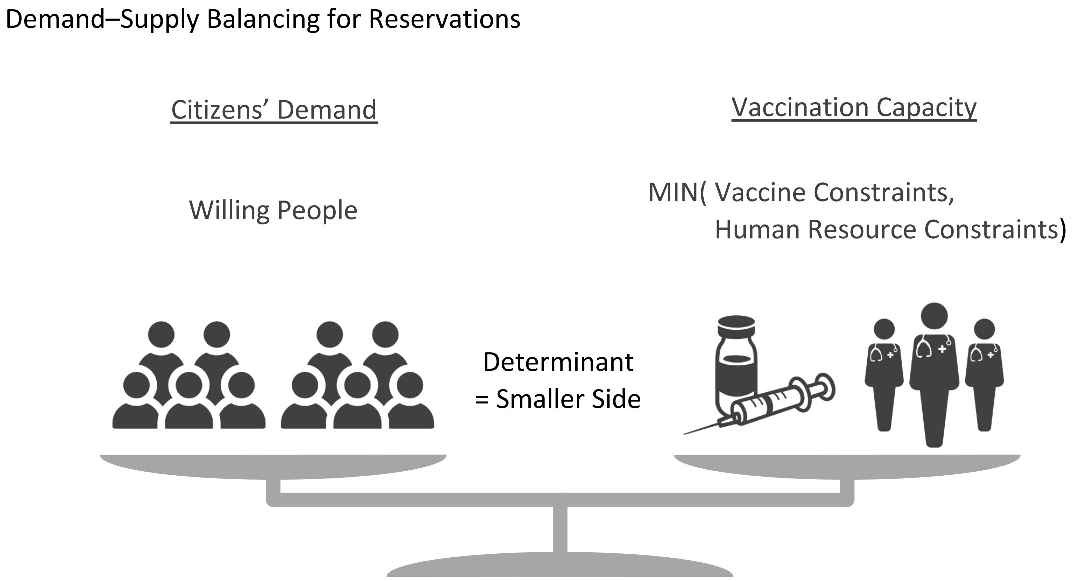


Figure 5-4 Demand-Supply Balancing for Reservations
Schematic of the algorithm to determine the reservation amount each time step as the minimum value among the remaining willing people and the maximum vaccination capacity based on available vaccines and cooperative healthcare workers.

5.6. Vaccine Constraints on Vaccination Capacity

5.6.1. Objective Vaccines and Distribution Datasets

The model simulates the primary-series vaccinations of two vaccines, Pfizer/BioNTech and Takeda/Moderna vaccines, in Japan based on distribution datasets introduced in Chapter 3.8. AstraZeneca vaccines, the other authorized vaccines in the simulation time range, are excluded from the model due to the limitation of distribution datasets and limited impacts on the total vaccinations.

The vaccine allocations for reservations are simulated based on the four categories of vaccine distributions in Japan, as Table 5-1 lists. Two categories were with Pfizer/BioNTech vaccines of 9.65 and 163.82 million doses for healthcare workers and other citizens. The other two categories were with Takeda/Moderna vaccines of 10.34 and 17.60 million doses for vaccinations at large sites and workplaces.

Table 5-1 Vaccine Distribution Category
Actual vaccine distribution categories for the primary series in Japan. "Freq.," "Pop.," "MM," and "Ref." stand for "Frequency," "Population," "Million," and "Reference," respectively.

Category Name (ID)	Vaccine (Delivery Freq.)	Operator of Vaccination Site	Occupation of Target Citizens	Target Age Group	Target Pop. Size (MM person)	Initiation Date in 2021	Distributed Vaccines by mid-Sept. 2021 (MM dose)	Ref.
Vaccinations for Healthcare Workers (PB-HW)	Pfizer/ BioNTech (14 days)	Prefectures Hospitals and Clinics	Healthcare	All eligible age groups	4.8	2/17	9.65 (4.8%)	[206]–[208]
Vaccinations for Elderly and Other Citizens (PB-OC)	Pfizer/ BioNTech (14 days)	Municipalities Hospitals and Clinics	All	1) 65 and older 2) Citizens with underlying diseases, etc. 3) Others	1) 36 2) -	1) 4/12 2)Depends on region 3)Depends on region	163.82 (81.3%)	[206]–[208]
Vaccinations at Large Sites (TM-LS)	Takeda/ Moderna (7 days)	Municipalities Hospitals JSDF	All	1) 65 and older 2) Citizens with underlying diseases, etc. 3) Others	-	1) 5/24 2)Depends on site	10.34 (5.1%)	[206], [207], [215]
Vaccinations in Workplaces (TM-WP)	Takeda/ Moderna (7 days)	Cooperative Organizations	All	1) 65 and older 2) Citizens with underlying diseases, etc. 3) Others	-	Depends on sites (Earliest example on 6/13)	17.60 (8.7%)	[206], [207], [216]

5.6.2. Comparing Vaccine Inflow and Stock

The vaccine constraint on vaccination capacity with first doses is defined as:

$$\begin{aligned}\text{Vaccine Constraint} = \max(&\text{ Allocated Available Vaccine Inflow with } vflow_{\text{deliver}},\\ &\text{Allocated Available Vaccine Stock with } v_{\text{site}}) \ .\end{aligned}$$

The model assumes that vaccine operators determine maximum vaccine capacities with vaccine inflows and stocks proportionally allocated to predicted willing populations $p_{\text{w\_predict}}$ by occupation category by age group, corresponding to vaccine distribution categories. In the initial status, operators do not know the citizens' willingness. Therefore, the simulation assumes that operators utilize the predicted willing population $p_{\text{w\_predict}}$ with the initially assumed willingness proportion of 100% as the proxy of the actual stock p_{w}.

5.6.3. Vaccine Inflow with Ceiling Effects

To calculate the maximum available vaccine inflows for first-dose reservations each time step, the model assumes that operators consider the different ceiling effects of vaccine distributions and corresponding reservation rules with Pfizer/BioNTech and Takeda/Moderna vaccines.

The observation in Chapter 3.8 found the thresholds of halved and nearly full vaccine distribution flows on first-dose vaccinations with the Pfizer/BioNTech and Takeda/Modena vaccines, respectively. The finding implies that operators tend to reserve Pfizer/BioNTech vaccines for both the first and second doses with first-dose reservations, while most of the other operators with Takeda/Moderna vaccines receive as many first-dose reservations as possible under constraints of weekly vaccine inflows and incoming second doses. These estimated mental models are integrated into the simulation algorithm with the following equation.

For operations on Pfizer/BioNTech vaccines

$$\text{Allocated Available Vaccine Inflow} = \text{Allocated } vflow_{\text{deliver}} * \text{Ceiling Coefficient}$$

For operations on Takeda/Moderna vaccines

$$\begin{aligned}\text{Allocated Available Vaccine Inflow} = \text{Allocated } vflow_{\text{deliver}} &* \text{Ceiling Coefficient}\\ &- \text{Reservations for Second Doses}\end{aligned}$$

The ceiling coefficients are 48.03% and 88.76% for Pfizer/BioNTech and Takeda/Moderna vaccines, respectively, based on the results in Chapter 3.8.

5.6.4. Vaccine Stock

With the decreasing vaccine deliveries, especially at the end of the vaccination campaigns, vaccine stocks on vaccination sites v_{site} are utilized to receive new reservations. The model assumes that operators calculate the maximum available vaccine stocks for first-dose reservations at a time step by the following equation.

For operations on Pfizer/BioNTech vaccines

$$\begin{aligned}\text{Allocated Available Vaccine Stock} = {} & \text{Allocated } v_{\text{site}} \div \text{Delivery Frequency} \\ & \div \text{Number of Scheduled Doses in Primary Series}\end{aligned}$$

For operations on Takeda/Moderna vaccines

$$\begin{aligned}\text{Allocated Available Vaccine Stock} = {} & (\text{Allocated } v_{\text{site}} \div \text{Delivery Frequency} \\ & - \text{Reservations for Second Doses}) \\ & \div \text{Number of Scheduled Doses in Primary Series}\end{aligned}$$

The delivery frequencies are 14 days and 7 days with distributions of the Pfizer/BioNTech and Takeda/Moderna vaccines, respectively. The numbers of scheduled doses with both the Pfizer/BioNTech and Takeda/Moderna vaccines are two for the primary series.

5.7. Human Resource Constraints on Vaccination Capacity

5.7.1. Screeners and Shooters for Vaccination Processes

Each vaccination has three steps on site, screening, dilution and filling of vaccines, and injection [217]. Only doctors could screen people who are eligible and medically appropriate for vaccinations under regulations in Japan. Dilution and filling of vaccines are implemented by nurses or pharmacists. Doctors or nurses can inject vaccines. To increase available human resources, MHLW allowed vaccine injection by dentists on April 26, 2021 [218], clinical laboratory technicians and emergency medical technicians on June 4 [219]. MHLW also enabled vaccine dilution and filling by clinical engineering technicians on June 4, 2021 [219].

This research considers available cooperative screeners and shooters as the representatives of human resource constraints on vaccination capacity. In the simulation, doctors are the only cohort for screeners, and nurses are for shooters with dilution and filling processes. The populations of other shooter candidates are not counted in the available cohort. The sum of these populations equals 16% of 1,281 thousand nurses in 2020 [220]: dentists of 107 thousand in 2020 [221], clinical laboratory technicians of 55 thousand (full-time equivalent) in 2020 [222], and emergency medical technicians in firefighter brigades of 41 thousand in 2021 [223].

Within doctors, industrial physicians are considered as the available cohort of screeners for workplace vaccinations with Takeda/Moderna vaccines because MHLW had requested workplace vaccination operators to prepare human resources by themselves and not to affect the vaccinations by local governments [224]. The population of other doctors is counted in the available maximum shooters for vaccinations with Pfizer/BioNTech vaccines and Takeda/Moderna vaccines at large sites. The population of active industrial physicians certified by the Japan Medical Associations was 32 thousand in 2020 [225], while the total doctors' population was 340 thousand in 2020 [221].

5.7.2. Full Immunization Assumption and Participation Rate

The key assumption of human resources in the model is that only fully vaccinated doctors and nurses cooperate with the vaccination project as screeners and nurses after they experience the immunity development interval with the second dose. The national government prioritized these healthcare workers to take vaccine shots first, considering their infection risks [206]. Following this risk management viewpoint, this simulation assumes that doctors and nurses tend to avoid participating in the vaccination campaign until they get fully immunized. The numbers of fully vaccinated doctors and nurses are the maximum amounts of available screeners and shooters, respectively.

The exception to this assumption is the vaccinations of healthcare workers. Due to the low infection risks with professional knowledge and practices, the model assumes no human resource constraints on the vaccination of healthcare workers.

The model also considers the participation rates of fully vaccinated doctors and nurses in the vaccination project. Due to their daily work and emergency responses during the pandemic, only some part of the cohorts could commit to the project full-time. Therefore, the populations of available cooperative screeners and shooters are defined as the product of maximum available workers and participation rates.

5.7.3. Shooter–Screener Ratio and Determinant of Human Resource Constraint

The number of available cooperative screeners and shooters are converted into the vaccination capacity constraints by the following equations:

$$\begin{aligned}
&\text{Screener Constraint on Vaccination Capacity (dose/day)}\\
&\qquad = \text{Number of Fully Immunized Screeners (person)} \times \text{ Participation Rate (\%)}\\
&\qquad \times \text{ Weekly Proportion of Working Days (\%)}\\
&\qquad \times \text{ Shooter}-\text{Screener Ratio on Vaccination Site (dimentionless)}\\
&\qquad \times \text{ Productivity of Shooters (dose/person/day)}
\end{aligned}$$

$$\begin{aligned}
&\text{Shooter Constraint on Vaccination Capacity (dose/day)}\\
&\qquad = \text{Number of Fully Immunized Shooters (person)} \times \text{ Participation Rate (\%)}\\
&\qquad \times \text{ Weekly Proportion of Working Days (\%)}\\
&\qquad \times \text{ Productivity of Shooters (dose/person/day)}
\end{aligned}$$

In the simulation model, the smaller side is treated as the vaccination capacity constraint from the human resource viewpoint.

The shooter–screener ratio is the proxy of logistics excellence on vaccination sites. The larger the ratio, the fewer screeners are required to prepare a vaccination capacity. For example, the planned shooter–screener (nurse–doctor) ratio could been estimated at 1.85 on average and 2.02 at maximum with Pfizer/BioNTech vaccinations for the elderly and other citizens on June 14, 2021 [226]. In this vaccination logistics by municipalities, 87% of vaccination sites are with clinics and small facilities. On the other hand, the shooter–screener (doctor–nurse) ratio at JSDF's large vaccination sites with Takeda/Moderna vaccines ranged from 4.33 to 5.33 [227].

5.7.4. Human Resource Allocations among Vaccine Distribution Categories

The model assumes the macroscopic adjustment mechanism on human resources in Japan, which allocates the available cooperative doctors and nurses to operations with three vaccine distribution categories of vaccinations for the elderly and other citizens with Pfizer/BioNTech vaccines (PB-OC), those at large vaccination sites, and in workplaces with Takeda/Moderna vaccines (TM-LC and TM-WP) in this order. The amounts of human resource allocations are determined by considering the maximum shooter–screener ratio achievable with operations with each vaccine distribution category.

First, cooperative doctors and nurses are allocated between PB-OC and TM-LC, considering the ratio of vaccine constraints based on $vflow_{\mathrm{deliver}}$ and v_{rsv2}. Then, the rest of the cooperative nurses are counted in the human resource capacity with occupational physicians for TM-WP administrations.

Human resource capacities are allocated to populations by occupation category by age group with the proportion of the predicted willing populations $p_{\mathrm{w\_predict}}$.

5.8. System Dynamics of Vaccination Processes

Figure 5-5 summarizes the system dynamics of vaccination processes with stocks and flows of population and vaccines with the mechanisms of demand-supply. There are three key causal loops: Reinforcing loop with human resource increase, balancing loop with willing people, and balancing loop with available vaccines.

The reinforcing loop of human resource increase indicates that, as the cumulative vaccination increases, the population of fully vaccinated people p_{fi}, human resource capacity with doctors and nurses, and the daily reservations go up. The balancing loops of resource depletions exhibit that remaining willing populations p_{w} and p_{i1} and not-reserved vaccine stocks in v_{site} decrease as vaccinations increase, and the decreases lead to the decline of vaccinations.

As the daily reservations are the leading indicators of daily vaccinations, the trends of vaccination speeds are determined by the integrated causal-loop effects of the increasing human resource capacity and depleting population and vaccines.

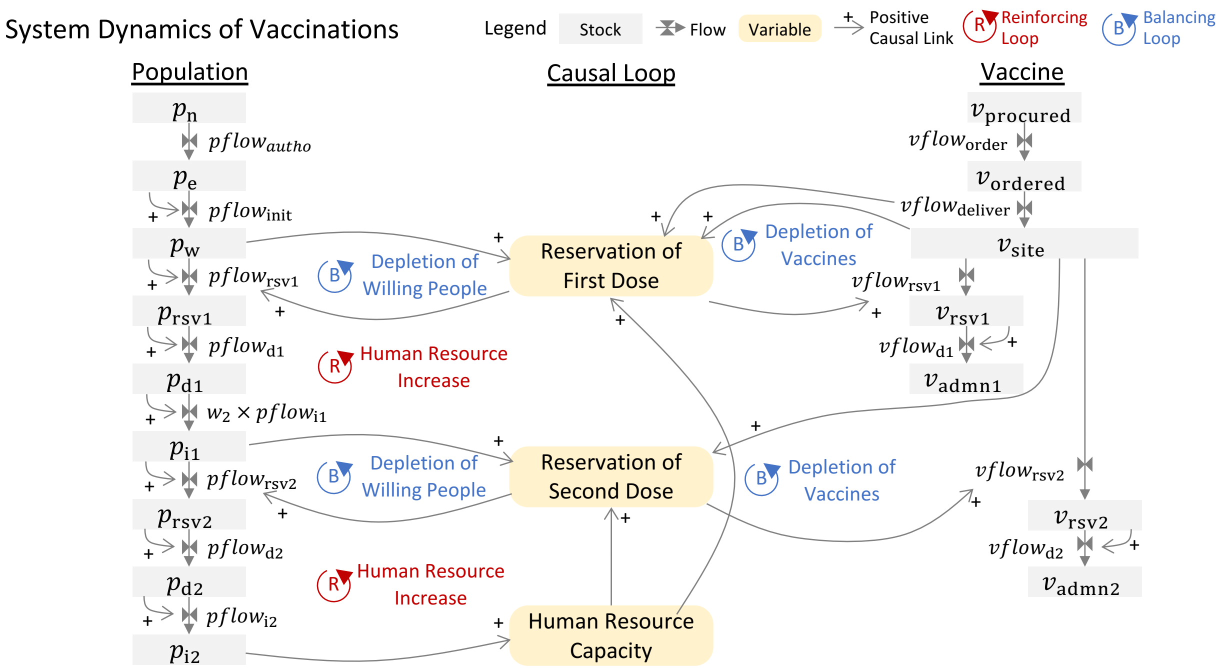


Figure 5-5 System Dynamics of Vaccinations
System dynamics of vaccination processes with population and vaccine stock-flow diagrams. Flows of cancellations are omitted.

5.9. Variables

Table 5-2 lists the basic variables referred to in each variable. Table 5-3 displays the correspondence of vdc and vc, sc, oc, age. Table 5-4 and Table 5-5 introduce input and output variables in the simulation model each.

Table 5-2 Basic Variables and Domains
Basic variables and domains referred to in other variables.

Variable	Domain	Note
$\boldsymbol{t}$	1–517	Daily time steps. $t = 1$ to 31 and 487 to 517, corresponding to October 31 to November 30, 2021, and March 1 to 31, 2022, are buffers for time-series simulation algorithms.
$\boldsymbol{vc}$	1 or 2	Vaccine Category. $vc = 1$ and 2 correspond to Pfizer/BioNTech and Takeda/Moderna vaccines each.
$\boldsymbol{sc}$	1 or 2	Site Category. $sc = 1$ corresponds to vaccination sites operated by local governments or JSDF. $sc = 2$ for workplaces of cooperative organizations.
$\boldsymbol{oc}$	1–5	Occupation Category. $oc = 1, 2, 3, 4,$ and 5 correspond to doctors excluding occupational physicians, occupational physicians, nurses, other healthcare workers, and other citizens.
$\boldsymbol{age}$	1–21	Age Group. $age = 1, 2, 3,$ and 4 correspond to 0–11 years old (y.o.), 12–15 y.o., 16–17 y.o., and 18–19 y.o. The values of from 5 to 20 correspond to five-year age group from 20–24 to 95–99. $age = 21$ for 100 y.o. and older.
$\boldsymbol{vdc}$	1–4	Vaccine Distribution Category. $vdc = 1$ and 2 correspond to vaccine distributions for vaccinations of healthcare workers, the elderly and other citizens with Pfizer/BioNTech vaccines. $vdc = 3$ and 4 for vaccinations at large sites and in workplaces each with Takeda/Moderna vaccines.

Table 5-3 Correspondence Table of Vaccine Distribution Categories
Correspondences of vaccine distribution categories with vaccine categories, site categories, occupation categories, and age groups. The values of age groups represent the maximum range in the simulation.

Vaccine	Vaccine Distribution Category Name	$\boldsymbol{vdc}$	$\boldsymbol{vc}$	$\boldsymbol{sc}$	$\boldsymbol{oc}$	$\boldsymbol{age}$
Pfizer/BioNTech	Vaccinations for Healthcare Workers	1	1	1	1–4	5–21
	Vaccinations for Elderly and Other Citizens	2	1	1	5	2–21
Takeda/Moderna	Vaccinations at Large Sites	3	2	1	1–5	2–21
	Vaccinations in Workplaces	4	2	2	5	2–21

Table 5-4 Input Variables
Input variables of the simulation model. “dmnl” stands for “dimensionless.”

Variable Category	Variable	Unit	Note	Initial Value	Reference of Initial Value
Population	$p_{\text{ttl}}(oc, age)$	person	Total population in Japan by occupation by age group	Doctors’ population, except for occupational physicians, is calculated as the gap between the national statistics as of December 31, 2020, and the numbers of occupational physicians. The number of age 24 and younger in the original national dataset is treated as the value with the age group of 20–24 in the simulation.	[221]
				For the occupational physicians’ population, the number of active certified occupational physicians by Japan Medical Associations as of August 14, 2019, is referred to. The age groups by ten years in the reference are decomposed into the age groups in Table 5-2 with the assumption of equal population distribution in each year old in each age group.	[225]
				Nurses’ population is the value as of the end of 2020 with the national dataset. The population under 25 in the original dataset is treated as the value with the age group of 20–24 in the simulation.	[220]
				The age distributions of other healthcare workers are calculated with the age distributions of doctors, occupational physicians, and nurses. This age distribution is multiplied by the gap between the introduced population of 4.8 million healthcare workers by the Prime Minister’s Office of Japan and the summed population of doctors, occupational physicians, and nurses.	[208]
				The age-stratified populations of other citizens are the gap of the total populations and the summed populations of doctors, occupational physicians, nurses, and other healthcare workers. Total populations in Japan	[53]

				are as of January 1, 2022. Regarding the age groups under 20 years old, the reference data of age groups by five years are decomposed and recombined to prepare age groups in Table 5-2 with the assumption of equal population distribution in each year old in each age group.	
	$w_{\mathrm{d1}}(oc, age)$	%	Proportion of willing people to take first dose	74.39%–100.00% The values are calculated by dividing the actual data of age-stratified cumulative people who have taken the first doses and more as of April 10, 2023, by the total populations in corresponding age groups as of January 1, 2022. The value of 101% with age 100 years old and older is calibrated to 100%. The same values are applied for all the occupation group by age group.	[51] [53]
	$w_{\mathrm{d2}}(oc, age)$	%	Proportion of willing partially vaccinated people to take second dose	99.17%–99.82% The values are calculated by dividing the actual data of age-stratified cumulative people who have taken first and second doses as of April 10, 2023, by the total populations in corresponding age groups as of January 1, 2022. The same values are applied for all the occupation groups by age group.	[51] [53]
	$w_{\mathrm{d1\_predict}}(oc, age)$	%	Proportion of willing people to take first doses predicted by vaccination site operators	100% Vaccination operators' initial prediction on the citizens' willingness to take the first doses. This variable is utilized to simulate human resource and vaccine allocations by operators.	Assumption
	$w_{\mathrm{d2\_predict}}(oc, age)$	%	Proportion of willing partially vaccinated people to take second doses predicted by vaccination site operators	100% Vaccination operators' initial prediction on the partially vaccinated citizens' willingness to take second doses. This variable is utilized to simulate human resource and vaccine allocations by operators.	Assumption
	cp_{d1}	%	Cancellation probability with first-dose reservations	1.021% The cancellation probability is calculated with the actual data of reservations and vaccinations in JSDF vaccination sites from May 24 to September 23, 2021. The value is	[227]

				the average value of two JSDF vaccination sites in Tokyo and Osaka.	
	cp_{d2}	%	Cancellation probability with second-dose reservations	1.021% The same value to cp_{d1}.	-
Authorization and Initiation	$date_{\mathrm{autho}}(vc, age)$	date	Date of vaccine authorization	$vc = 1$, Pfizer/BioNTech vaccines $age = 3$ to 21, Age 16 y.o. and older: February 14, 2021 (t = 107)	[52], [206]
				$age = 2$, Age 12–15 y.o. June 1, 2021 (t = 214)	[52]
				$vc = 2$, Takeda/Moderna vaccines $age = 4$ to 21, Age 18 y.o. and older May 21, 2021 (t = 203)	[206]
				$age = 2$ and 3, Age 12–17 y.o. August 3, 2021 (t = 277)	[52]
				Other cases July 26, 2023 (t = 999)	Assumption
	$date_{\mathrm{init}}(vc, sc, oc, age)$	date	Initiation date of vaccination	$vc = 1$, Pfizer/BioNTech vaccines $sc = 1, oc = 1$ to 4 Vaccinations for healthcare workers $age = 5$ to 21 February 17, 2021 (t = 110)	[208]
				$sc = 1, oc = 5$ Vaccinations for Elderly and Other Citizens $age = 14$ to 21, Age 65 y.o. and older April 12, 2021 (t = 164)	[208]
				$age = 4$ to 13, Age 18–64 y.o. June 17, 2021 (t = 230) Refer to the initiation date of the vaccinations at large sites.	Assumption
				$vc = 2$, Takeda/Moderna vaccines $sc = 1, oc = 1$ to 4 Vaccinations at large sites $age = 14$ to 21, Age 65 y.o. and older May 24, 2021 (t = 206)	[228]
				$age = 4$ to 13, Age 18–64 y.o. June 17, 2021 (t = 230)	[228]
				$age = 2$ and 3, Age 12–17 y.o.	

				August 3, 2021 (t = 277) Refer to authorization date.	[52]
				$sc = 2, oc = 5$ Vaccinations in workplaces $age = 4$ to 21, Age 18 y.o. and older June 13, 2021 (t = 226)	[207], [216]
				$age = 2$ and 3, Age 12–17 y.o. August 3, 2021 (t = 277) Refer to authorization date.	[52]
				Other cases July 26, 2023 (t = 999)	Assumption
Vaccine Characteristic	$num_{\mathrm{dose}}(vc)$	dose	Number of doses required in primary series by vaccine	$vc = 1$, Pfizer/BioNTech vaccines 2 doses	[3]
				$vc = 2$, Takeda/Moderna vaccines 2 doses	[3], [72]
	$intrvl_{\mathrm{i1}}(vc)$	day	Immunity development interval with first dose	$vc = 1$, Pfizer/BioNTech vaccines 12 days	[229]
				$vc = 2$, Takeda/Moderna vaccines 14 days	[230]
	$intrvl_{\mathrm{d1d2}}(vc)$	day	Interval between first and second doses	$vc = 1$, Pfizer/BioNTech vaccines 21 days	[3]
				$vc = 2$, Takeda/Moderna vaccines 28 days	[3], [72]
	$intrvl_{\mathrm{i2}}(vc)$	day	Immunity development interval with second dose	$vc = 1$, Pfizer/BioNTech vaccines 7 days	[229]
				$vc = 2$, Takeda/Moderna vaccines 14 days	[230]
Vaccine Supply	$vflow_{\mathrm{deliver}}(vdc)$	dose/day	Daily delivered vaccines on vaccination sites	The dataset prepared in Chapter 3.8.	[206], [207]
	$intrvl_{\mathrm{deliver}}(vdc)$	day	Interval from order confirmation to delivery of ordered vaccines	$vdc = 1$ Vaccinations for healthcare workers 7 days	[231]
				$vdc = 2$ Vaccinations for elderly and other citizens 11 days	[206]

				According to the delivery schedule in mid and late-May 2021 with Pfizer/BioNTech vaccines. $vdc = 3$ Vaccinations at large sites 11days $vdc = 4$ Vaccinations in workplaces 11days The same value to the case of $vdc = 3$.	[232] Assumption
	$freq_{\mathrm{deliver}}(vdc)$	day	Frequency of vaccine delivery	$vc = 1$, Pfizer/BioNTech vaccines 14 days $vc = 2$, Takeda/Moderna vaccines 7 days	[206], [207]
Human Resource	pr_{doctor}	%	Participation rate of doctors excluding occupational physicians in vaccination project	21.12% The planned number of doctors participating in vaccinations by municipalities as of June 14, 2021, is divided by the total population of doctors as of December 31, 2020, excluding active occupational physicians certified by the Japan Medical Association as of August 14, 2019.	[226] [221] [225]
	pr_{op}	%	Participation rate of occupational physicians in vaccination project	12.74% The number of vaccination sites at workplaces that had received Takeda/Moderna vaccines by October 31, 2021, is divided by the total population of active occupational physicians certified by the Japan Medical Association as of August 14, 2019.	[233] [225]
	pr_{nurse}	%	Participation rate of nurses in vaccination project	9.378% The planned number of nurses participating in vaccinations by municipalities as of June 14, 2021, is divided by the total population of nurses as of the end of 2020.	[226] [220]
	$maxratio_{\mathrm{NperDOP}}(vc, sc)$	dmnl	Maximum achievable ratio of nurses to doctors or occupational physicians on vaccination site	$vc = 1$, Pfizer/BioNTech vaccines $sc = 1$ Vaccinations operated by municipalities 2.02	[226]

				The maximum ratio of planned numbers of nurses and doctors participating in vaccinations at school facilities operated by municipalities as of June 14, 2021, among other five facility types for vaccination sites: clinics for individual vaccinations, hospitals and clinics for mass vaccinations, health centers, public halls, and other facilities. $sc = 2$ 0 No administration at workplaces with Pfizer/BioNTech vaccines.	
				$vc = 2$, Takeda/Moderna vaccines $sc = 1$ Vaccination at large facilities 5.33 The nurse–doctor ratio observed at JSDF vaccination site in Osaka in 2021, which is large than the number at other JSDF site in Tokyo, 4.33.	[227]
				$sc = 2$ Vaccination in workplaces 5.33 The same value to the case of $vc = 2, sc = 1$.	Assumption
	day_{work}	day	Working days per week	5 days	Assumption
	prd	dose/day /person	Number of daily vaccine doses one nurse can administer	34.86 The average value of maximum daily capacities divided by the total number of nurses at JSDF vaccination sites in Tokyo and Osaka.	[227]
Other Operational Factor	$ceiling(vdc)$	%	Coefficient of ceiling effect on daily reservations with vaccine distributions	$vc = 1$, Pfizer/BioNTech vaccines 48.03% $vc = 2$, Takeda/Moderna vaccines 88.76%	Assumption based on Chapter 3.8
	$intrvl_{\mathrm{rsv}}$	day	Interval between a reservation and vaccination	7 days	[215]

Table 5-5 Output Variables
Input variables of the simulation model.

Variable Category	Variable	Unit	Note	Initial Value	Reference of Initial Value
Population	$p_{\mathrm{n}}(t, oc, age)$	person	Stock of population ineligible to take any vaccine	p_{ttl}	Assumption
	$pflow_{\mathrm{autho}}(t, oc, age)$	person/day	Flow of population with vaccine authorization	0	-
	$p_{\mathrm{e}}(t, oc, age)$	person	Stock of population eligible, but not in turn, to take vaccine	0	-
	$pflow_{\mathrm{init}}(t, oc, age)$	person/day	Flow of population with initiation of vaccination	0	-
	$p_{\mathrm{w}}(t, oc, age)$	person	Stock of population in turn, and willing to take first dose	0	-
	$p_{\mathrm{u}}(t, oc, age)$	person	Stock of population in turn, and unwilling to take first dose	0	-
	$pflow_{\mathrm{rsv1}}(t, vc, sc, oc, age)$	person/day	Flow of population who get first-dose reservations	0	-
	$p_{\mathrm{rsv1}}(t, vc, sc, oc, age)$	person	Stock of population with reservation of first dose	0	-
	$pflow_{\mathrm{d1}}(t, vc, sc, oc, age)$	person/day	Flow of population with first doses	0	-
	$pflow_{\mathrm{cncl1}}(t, vc, sc, oc, age)$	person/day	Flow of population with the cancellation of first dose	0	-
	$p_{\mathrm{d1}}(t, vc, sc, oc, age)$	person	Stock of population who have taken first dose, and have not experienced immunity development interval	0	-
	$pflow_{\mathrm{i1}}(t, vc, sc, oc, age)$	person/day	Flow of population completing immunity development with first dose	0	-
	$p_{\mathrm{i1}}(t, vc, sc, oc, age)$	person	Stock of population who have experienced immunity development interval with first dose, and is willing to take second dose	0	-
	$p_{\mathrm{i1fin}}(t, vc, sc, oc, age)$	person	Stock of population who have experienced immunity development interval with first dose, and is unwilling to take second dose	0	-
	$pflow_{\mathrm{rsv2}}(t, vc, sc, oc, age)$	person/day	Flow of population who get second-dose reservations	0	-
	$p_{\mathrm{rsv2}}(t, vc, sc, oc, age)$	person	Stock of population with reservation of second dose	0	-
	$pflow_{\mathrm{d2}}(t, vc, sc, oc, age)$	person/day	Flow of population with second doses	0	-

	$pflow_{\mathrm{cncl2}}(t, vc, sc, oc, age)$	person/day	Flow of population with the cancellation of second dose	0	-
	$p_{\mathrm{d2}}(t, vc, sc, oc, age)$	person	Stock of population who have taken second dose, and have not experienced immunity development interval	0	-
	$pflow_{\mathrm{i2}}(t, vc, sc, oc, age)$	person/day	Flow of population completing immunity development with second dose	0	-
	$p_{\mathrm{i2}}(t, vc, sc, oc, age)$	person	Stock of population who have experienced immunity development interval with second dose	0	-
Vaccine Supply	$v_{\mathrm{procured}}(t, vc)$	dose	Stock of vaccines a national government has	$vc = 1$ 174 million doses $vc = 2$ 28 million doses	Assumption based on the distributed vaccines in Japan [207]
	$vflow_{\mathrm{ordered}}(t, vdc)$	dose/day	Flow of vaccines ordered by vaccination operators	0	-
	$v_{\mathrm{ordered}}(t, vdc)$	dose	Stock of vaccines ordered by vaccination operators	0	-
	$vflow_{\mathrm{deliver}}(t, vdc)$	dose/day	Flow of vaccines on the way of delivery without reservation	0	-
	$v_{\mathrm{site}}(t, vdc)$	dose	Stock of vaccines on each vaccination site without reservations	0	-
	$vflow_{\mathrm{rsv1}}(t, vc, sc, oc, age)$	dose/day	Flow of vaccines on sites reserved for first doses	0	-
	$vflow_{\mathrm{rsv2}}(t, vc, sc, oc, age)$	dose/day	Flow of vaccines on sites reserved for second doses	0	-
	$v_{\mathrm{rsv1}}(t, vc, sc, oc, age)$	dose	Stock of vaccines on sites with reservations for first doses	0	-
	$v_{\mathrm{rsv2}}(t, vc, sc, oc, age)$	dose	Stock of vaccines on sites with reservations for second doses	0	-
	$vflow_{\mathrm{d1}}(t, vc, sc, oc, age)$	dose/day	Flow of daily first doses	0	-
	$vflow_{\mathrm{d2}}(t, vc, sc, oc, age)$	dose/day	Flow of daily second doses	0	-
	$vflow_{\mathrm{cncl1}}(t, vc, sc, oc, age)$	dose/day	Flow of cancellations with first doses	0	-
	$vflow_{\mathrm{cncl2}}(t, vc, sc, oc, age)$	dose/day	Flow of cancellations with second doses	0	-
	$v_{\mathrm{admn1}}(t, vc, sc, oc, age)$	dose	Stock of vaccines administered as first doses	0	-
	$v_{\mathrm{admn2}}(t, vc, sc, oc, age)$	dose	Stock of vaccines administered as second doses	0	-
Human Resource	$capacity_{\mathrm{hr}}(t, vc, sc, oc, age)$	dose/day	Allocated available human resource capacity	0	-
Other Operational Factor	$rsvflow1(t, vc, sc, oc, age)$	reservation/day	Reservations for first doses	0	-
	$rsvflow2(t, vc, sc, oc, age)$	reservation/day	Reservations for second doses	0	-

5.10. Algorithms

5.10.1. Core Workflow

The following operations in order introduce the stock-flow algorithm of populations and vaccines in the simulation model. "× 1" in the equations is for unit adjustment.

For $t = 1$, input initial values into p_{n} and v_{procured}, prepare $pflow_{\mathrm{autho}}(t, oc, age)$ and $pflow_{\mathrm{init}}(t, oc, age)$.

For $t = 2$ to 31, update stocks.

$$p_{\mathrm{n}}(t, oc, age) = p_{\mathrm{n}}(t-1, oc, age)$$

$$v_{\mathrm{n}}(t, vc) = p_{\mathrm{n}}(t-1, vc)$$

For $t = 32$ to 486, calculate the following equations,

Update upstream vaccine stocks and flows.

$$vflow_{\mathrm{order}}(t, r, vdc) = vflow_{\mathrm{deliver}}(t + intrvl_{\mathrm{deliver}}, r, vdc)$$

$$v_{\mathrm{procured}}(t, vc) = v_{\mathrm{procured}}(t-1, vc) \\ - \textstyle\sum_{vdc} vflow_{\mathrm{order}}(t, vdc)$$

$$v_{\mathrm{ordered}}(t, vdc) = v_{\mathrm{ordered}}(t-1, vdc) + vflow_{\mathrm{order}}(t, vdc) - vflow_{\mathrm{deliver}}(t, vdc)$$

$$v_{\mathrm{site}}(t, vdc) = v_{\mathrm{site}}(t-1, vdc) + vflow_{\mathrm{deliver}}(t, vdc)$$

Update upstream population stocks and flows.

$$p_{\mathrm{n}}(t, oc, age) = p_{\mathrm{n}}(t-1, oc, age) - pflow_{\mathrm{autho}}(t, oc, age)$$

$$p_{\mathrm{e}}(t, oc, age) = p_{\mathrm{e}}(t-1, oc, age) + pflow_{\mathrm{autho}}(t, oc, age) \\ - pflow_{\mathrm{init}}(t, oc, age)$$

$$p_{\mathrm{w}}(t, oc, age) = p_{\mathrm{w}}(t-1, oc, age) + w_{\mathrm{d1}}(oc, age) \times pflow_{\mathrm{init}}(t, oc, age)$$

$$p_{\mathrm{w_{predict}}}(t, oc, age) = p_{\mathrm{w_{predict}}}(t-1, oc, age) \\ + w_{\mathrm{d1}}(oc, age) \times pflow_{\mathrm{init}}(t, oc, age)$$

$$p_{\mathrm{u}}(t, oc, age) = p_{\mathrm{u}}(t-1, oc, age) + (1 - w_{\mathrm{d1}}(oc, age)) \times pflow_{\mathrm{init}}(t, oc, age)$$

$$p_{\mathrm{u\_predict}}(t, oc, age) = p_{\mathrm{u\_predict}}(t-1, oc, age) \\ +(1 - w_{\mathrm{d1}}(oc, age)) \times pflow_{\mathrm{init}}(t, oc, age)$$

Run reservation algorithms in Chapter 5.10.2.

Update stocks and flows with vaccination and immune development.

$$pflow_{\mathrm{d1}}(t, vc, sc, oc, age) = (1 - cp_{\mathrm{d1}}) \times pflow_{\mathrm{rsv1}}(t\ - intrvl_{\mathrm{rsv}}, vc, sc, oc, age)$$
$$pflow_{\mathrm{cncl1}}(t, vc, sc, oc, age) = cp_{\mathrm{d1}} \times pflow_{\mathrm{rsv1}}(t\ - intrvl_{\mathrm{rsv}}, vc, sc, oc, age)$$
$$vflow_{\mathrm{d1}}(t, vc, sc, oc, age) = pflow_{\mathrm{d1}}(t, vc, sc, oc, age) \times 1$$
$$vflow_{\mathrm{cncl1}}(t, vc, sc, oc, age) = pflow_{\mathrm{cncl1}}(t, vc, sc, oc, age) \times 1$$
$$pflow_{\mathrm{i1}}(t, vc, sc, oc, age) = pflow_{\mathrm{d1}}(t\ - intrvl_{\mathrm{i1}}(vc), vc, sc, oc, age)$$

$$\begin{aligned} p_{\mathrm{rsv1}}(t, vc, sc, oc, age) = {} & p_{\mathrm{rsv1}}(t-1, vc, sc, oc, age) \\ & + pflow_{\mathrm{rsv1}}(t, vc, sc, oc, age) \\ & - pflow_{\mathrm{d1}}(t, vc, sc, oc, age) - pflow_{\mathrm{cncl1}}(t, vc, sc, oc, age) \end{aligned}$$
$$\begin{aligned} v_{\mathrm{rsv1}}(t, vc, sc, oc, age) = {} & v_{\mathrm{rsv1}}(t-1, vc, sc, oc, age) \\ & + vflow_{\mathrm{rsv1}}(t, vc, sc, oc, age) \\ & - vflow_{\mathrm{d1}}(t, vc, sc, oc, age) - vflow_{\mathrm{cncl1}}(t, vc, sc, oc, age) \end{aligned}$$
$$\begin{aligned} p_{\mathrm{d1}}(t, vc, sc, oc, age) = {} & p_{\mathrm{d1}}(t-1, vc, sc, oc, age) \\ & + pflow_{\mathrm{d1}}(t, vc, sc, pc, age) \\ & - pflow_{\mathrm{i1}}(t, vc, sc, oc, age) \end{aligned}$$
$$\begin{aligned} v_{\mathrm{admn1}}(t, vc, sc, oc, age) = {} & v_{\mathrm{admn1}}(t-1, vc, sc, oc, age) \\ & + vflow_{\mathrm{d1}}(t, vc, sc, oc, age) \end{aligned}$$

$$\begin{aligned} p_{\mathrm{i1}}(t, vc, sc, oc, age) = {} & p_{\mathrm{i1}}(t-1, vc, sc, oc, age) \\ & + w_{\mathrm{d2}}(oc, age) \times pflow_{\mathrm{i1}}(t, vc, sc, oc, age) \\ & - pflow_{\mathrm{rsv2}}(t, vc, sc, oc, age) \end{aligned}$$
$$\begin{aligned} p_{\mathrm{i1fin}}(t, vc, sc, oc, age) = {} & p_{\mathrm{i1fin}}(t-1, vc, sc, oc, age) \\ & + (1 -\ w_{\mathrm{d2}}(oc, age)) \times pflow_{\mathrm{i1}}(t, vc, sc, oc, age) \end{aligned}$$

$$pflow_{\mathrm{d2}}(t, vc, sc, oc, age) = (1 - cp_{\mathrm{d2}}) \times pflow_{\mathrm{rsv2}}(t\ - intrvl_{\mathrm{rsv}}, vc, sc, oc, age)$$
$$pflow_{\mathrm{cncl2}}(t, vc, sc, oc, age) = cp_{\mathrm{d2}} \times pflow_{\mathrm{rsv2}}(t\ - intrvl_{\mathrm{rsv}}, vc, sc, oc, age)$$
$$vflow_{\mathrm{d2}}(t, vc, sc, oc, age) = pflow_{\mathrm{d2}}(t, vc, sc, oc, age) \times 1$$

For $vc = 1$, operations with Pfizer/BioNTech vaccine distributions

$$vflow_{\mathrm{cncl2}}(t, vc, sc, oc, age) = pflow_{\mathrm{cncl1}}(t, vc, sc, oc, age) \times 1$$

For $vc = 2$, operations with Takeda/Moderna vaccine distributions

$$vflow_{\mathrm{cncl2}}(t, vc, sc, oc, age) = pflow_{\mathrm{cncl2}}(t, vc, sc, oc, age) \times 1$$

$$pflow_{\mathrm{i2}}(t, vc, sc, oc, age) = pflow_{\mathrm{d2}}(t\ - intrvl_{\mathrm{i2}}(vc), vc, sc, oc, age)$$

$$\begin{aligned} p_{\mathrm{d2}}(t, vc, sc, oc, age) = p_{\mathrm{d2}}(t-1, vc, sc, oc, age) \\ + pflow_{\mathrm{d2}}(t, vc, sc, oc, age) \\ - pflow_{\mathrm{i2}}(t, vc, sc, oc, age) \end{aligned}$$

$$\begin{aligned} p_{\mathrm{i2}}(t, vc, sc, oc, age) = p_{\mathrm{i2}}(t-1, vc, sc, oc, age) \\ + pflow_{\mathrm{i2}}(t, vc, sc, oc, age) \end{aligned}$$

Add $w_{\mathrm{d2}}(oc, age) \times pflow_{\mathrm{cncl2}}(t, vc, sc, oc, age)$ to $p_{\mathrm{i1}}(t, vc, sc, oc, age)$.

Add $\left(1 - w_{\mathrm{d2}}(oc, age)\right) \times pflow_{\mathrm{cncl2}}(t, vc, sc, oc, age)$ to $p_{\mathrm{i1fin}}(t, vc, sc, oc, age)$.

Update $p_{\mathrm{w}}, p_{\mathrm{w\_predict}}, p_{\mathrm{u}}$, and $p_{\mathrm{u\_predict}}$ with summed inflows and outflows.

Add $\sum_{vc,sc} \begin{aligned}(- pflow_{\mathrm{rsv1}}(t, vc, sc, oc, age) \\ + w_{\mathrm{d1}}(oc, age) \times pflow_{\mathrm{cncl1}}(t, vc, sc, oc, age))\end{aligned}$

to corresponding $p_{\mathrm{w}}(t, oc, age)$ and $p_{\mathrm{w\_predict}}(t, oc, age)$.

Add $\sum_{vc,sc} (1 - w_{\mathrm{d1}}(oc, age)) \times pflow_{\mathrm{cncl1}}(t, vc, sc, oc, age))$

to corresponding $p_{\mathrm{u}}(t, oc, age)$ and $p_{\mathrm{u\_predict}}(t, oc, age)$.

Update $v_{\mathrm{site}}(t, vdc)$ with summed inflows and outflows.

Add $\sum_{vc,sc,oc,age} \begin{aligned}(-vflow_{\mathrm{rsv1}}(t, vc, sc, oc, age) - vflow_{\mathrm{rsv2}}(t, vc, sc, oc, age) \\ + vflow_{\mathrm{cncl1}}(t, vc, sc, oc, age) + vflow_{\mathrm{cncl2}}(t, vc, sc, oc, age))\end{aligned}$

to corresponding $v_{\mathrm{site}}(t, vdc)$.

For $t = 487$ to 517, update stocks and flows with no additional vaccine authorization, initiation, vaccine order and reservation.

Update upstream vaccine stocks and flows.

$$v_{\mathrm{procured}}(t, vc) = v_{\mathrm{procured}}(t-1, vc)$$
$$v_{\mathrm{ordered}}(t, vdc) = v_{\mathrm{ordered}}(t-1, vdc) - vflow_{\mathrm{deliver}}(t, vdc)$$
$$v_{\mathrm{site}}(t, vdc) = v_{\mathrm{site}}(t-1, vdc) + vflow_{\mathrm{deliver}}(t, vdc)$$

Update upstream population stocks and flows.

$$p_{\mathrm{n}}(t, oc, age) = p_{\mathrm{n}}(t-1, oc, age)$$
$$p_{\mathrm{e}}(t, oc, age) = p_{\mathrm{e}}(t-1, oc, age)$$
$$p_{\mathrm{w}}(t, oc, age) = p_{\mathrm{w}}(t-1, oc, age)$$
$$p_{\mathrm{w}_{\mathrm{predict}}}(t, oc, age) = p_{\mathrm{w}_{\mathrm{predict}}}(t-1, oc, age)$$
$$p_{\mathrm{u}}(t, oc, age) = p_{\mathrm{u}}(t-1, oc, age)$$
$$p_{\mathrm{u\_predict}}(t, oc, age) = p_{\mathrm{u\_predict}}(t-1, oc, age)$$

Input zero to reservation variables.

$$capacity_{\mathrm{hr}}(t, vc, sc, oc, age) = 0$$

$$rsvflow1(t, vc, sc, oc, age) = 0$$

$$pflow_{\mathrm{rsv1}}(t, vc, sc, oc, age) = 0$$

$$vflow_{\mathrm{rsv1}}(t, vc, sc, oc, age) = 0$$

$$rsvflow2(t, vc, sc, oc, age) = 0$$

$$pflow_{\mathrm{rsv2}}(t, vc, sc, oc, age) = 0$$

$$vflow_{\mathrm{rsv2}}(t, vc, sc, oc, age) = 0$$

Update stocks and flows with vaccination and immune development.

Update $p_{\mathrm{w}}, p_{\mathrm{w\_predict}}, p_{\mathrm{u}}$, and $p_{\mathrm{u\_predict}}$ with summed inflows and outflows.

Update $v_{\mathrm{site}}(t, vdc)$ with summed inflows and outflows.

Algorithms for these three workflows are the same to $t = 32$ to 486.

5.10.2. Reservation

The following reservation algorithms run in the core workflow each time step of $t = 32$ to 486. Unit adjustment factors are abbreviated.

For $vc = 1$, operations on Pfizer/BioNTech vaccines

$$rsvflow1(t, vc, sc, oc, age) = \min \begin{pmatrix} \max \begin{pmatrix} \text{Allocated Available Vaccine Inflow} \\ \text{Allocated Available Vaccine Stock} \end{pmatrix} \\ \text{Allocated Available Human Resrouce Capacity} \\ p_{\mathrm{w}}(t, oc, age) \end{pmatrix}$$

Subscript variables t, vc, sc, oc, and age are abbreviated.

$$pflow_{\mathrm{rsv1}}(t, vc, sc, oc, age) = rsvflow1(t, vc, sc, oc, age)$$

$$vflow_{\mathrm{rsv1}}(t, vc, sc, oc, age) = rsvflow1(t, vc, sc, oc, age)$$

$$vflow_{\mathrm{rsv2}}(t, vc, sc, oc, age) = rsvflow1(t, vc, sc, oc, age)$$

$$\begin{aligned} rsvflow2(t, vc, sc, oc, age) = {} & w_{\mathrm{d2}}(oc, age) \times \\ & (\, pflow_{\mathrm{d1}}(t - (intrvl_{\mathrm{d1d2}}(vc) - intrvl_{\mathrm{rsv}}), vc, sc, oc, age) \\ & + pflow_{\mathrm{cncl2}}(t - 1, vc, sc, oc, age)\,) \end{aligned}$$

$$pflow_{\mathrm{rsv2}}(t, vc, sc, oc, age) = rsvflow2(t, vc, sc, oc, age)$$

For $vc = 2$, operations on Takeda/Moderna vaccines,

$$
\begin{aligned}
rsvflow2(t, vc, sc, oc, age) = w_{\mathrm{d2}}(oc, age) \times \\
&\left(pflow_{\mathrm{d1}}(t - (intrvl_{\mathrm{d1d2}}(vc) - intrvl_{\mathrm{rsv}}), vc, sc, oc, age) \right. \\
&\left. + pflow_{\mathrm{cncl2}}(t - 1, vc, sc, oc, age) \right)
\end{aligned}
$$

$$pflow_{\mathrm{rsv2}}(t, vc, sc, oc, age) = rsvflow2(t, vc, sc, oc, age)$$

$$vflow_{\mathrm{rsv2}}(t, vc, sc, oc, age) = rsvflow2(t, vc, sc, oc, age)$$

$$
\begin{aligned}
&rsvflow1(t, vc, sc, oc, age) \\
&= \max \begin{pmatrix} \min \begin{pmatrix} \max \begin{pmatrix} \text{Allocated Available Vaccine Inflow} \\ \text{Allocated Available Vaccine Stock} \end{pmatrix} \\ \text{Allocated Available Human Resrouce Capacity} \\ \text{Adjusted } p_{\mathrm{w}} \end{pmatrix} \\ 0 \end{pmatrix}
\end{aligned}
$$

Subscript variables t, vc, sc, oc, and age are abbreviated.

For $vdc = 3$

Adjusted $p_{\mathrm{w}}(t, oc, age) = p_{\mathrm{w}}(t, oc, age) - pflow_{\mathrm{rsv1}}(t, 1, 1, oc, age)$

For $vdc = 4$

$$
\begin{aligned}
\text{Adjusted } p_{\mathrm{w}}(t, oc, age) = p_{\mathrm{w}}(t, oc, age) - pflow_{\mathrm{rsv1}}(t, 1, 1, oc, age) \\
- pflow_{\mathrm{rsv1}}(t, 2, 1, oc, age)
\end{aligned}
$$

$$pflow_{\mathrm{rsv1}}(t, vc, sc, oc, age) = rsvflow1(t, vc, sc, oc, age)$$

$$vflow_{\mathrm{rsv1}}(t, vc, sc, oc, age) = rsvflow1(t, vc, sc, oc, age)$$

5.10.3. Vaccine Inflow Allocation

Allocated available vaccine inflows in the reservation algorithms are derived from the following operations. To avoid excess reservations in the last two weeks of Takeda/Moderna vaccine deliveries, allocated available vaccine inflows are defined as zero.

For $vc = 1$, operations on Pfizer/BioNTech vaccines, considering vc, sc, oc, age, and vdc correspondences,

$$
\begin{aligned}
&\text{Allocated Available Vaccine Inflow } (t, vc, sc, oc, age) \\
&\qquad = \text{Allocated Vaccine Inflow } (t, oc, age, vdc) \times ceiling(vdc)
\end{aligned}
$$

Allocated Vaccine Inflow $(t, oc, age, vdc) =$

If $p_{\mathrm{w\_predict}}(t, oc, age) = 0$ or $t < (date_{\mathrm{init}}(vc, sc, oc, age) - intrvl_{\mathrm{rsv}})$,

0

Else,

$$vflow_{deliver}(t, vdc) \times p_{\mathrm{w\_predict}}(t, oc, age) \div \sum_{oc,age} p_{\mathrm{w\_predict}}(t, oc, age)$$

The summation of $p_{\text{w\_predict}}$ includes only the age groups whose initiation dates with the corresponding vaccine distribution categories $date_{\text{init}}(vc, sc, oc, age)$ minus $intrvl_{\text{rsv}}$ is equal to or smaller than the time step t.

For $vc = 2$, operations on Takeda/Moderna vaccines, considering vc, sc, oc, age, and vdc correspondences,

$$\text{Allocated Available Vaccine Inflow } (t, vc, sc, oc, age) \\ = \max\begin{pmatrix}(\text{Allocated Vaccine Inflow } (t, oc, age, vdc) \times ceiling(vdc) \\ - rsvflow2(t, vc, sc, oc, age)) \\ 0\end{pmatrix}$$

To avoid negative values, the max function is introduced with zero.

$\text{Allocated Vaccine Inflow } (t, oc, age, vdc)$ is calculated by the same algorithm of $vc = 1$.

5.10.4. Vaccine Stock Allocation

Allocated available vaccine stocks in the reservation algorithms are derived from the following operations.

For $vc = 1$, operations on Pfizer/BioNTech vaccines, considering vc, sc, oc, age, and vdc correspondences,

$$\text{Allocated Available Vaccine Stock } (t, vc, sc, oc, age) \\ = \text{Allocated Vaccine Stock } (t, oc, age, vdc) \div freq_{\text{deliver}}(vdc) \div num_{\text{dose}}(vc)$$

$\text{Allocated Vaccine Stock } (t, vdc) =$

If $p_{\text{w\_predict}}(t, oc, age) = 0$ or $t < (date_{\text{init}}(vc, sc, oc, age) - intrvl_{\text{rsv}})$,

0

Else

$$v_{\text{site}}(t, vdc) \times p_{\text{w\_predict}}(t, oc, age) \div \sum_{oc,age} p_{\text{w\_predict}}(t, oc, age)$$

The summation of $p_{\text{w\_predict}}$ includes only the age groups whose initiation dates with the corresponding vaccine distribution categories $date_{\text{init}}(vc, sc, oc, age)$ minus $intrvl_{\text{rsv}}$ is equal to or smaller than the time step t.

For $vc = 2$, operations on Takeda/Moderna vaccines, considering vc, sc, oc, age, and vdc correspondences,

$$\text{Allocated Available Vaccine Stock } (t, vc, sc, oc, age) \\ = \max\begin{pmatrix}(\text{Allocated Vaccine Stock } \div freq_{\text{deliver}} - rsvflow2) \div num_{\text{dose}} \\ 0\end{pmatrix}$$

Subscript variables t, vc, sc, oc, age, and vdc are abbreviated.

Allocated Vaccine Stock $(t, vdc) =$

If $p_{\text{w\_predict}}(t, oc, age) = 0$ or $t < (date_{\text{init}}(vc, sc, oc, age) - intrvl_{\text{rsv}})$,

0

Else,

$$\left[v_{\text{site}}(t, vdc) - \textstyle\sum_{oc,age}\left(p_{\text{rsv2}}(t-1, vc, sc, oc, age) + p_{\text{d1}}(t-1, vc, sc, oc, age) + p_{\text{i1}}(t-1, vc, sc, oc, age)\right)\right] \times p_{\text{w\_predict}}(t, oc, age) \div \textstyle\sum_{oc,age} p_{\text{w\_predict}}(t, oc, age)$$

The summation of $p_{\text{w\_predict}}$ includes only the age groups whose initiation dates with the corresponding vaccine distribution categories $date_{\text{init}}(vc, sc, oc, age)$ minus $intrvl_{\text{rsv}}$ is equal to or smaller than the time step t.

5.10.5. Human Resource Capacity

Allocated available human resource capacities in the reservation algorithms are derived from the following operations.

Considering vc, sc, oc, age, and vdc correspondences,

$$\text{Allocated Available Human Resource Capacity}(t, vc, sc, oc, age) = \text{Allocated Human Resource Capacity } capacity_{\text{hr}}\ (t, vc, sc, oc, age) \div num_{\text{dose}}(vc)$$

$capacity_{\text{hr}}\ (t, vc, sc, oc, age) =$

For $vdc = 1$, vaccinations for healthcare workers with Pfizer/BioNTech vaccines,

10,000,000

Assumption of no human resource constraint.

For $vdc = 2$, vaccinations for elderly and other citizens with Pfizer/BioNTech vaccines,

If $p_{\text{w\_predict}}(t, oc, age) = 0$ or $t < (date_{\text{init}}(vc, sc, oc, age) - intrvl_{\text{rsv}})$,

0

Else,

$$\min\begin{pmatrix}\text{Screener Constraint } (t, vc, sc, oc, age) \\ \text{Shooter Constraint } (t, vc, sc, oc, age)\end{pmatrix} \times \text{Allocation Ratio between } vdc = 2 \text{ and } 3\ (t) \times \text{Weekly Proportion of Working Days} \times \text{Productivity of Shooters } prd \times p_{\text{w\_predict}}(t, oc, age) \div \textstyle\sum_{oc,age} p_{\text{w\_predict}}(t, oc, age)$$

The summation of $p_{\mathrm{w\_predict}}$ includes only the age groups whose initiation dates with the corresponding vaccine distribution categories $date_{\mathrm{init}}(vc, sc, oc, age)$ minus $intrvl_{\mathrm{rsv}}$ is equal to or smaller than the time step t.

where

$$\begin{aligned}&\text{Screener Constraint }(t, vc, sc, oc, age)\\ &\quad= \text{Fully Immunized Doctors } \textstyle\sum_{vc,sc,age} p_{\mathrm{i2}}(t-1, vc, sc, 1, age)\\ &\qquad\times \text{Participation Rate } pr_{\mathrm{doctor}}\\ &\qquad\times \text{Maximum Achievable Ratio of Nurses to Doctors}\\ &\qquad\quad maxratio_{\mathrm{NperDOP}}(vc, sc)\end{aligned}$$

$$\begin{aligned}&\text{Shooter Constraint }(t, vc, sc, oc, age)\\ &\quad= \text{Fully Immunized Nurses } \textstyle\sum_{vc,sc,age} p_{\mathrm{i2}}(t-1, vc, sc, 3, age)\\ &\qquad\times \text{Participation Rate } pr_{\mathrm{nurse}}\end{aligned}$$

$$\begin{aligned}&\text{Allocation Ratio between } vdc = 2 \text{ and } 3\ (t)\\ &\quad= \max\left(\frac{vflow_{\mathrm{deliver}}(t,2)}{\sum_{sc,oc,age} v_{\mathrm{rsv2}}(t-1,1) \div (intrvl_{\mathrm{rsv}} + intrvl_{\mathrm{d1d2}}(1))}\right)\\ &\qquad\div \left(\begin{array}{c}\max\left(\dfrac{vflow_{\mathrm{deliver}}(t,2)}{\sum_{sc,oc,age} v_{\mathrm{rsv2}}(t-1,1) \div (intrvl_{\mathrm{rsv}} + intrvl_{\mathrm{d1d2}}(1))}\right)\\ + \max\left(\dfrac{vflow_{\mathrm{deliver}}(t,3)}{\sum_{sc,oc,age} v_{\mathrm{rsv2}}(t-1,2) \div intrvl_{\mathrm{rsv}}}\right)\end{array}\right)\end{aligned}$$

First and second max functions treats values on $vdc = 2$ with $vc = 1$ and third max function on $vdc = 3$ with $vc = 2$. Subscript variables sc, oc, and age are abbreviated.

$$\text{Weekly Proportion of Working Days} = day_{\mathrm{work}} \div 7$$

For $vdc = 3$, vaccinations at large sites with Takeda/Moderna vaccines,

If $p_{\mathrm{w\_predict}}(t, oc, age) = 0$ or $t < (date_{\mathrm{init}}(vc, sc, oc, age) - intrvl_{\mathrm{rsv}})$,
0

Else,

$$\begin{aligned}&\min\begin{pmatrix}\text{Screener Constraint }(t, vc, sc, oc, age)\\ \text{Shooter Constraint }(t, vc, sc, oc, age)\end{pmatrix}\\ &\times (1 - \text{Allocation Ratio between } vdc = 2 \text{ and } 3\ (t))\\ &\times \text{Weekly Proportion of Working Days}\\ &\times \text{Productivity of Shooters } prd\\ &\times p_{\mathrm{w\_predict}}(t, oc, age) \div \textstyle\sum_{oc,age} p_{\mathrm{w\_predict}}(t, oc, age)\end{aligned}$$

where the algorithms and variables for Screener Constraint, Shooter Constraint, Weekly Proportion of Working Days, Productivity of Shooters, and allocation coefficient with willing populations are the same to $vdc = 2$.

For $vdc = 4$, vaccinations in workplaces with Takeda/Moderna vaccines,

If $p_{\mathrm{w\_predict}}(t, oc, age) = 0$ or $t < (date_{\mathrm{init}}(vc, sc, oc, age) - intrvl_{\mathrm{rsv}})$,
0

Else,

$$\min\begin{pmatrix}\text{Screener Constraint } (t, vc, sc, oc, age) \\ \text{Shooter Constraint } (t, vc, sc, oc, age)\end{pmatrix}$$
$$\times \text{ Weekly Proportion of Working Days}$$
$$\times \text{ Productivity of Shooters } prd$$
$$\times\, p_{\mathrm{w\_predict}}(t, oc, age) \div \textstyle\sum_{oc,age} p_{\mathrm{w\_predict}}(t, oc, age)$$

where the algorithms and variables for Weekly Proportion of Working Days, Productivity of Shooters, and allocation coefficient with willing populations are same to $vdc = 2$ and 3.

$$\text{Screener Constraint } (t, vc, sc, oc, age)$$
$$= \text{Fully Immunized OPs } \textstyle\sum_{vc,sc,age} p_{\mathrm{i2}}(t-1, vc, sc, 2, age)$$
$$\times \text{ Participation Rate } pr_{\mathrm{op}}$$
$$\times \text{ Maximum Achievable Ratio of Nurses to OPs } maxratio_{\mathrm{NperDOP}}(vc, sc)$$

where "OP" stands for operational physicians.

$$\text{Shooter Constraint } (t, vc, sc, oc, age)$$
$$= \text{Fully Immunized Nurses } \textstyle\sum_{vc,sc,age} p_{\mathrm{i2}}(t-1, vc, sc, 3, age)$$
$$\times \text{ Participation Rate } pr_{\mathrm{nurse}}$$
$$- \textstyle\sum_{sc,oc,age}(rsvflow1(t-1, 1) + rsvflow2(t-1, 1)) \times 1 \div prd$$
$$- \textstyle\sum_{sc,oc,age}(rsvflow1(t-1, 2) + rsvflow2(t-1, 2)) \times 1 \div prd$$

First and second summations explain the populations of nurses already recruited on vaccination sites of $vdc = 2$ and 3.

5.11. Evaluation Metrics

This research evaluates the model fit over the actual cumulative and daily vaccination trends with the population coverage achievement periods and the number of vaccinations.

Regarding the achievement periods, the simulation errors and percentage errors are calculated by sampling values in 1% increments of vaccination coverages with total, first, and second doses administered. The percentage error of a coverage achievement period is equal to an error divided by the corresponding actual period.

A primary evaluation metric for the number of daily vaccinations is the R-Squared. The root mean squared errors, mean absolute errors, and mean absolute percentage errors are also calculated. The mean absolute percentage error for vaccination numbers is defined as the mean absolute error divided by the maximum actual daily vaccinations in the reference time. Predicted curves are compared with actual smoothed and not-smoothed daily curves by dose round by vaccine.

5.12. Chapter Summary

The system dynamics approach was selected for modeling and analyzing the operational mechanisms of vaccinations in the primary series in Japan. Population and vaccines were two pillars of stocks and flows in the model. A demand-supply balancing mechanism was introduced to simulate the number of reservations with the populations of willing people on the demand side, vaccine constraints and human resource constraints on the supply side.

Vaccine constraints were based on daily vaccine deliveries and vaccine stocks on sites. The different levels of the distribution ceiling effect were assumed with Pfizer/BioNTech and Takeda/Moderna vaccines each.

The human resource supplies were assumed to depend on the populations and participation rates of fully immunized doctors/occupational physicians as screeners and nurses as shooters for vaccinations on sites. The concept of the shooter-screener ratio was introduced as the proxy of operational excellence on vaccination sites. The product of fully immunized populations and the ratio determines the human resource bottleneck on vaccination capacity between doctors/occupational physicians and nurses.

Fittings to cumulative and daily vaccination trends will be evaluated by the gaps of the coverage achievement periods and the number of vaccinations each in the next chapter.

6. Model Behaviors on Vaccination Trends

This chapter observes the behaviors of the developed model with reference inputs to validate the key assumptions of operational mechanisms on vaccination speed: the system dynamics with willing populations as the demand factor, vaccine deliveries with the ceiling effect and vaccine stocks at sites as vaccine constraints, and fully immunized healthcare workers as human resource constraints. Chapter 6.1 exhibits the model behavior and simulation errors with cumulative vaccination trends. Chapter 6.2 compares the simulated and actual daily vaccination curves with the list of simulated determinants on first-dose reservations and administrations. Chapter 6.3 discusses the validity of the model assumptions. Chapter 6.4 lists model limitations and room for further research.

6.1. Cumulative Vaccinations

The simulation fitting to cumulative vaccination trends is evaluated with the errors of vaccination coverage achievement periods by vaccine by dose round.

6.1.1. All Vaccine Administrations

Figure 6-1 exhibits the simulated and actual trends of total, first-dose, and second-dose cumulative vaccinations from February 14 to November 30, 2021. Figure 6-1 (a) indicates the simulated curves of total doses, first doses, and second doses reach coverages of 155.00%, 78.03%, and 76.97% at the end of the reference time range, respectively. The simulation gaps of the maximum achieved coverages are -3.46%, -1.98%, and -1.48%, respectively. The difference of -3.46% in total doses is equal to 4.36 million doses, which is close to the missing amount of 4.39 million doses with the Takeda/Moderna vaccine distribution data discussed in Chapter 3.8.

Figure 6-1 (b) exhibits that the errors of coverage achievement periods diverge to the positive side around the maximum achieved coverages in accordance with the saturation of simulated curves below the actual. Table 6-1 shows that the errors of the simulated achievement period range from -4 to 18 days, -4 to 38 days, and -5 to 11 days with total, first, and second doses, respectively. The ranges of the percentage achievement period errors are -7.69% to 6.87%, -4.21% to 15.14%, and -4.17% to 4.12% with total, first, and second doses, respectively. The errors of the simulated achievement period of 10%, 40%, and 70% vaccination coverages with second doses are -2 days, 2 days, 10 days, respectively: corresponding percentage errors are -1.72%, 1.18%, and 4.24% each.

Figure 6-1 (c) shows the simulated curves ramp up with delays, overshoot in the first three months, and get close to the actual trends after June. Initiating the first doses lags by 5 days from the actual date, February 17, 2021.

6.1.2. Pfizer/BioNTech Vaccine Administrations

Figure 6-2 exhibits the simulated and actual trends of total, first-dose, and second-dose cumulative vaccinations with Pfizer/BioNTech vaccines from February 14 to November 30, 2021. Figure 6-2 (a) indicates the simulated curves of total doses, first doses, and second doses with Pfizer/BioNTech vaccines reaching coverages of 132.98%, 66.98%, and 66.00% at the end of the reference time range, respectively. The simulation gaps of the maximum achieved coverages are +0.21%, -0.09%, and +0.30%, respectively. The simulated curve of total doses does not hit the level of distributed vaccines represented by a blue area in Figure 6-2 (a).

Figure 6-2 (b) exhibits that the errors of coverage achievement periods with Pfizer/BioNTech vaccines diverge to the negative side around the maximum achieved coverages due to due to overshooting simulated curves. The figure and Table 6-1 show that the errors of the simulated achievement period range from -4 to 8 days, -4 to 11 days, and -11 to 7 days with total, first, and second doses each, respectively. The ranges of the percentage achievement period errors are -7.69% to 3.69%, -4.21% to 5.07%, and -4.17% to 3.00% with total, first, and second doses, respectively.

Figure 6-2 (c) shows the cumulative vaccination percentage errors with Pfizer/BioNTech vaccine operations like the trends with all vaccines in Figure 6-1 (c).

6.1.3. Takeda/Moderna Vaccine Administrations

Figure 6-3 exhibits the simulated and actual trends of total, first-dose, and second-dose cumulative vaccinations with Takeda/Moderna vaccines from February 14 to November 30, 2021. Figure 6-3 (a) indicates the simulated curves of total doses, first doses, and second doses with Takeda/Moderna vaccines reaching coverages of 22.01%, 11.05%, and 10.97% at the end of the reference time range, respectively. The simulation gaps of the maximum achieved coverages are -3.66%, -1.88%, and -1.78%, respectively.

Figure 6-3 (b) exhibits that the errors of coverage achievement periods with Takeda/Moderna vaccines diverge to the positive side around the maximum achieved coverages in the simulation. The figure and Table 6-1 show that the errors of the simulated achievement period range from -5 to 59 days, -6 to 49 days, and -8 to 8 days with total, first, and second doses, respectively. The ranges of the percentage achievement period errors are -8.33% to 44.36%, -9.23% to 42.98 %, and -8.42% to 6.96% with total, first, and second doses, respectively. The error and percentage error of the second-dose trend are 0 days and 0% at 10% coverage, below the saturation coverage with the data limitation on distributions.

Figure 6-3 (c) shows the simulated curve of total doses ramps up with delays, overshoots around the beginning of July, approaches from July to the beginning of September, and deviates from the actual trends after September. The figure reveals that the initiation date of the Takeda/Moderna vaccine administration lags by 7 days from the actual date, May 24, 2021.

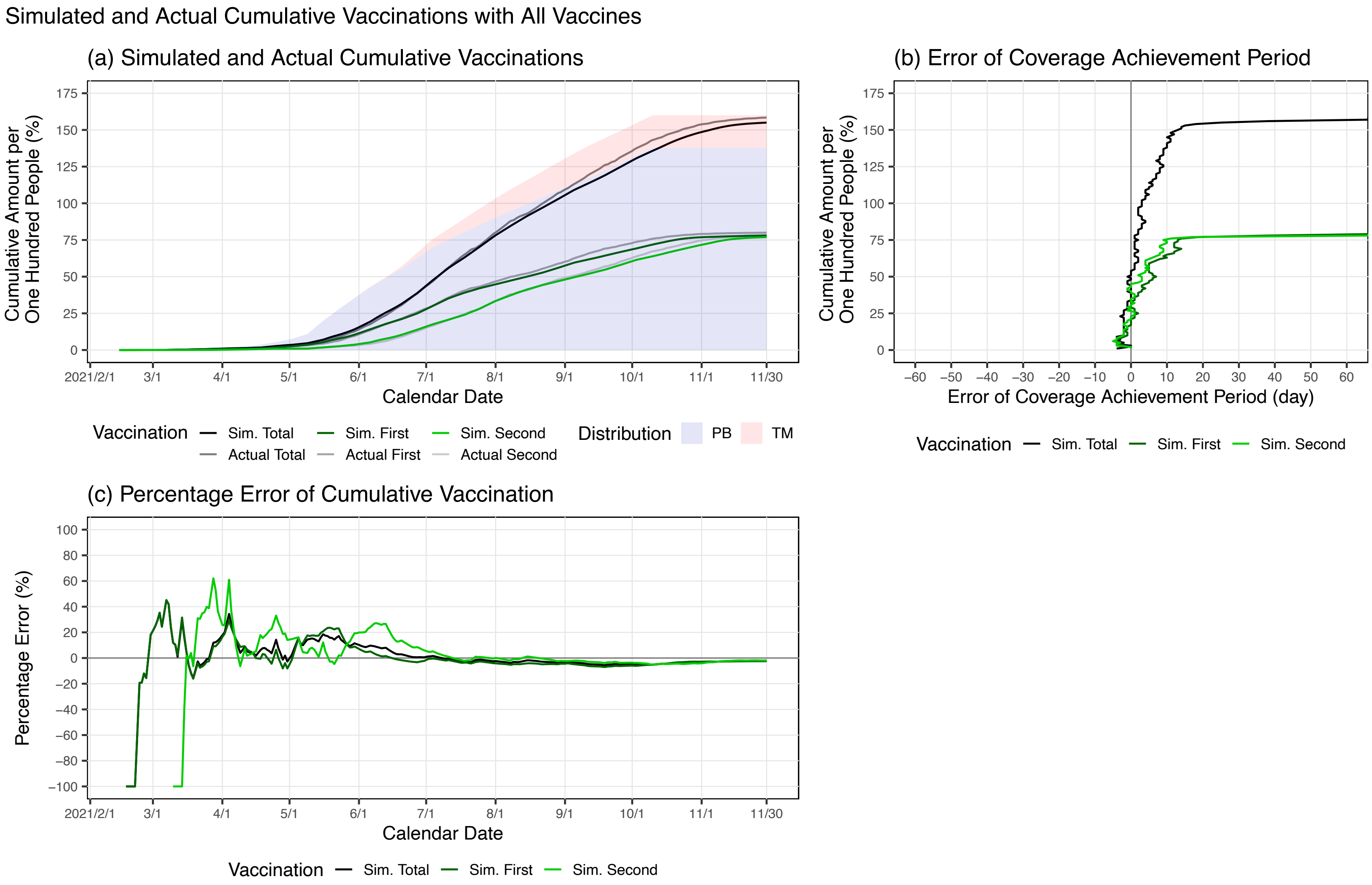


Figure 6-1 Simulated and Actual Cumulative Vaccinations with All Vaccines
(a) Simulated and actual cumulative vaccinations in Japan for the primary series with Pfizer/BioNTech and Takeda/Moderna vaccines. (b) Errors of coverage achievement period. (c) Percentage errors of cumulative vaccinations. "PB," "TM," and "Sim." stand for "Pfizer/BioNTech," "Takeda/Moderna," and "Simulated," respectively.

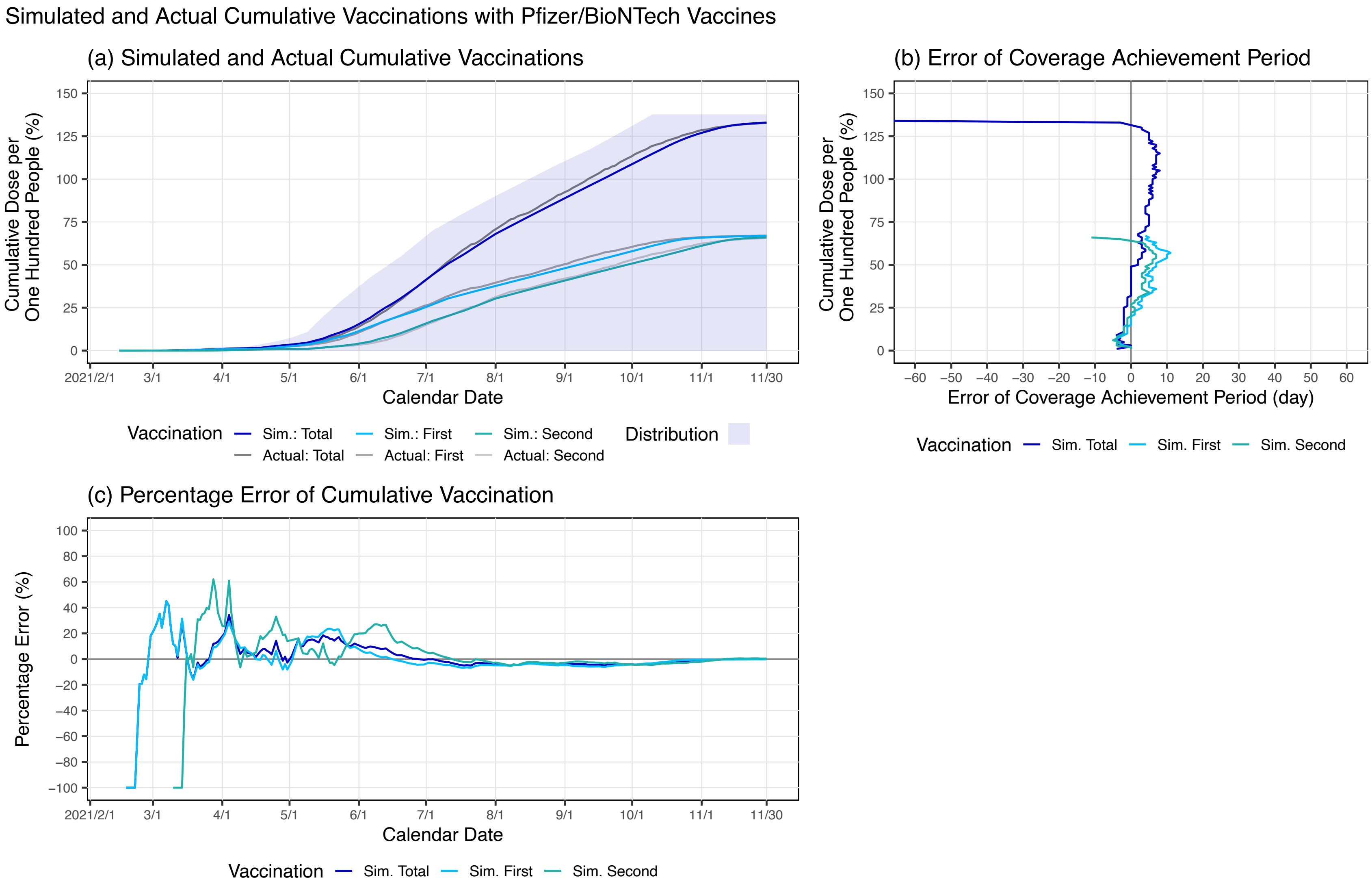


Figure 6-2 Simulated and Actual Cumulative Vaccinations with Pfizer/BioNTech Vaccines

(a) Simulated and actual cumulative vaccinations in Japan for the primary series with Pfizer/BioNTech vaccines. (b) Errors of coverage achievement periods. (c) Percentage errors of cumulative vaccinations. “Sim.” stands for “Simulated”.

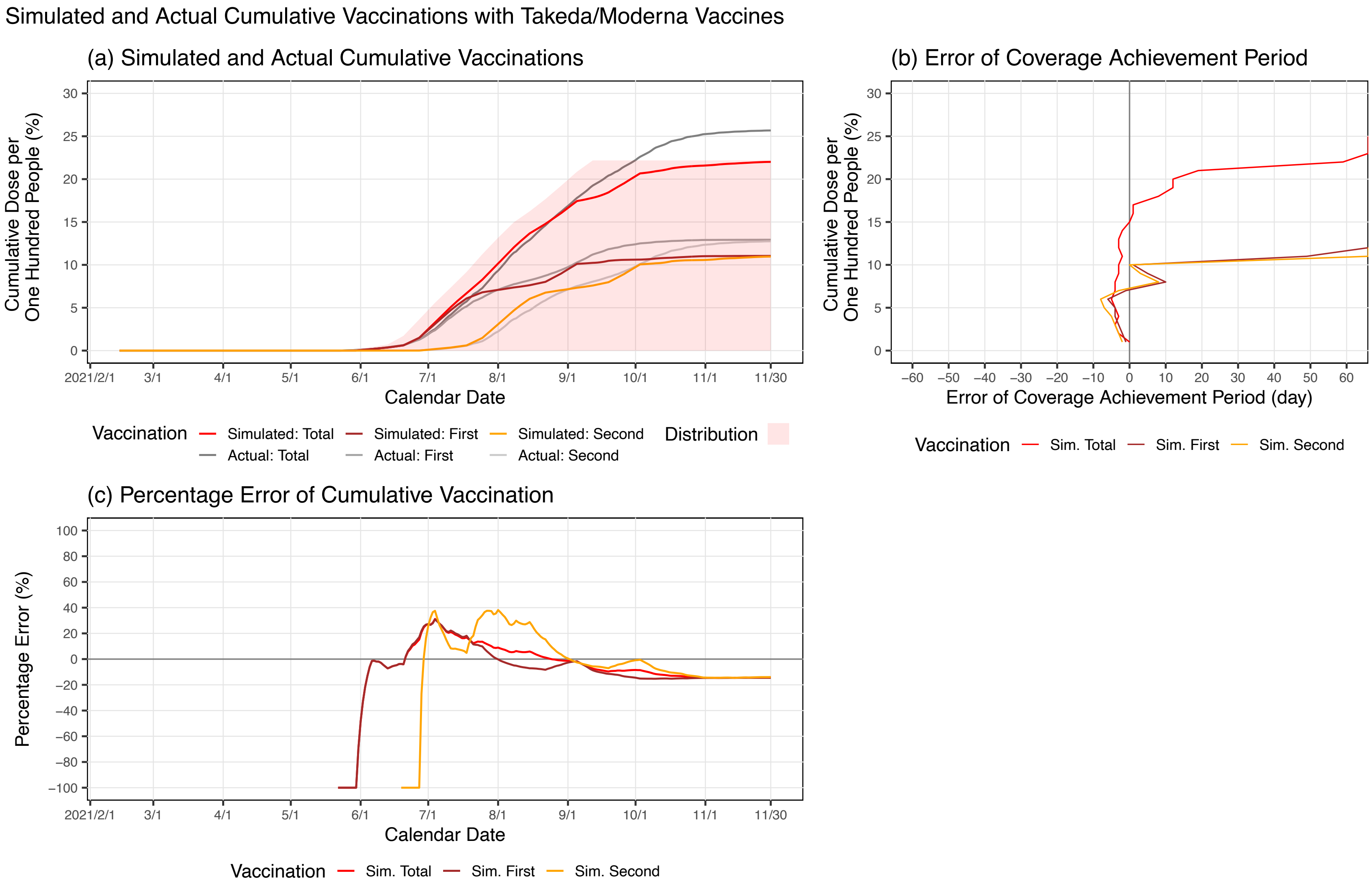


Figure 6-3 Simulated and Actual Cumulative Vaccinations with Takeda/Moderna Vaccines
(a) Simulated and actual cumulative vaccinations in Japan for the primary series with Takeda/Moderna vaccines. (b) Errors of coverage achievement periods. (c) Percentage errors of cumulative vaccination. “Sim.” stands for “Simulated”.

Table 6-1 Simulation Errors of Coverage Achievement Periods

Simulation errors of coverage achievement periods to actual values. The percentage error is an error divided by the actual achievement period of the corresponding vaccination coverage. For the dose round "Total," the simulation errors in the columns of 20%/10%, 80%/40%, and 140%/70% coverage periods correspond to the achievement periods of 20%, 80%, and 140% coverages. For the other dose rounds of "First" and "Second," the simulation errors in these columns correspond to the achievement periods of 10%, 40%, and 70% coverages with each vaccine. The start dates of the achievement periods are the authorization date of the Pfizer/BioNTech vaccine on February 14, 2021, for All and Pfizer/BioNTech vaccine trends, while the authorization dates on May 21, 2021, for Takeda/Moderna vaccine trend.

Error Metrics	Dose Round	Vaccine	Range (Corresponding Vaccination Coverage with Each Vaccine)	20%/10% Coverage Period with Each Vaccine	80%/40% Coverage Period with Each Vaccine	140%/70% Coverage Period with Each Vaccine
Error (day)	Total	All	-4 to 18 days (at 1% and 154% coverages)	-2 days	2 days	10 days
		Pfizer/BioNTech	-4 to 8 days (at 1% and 105% coverages)	-2 days	4 days	-
		Takeda/Moderna	-5 to 59 days (at 6% and 22% coverages)	12 days	-	-
	First	All	-4 to 38 days (at 5% and 78% coverages)	-1 day	3 days	12 days
		Pfizer/BioNTech	-4 to 11 days (at 5% and 57% coverages)	-1 day	5 days	-
		Takeda/Moderna	-6 to 49 days (at 6% and 11% coverages)	1 day	-	-
	Second	All	-5 to 11 days (at 6% and 76% coverages)	-2 days	0 day	8 days
		Pfizer/BioNTech	-11 to 7 days (at 66% and 54% coverages)	-2 days	4 days	-
		Takeda/Moderna	-8 to 8 days (at 6% and 8% coverages)	0 days	-	-
Percentage Error (%)	Total	All	-7.69% to 6.87% (at 1% and 154% coverages)	-1.72%	1.18%	4.24%
		Pfizer/BioNTech	-7.69% to 3.69% (at 1% and 105% coverages)	-1.72%	2.19%	-
		Takeda/Moderna	-8.33% to 44.36% (at 3% and 22% coverages)	10.00%	-	-
	First	All	-4.21% to 15.14% (at 5% and 78% coverages)	-0.93%	1.94%	5.41%
		Pfizer/BioNTech	-4.21% to 5.07% (at 5% and 57% coverages)	-0.93%	2.92%	-
		Takeda/Moderna	-9.23% to 42.98% (at 6% and 11% coverages)	0.93%	-	-
	Second	All	-4.17% to 4.12% (at 6% and 76% coverages)	-1.55%	0%	3.23%
		Pfizer/BioNTech	-4.17% to 3.00% (at 6% and 54% coverages)	-1.55%	2.06%	-
		Takeda/Moderna	-8.42% to 6.96% (at 6% and 8% coverages)	0.00%	-	-

6.2. Daily Vaccinations

This subchapter evaluates the simulation fitting to the actual daily vaccination trends with the R-squared values, which has the value range from 0 to 1. The larger the R-Squared is, the better the simulation predicts observed data.

The simulated determinants of daily reservations and vaccinations are checked with the decomposed vaccination trends with each vaccine.

6.2.1. All Vaccine Administrations

Table 6-2 introduces the R-Squared values are 0.943, 0.909, and 0.915 with the simulated and actual smoothed daily trends of the total, first, and second doses with all the vaccines from February 14 to November 30, 2021, respectively. The R-squared values with the actual not-smoothed curves of the total, first, and second doses are 0.882, 0.867, and 0.842, respectively.

Figure 6-4(a) exhibits that the simulated daily vaccination speed of total doses is faster than the actual pace by early June, equivalent on average from mid-June to the beginning of July, slower from July to early October except for the national holidays and the summer holiday season, and faster from mid-October to mid-November.

Figures 6-4 (b) displays the simulated and actual first-dose vaccination trends. The simulated daily vaccinations are almost equivalent to the actual from the initiation to late April, larger from early to mid-May, about equivalent from late June to early July, smaller from mid-July to early August, equivalent from mid-August to the beginning of September, smaller in early to mid-September, larger from late September to late October, and equivalent in November.

Figure 6-4 (c) shows the simulated and actual second-dose vaccination trends. The shape of the simulated second-dose vaccinations is similar to the first-dose curve, with a 3-week lag from the initiation to the beginning of July and a 4-week lag after August.

Figure 6-5 shows that the simulated trends with all the vaccines do not generate weekly oscillations and negative pulses on national holidays in the actual not-smoothed daily vaccinations.

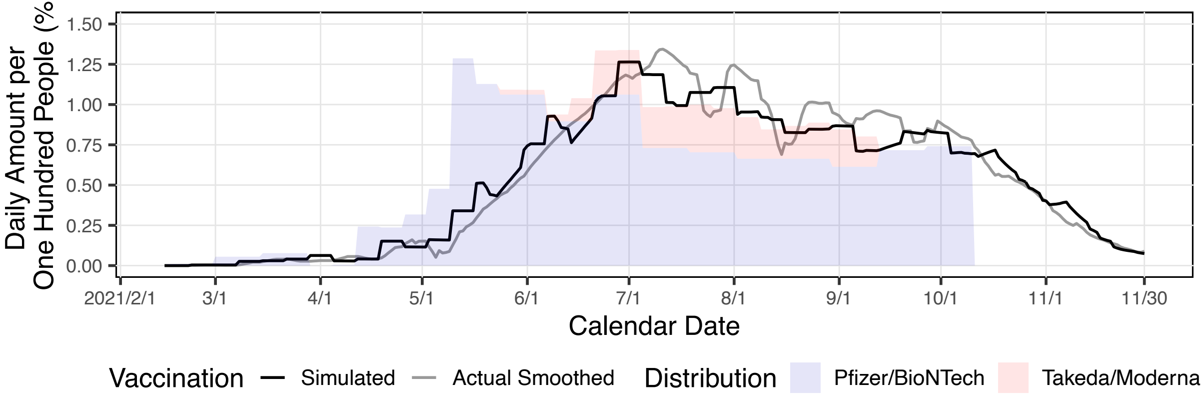
Table 6-2 Fitting Metrics of Daily Vaccinations

Fitting metrics of daily vaccination trends. The time range for "All" and "Pfizer/BioNTech" vaccine categories are from February 14 to November 30, 2021. For "Takeda/Moderna" and "Takeda/Moderna by September 12" vaccine categories, the ranges are from May 21 to November 30 and September 12, 2021. The mean absolute error is an absolute error divided by the maximum value of the actual smoothed/not-smoothed daily vaccinations.

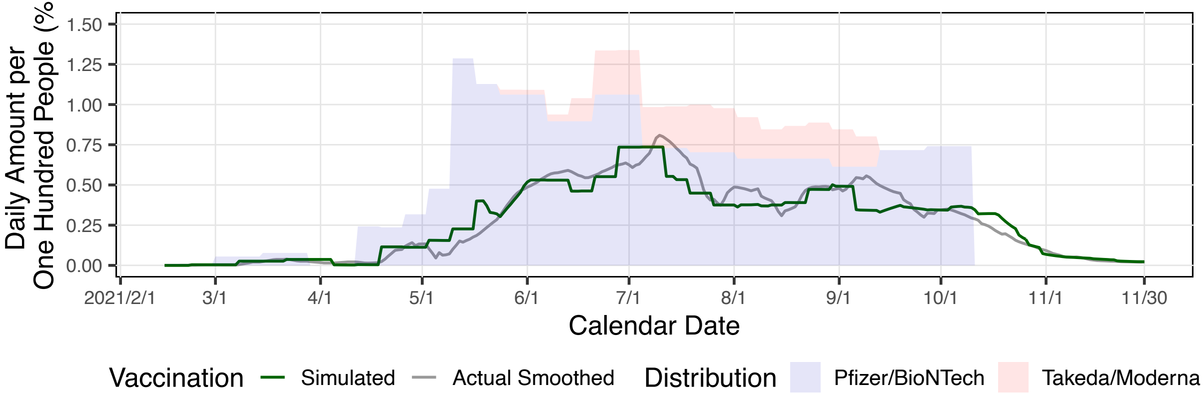
Vaccination Curve	Dose Round	Vaccine Category	R-Squared	Root Mean Squared Error (Dose per One Hundred People)	Mean Absolute Error (Dose per One Hundred People)	Mean Absolute Percentage Error
Smoothed Daily	Total	All	0.943	0.105	0.075	5.55%
		Pfizer/BioNTech	0.931	0.094	0.068	6.14%
		Takeda/Moderna	0.627	0.058	0.038	12.76%
		Takeda/Moderna by September 12	0.661	0.059	0.038	12.84%
	First	All	0.909	0.071	0.047	5.84%
		Pfizer/BioNTech	0.897	0.061	0.043	7.11%
		Takeda/Moderna	0.367	0.049	0.033	15.54%
		Takeda/Moderna by September 12	0.113	0.057	0.044	20.53%
	Second	All	0.915	0.066	0.044	5.78%
		Pfizer/BioNTech	0.898	0.060	0.042	6.80%
		Takeda/Moderna	0.282	0.050	0.035	16.94%
		Takeda/Moderna by September 12	0.476	0.050	0.033	15.96%
Daily	Total	All	0.882	0.156	0.109	7.78%
		Pfizer/BioNTech	0.858	0.140	0.098	8.54%
		Takeda/Moderna	0.698	0.054	0.038	11.14%
		Takeda/Moderna by September 12	0.694	0.057	0.040	11.74%
	First	All	0.867	0.089	0.066	7.78%
		Pfizer/BioNTech	0.833	0.081	0.060	9.59%
		Takeda/Moderna	0.554	0.042	0.028	11.30%
		Takeda/Moderna by September 12	0.327	0.051	0.037	15.13%
	Second	All	0.842	0.095	0.065	7.93%
		Pfizer/BioNTech	0.814	0.086	0.060	9.44%
		Takeda/Moderna	0.474	0.045	0.030	12.10%
		Takeda/Moderna by September 12	0.615	0.044	0.029	11.41%

Simulated and Actual Smoothed Daily Vaccinations with All Vaccines

(a) Total Doses



(b) First Doses



(c) Second Doses

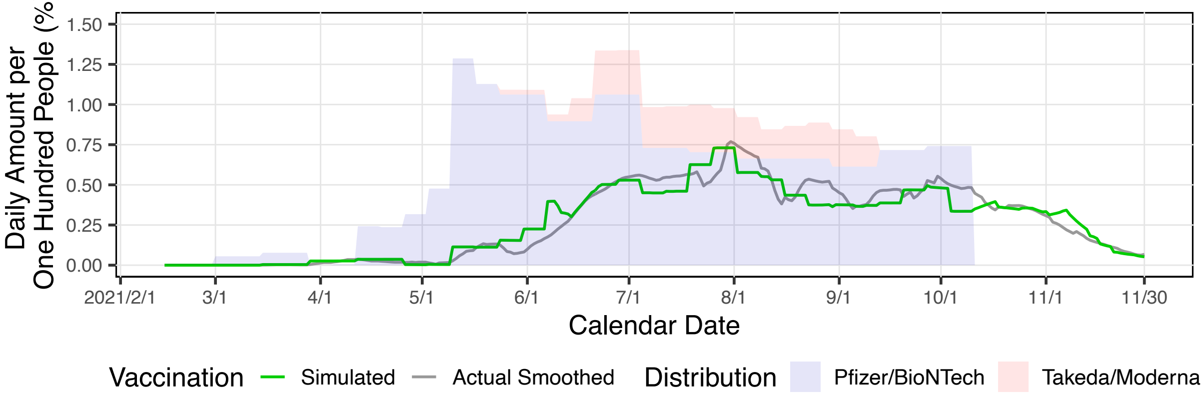
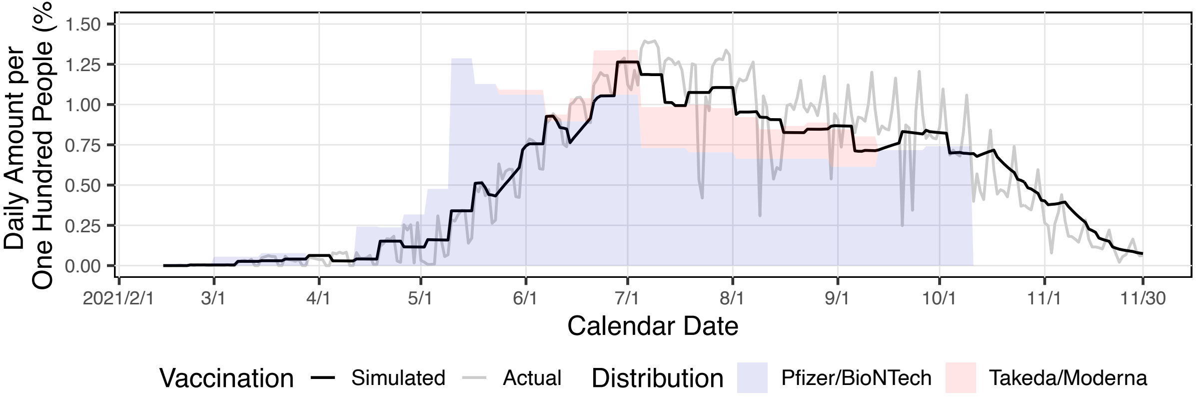


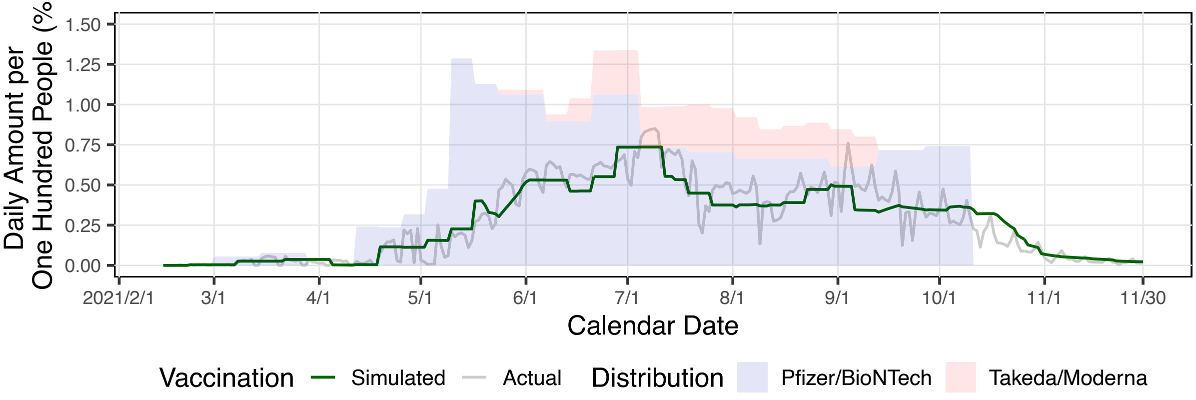
Figure 6-4 Simulated and Actual Smoothed Daily Vaccinations with All Vaccines
Simulated daily vaccination trends and actual 7-day smoothed daily vaccination trends in Japan for the primary series with Pfizer/BioNTech and Takeda/Moderna vaccines. Colored areas indicate the daily vaccine deliveries to vaccination sites.

Simulated and Actual Daily Vaccinations with All Vaccines

(a) Total Doses



(b) First Doses



(c) Second Doses

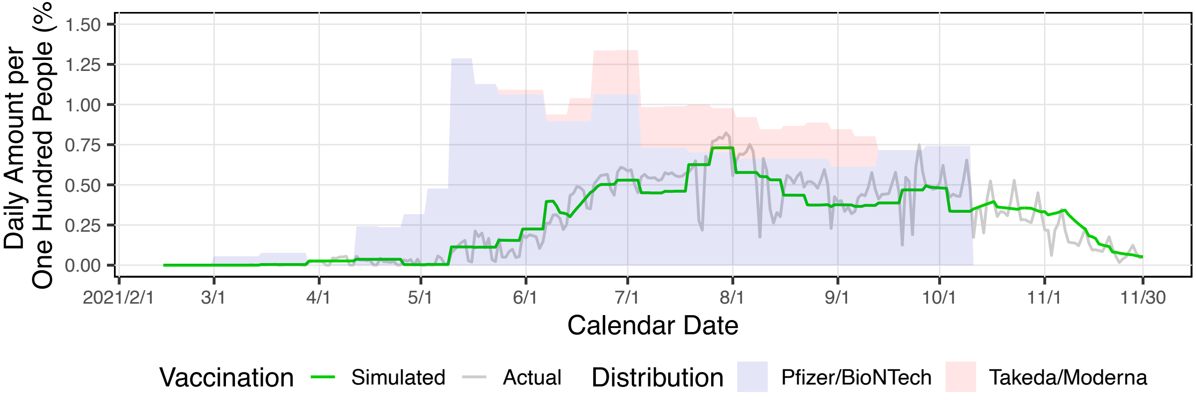


Figure 6-5 Simulated and Actual Daily Vaccinations with All Vaccines
Simulated and actual daily vaccinations in Japan for the primary series with Pfizer/BioNTech and Takeda/Moderna vaccines. Colored areas indicate the daily vaccine deliveries to vaccination sites.

6.2.2. Pfizer/BioNTech Vaccine Administrations

Table 6-2 introduces the R-squared values are 0.931, 0.897, and 0.898 with the simulated and actual smoothed daily trends of the total, first, and second doses with Pfizer/BioNTech vaccines, respectively. The R-squared values with the actual not-smoothed curves of the total, first, and second doses are 0.858, 0.833, and 0.814, respectively.

Figure 6-6(a) exhibits that the simulated daily vaccination speed of total doses is faster than the actual pace by early June, slower from mid-June to early October except for the national holidays and the summer holiday season, and faster from mid-October to mid-November.

Figure 6-6 (b) exhibits that the level of the simulated first-dose trend from late April to mid-May and in June approximately follows the halved daily vaccine distribution one week before. The simulated first-dose level in mid and late-May is smaller than the daily vaccine distribution with the ceiling coefficient. In mid-May, there is a local peak with the simulated first-dose trend, which is the summation of the first doses for healthcare workers and elderly citizens. The peak disappears with the decreasing vaccination trend with the Pfizer/BioNTech vaccines on healthcare workers.

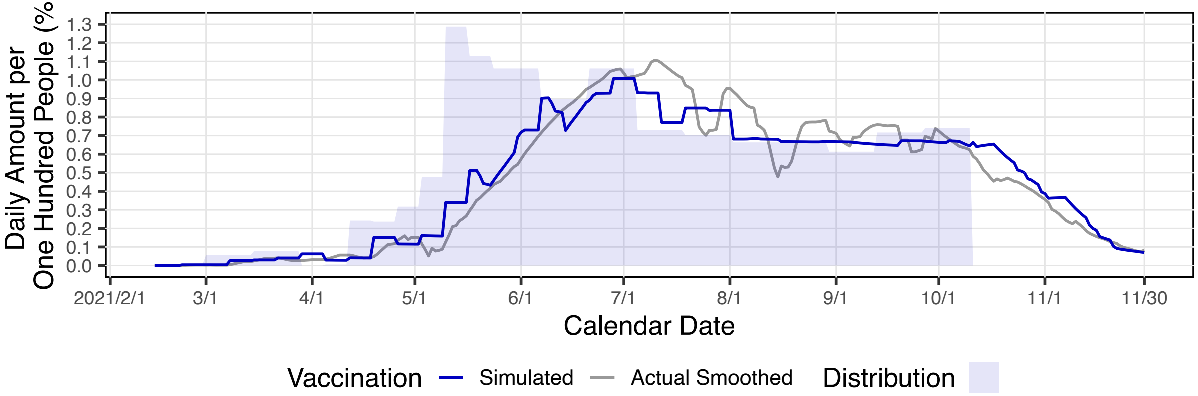
Table 6-3 lists the simulated determinants of first-dose reservations and corresponding vaccine administrations each time step by vaccine distribution category with typical age groups. The model exhibits that the determinant of the first-dose administrations with Pfizer/BioNTech vaccines for healthcare workers at 40–44 years old (PB-HW 40–44 years old) is the vaccine deliveries and stocks at sites from the initiation of vaccinations to mid-May. The reservations and corresponding vaccinations for healthcare workers face the limited willing populations on May 13 and 20 each. The determinant of administrations for elderly citizens with Pfizer/BioNTech vaccines (PB-OC 65–69 years old) is the vaccine deliveries and stocks at sites from the initiation of vaccinations to mid-May and the number of cooperative nurses from mid-May to late May. From June to early August, the vaccine deliveries are the determinants of the simulated daily vaccinations for the elderly and other citizens with Pfizer/BioNTech vaccines. From the beginning of August to mid-September, the stocks of Pfizer/BioNTech vaccines are the simulated determinant of first-dose administrations. The simulated first-dose administrations for the elderly at age 65–69 years old and other citizens at 12–15 years old with Pfizer/BioNTech vaccines face the constraints of vaccine deliveries from late September to early October, and the depleted willing people from early October. The simulated vaccinations for other citizens at 40–44 years old face the vaccine delivery constraint from late September to early October, the vaccine stock constraint from mid to late October, and the willing population constraint after mid to late October.

Figure 6-6 (c) shows the shape of the simulated second-dose vaccinations with Pfizer/BioNTech vaccines is like the first-dose curve, with a 3-week lag.

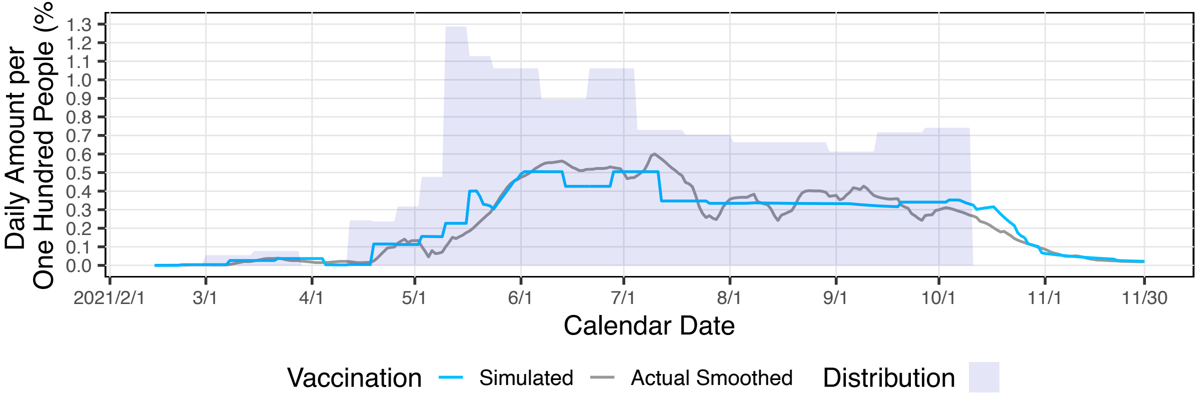
Figure 6-7 shows that the simulated trends with Pfizer/BioNTech vaccines do not generate weekly oscillations and negative pulses on national holidays in the actual not-smoothed daily vaccinations.

Simulated and Actual Smoothed Daily Vaccinations with Pfizer/BioNTech Vaccines

(a) Total Doses



(b) First Doses



(c) Second Doses

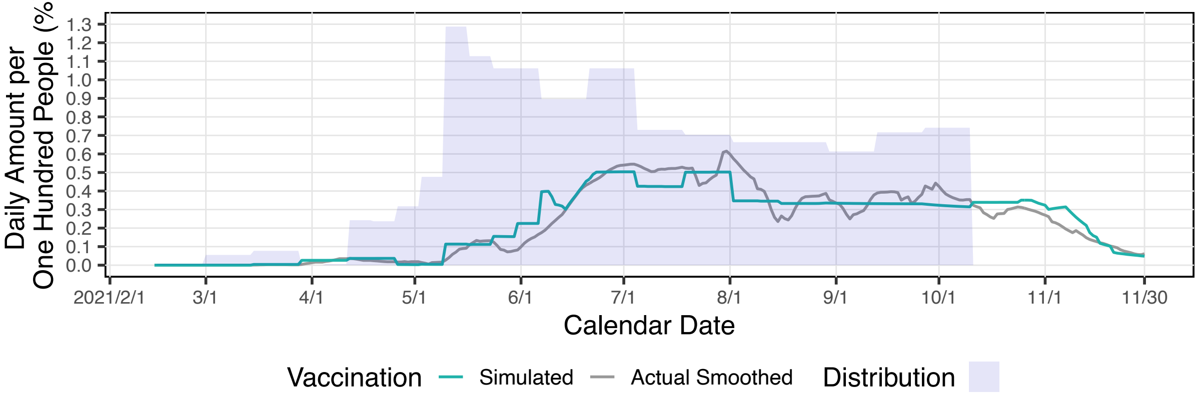
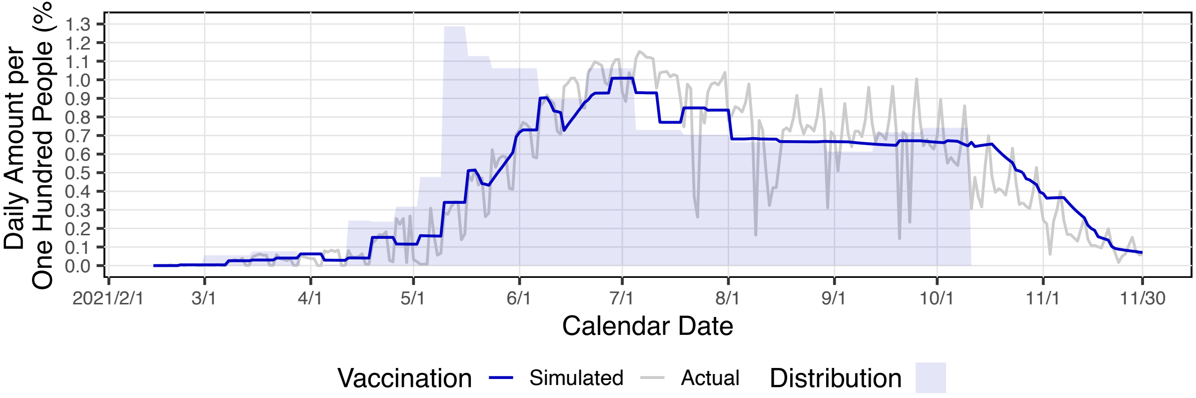


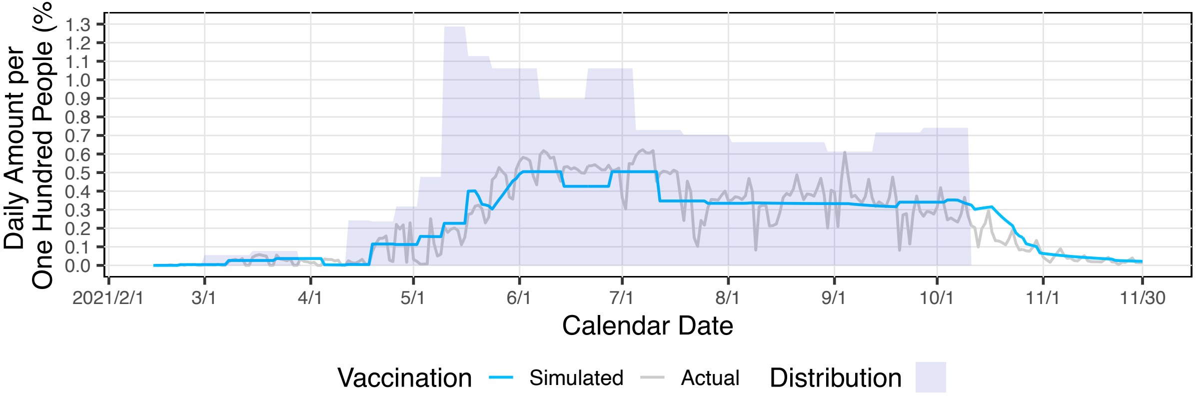
Figure 6-6 Simulated and Actual Smoothed Daily Vaccinations with Pfizer/BioNTech Vaccines
Simulated daily vaccination trends and actual 7-day smoothed daily vaccination trends in Japan for the primary series with Pfizer/BioNTech vaccines. Colored areas indicate the daily deliveries of Pfizer/BioNTech vaccines to vaccination sites.

Simulated and Actual Daily Vaccinations with Pfizer/BioNTech Vaccines

(a) Total Doses



(b) First Doses



(c) Second Doses

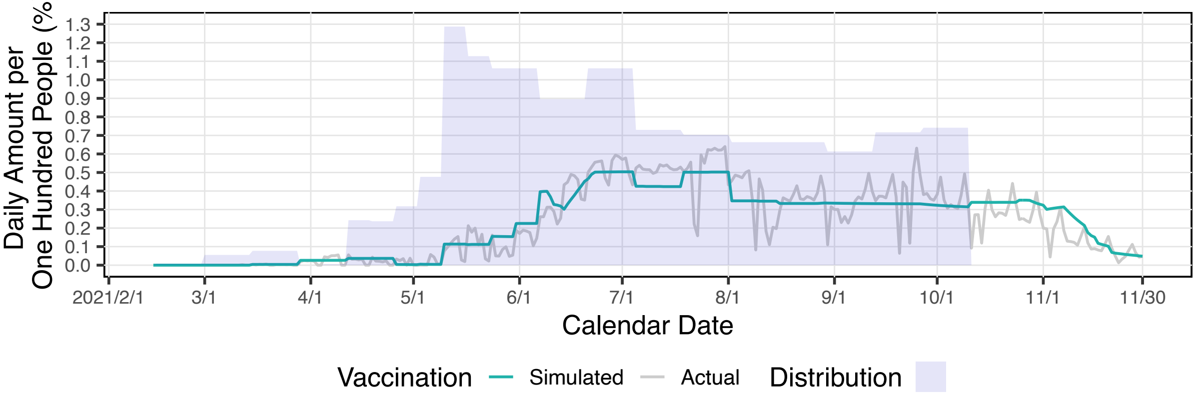


Figure 6-7 Simulated and Actual Daily Vaccinations with Pfizer/BioNTech Vaccines
Simulated and actual daily vaccinations in Japan for the primary series with Pfizer/BioNTech vaccines. Colored areas indicate the daily deliveries of Pfizer/BioNTech vaccines to vaccination sites.

Table 6-3 Simulated Determinants of First-Dose Reservations

The determinants of first-dose reservations $rsvflow1$ in the simulation each time step by vaccine distribution category with the examples of age groups. The Corresponding Date column lists the dates 7 days after the values of the First-Dose Reservation Date, which indicates the time steps with the values in $rsvflow1$. “Vflow,” “Vstock,” “Nurse,” and “People” stand for the vaccine inflows, vaccine stocks, human resource capacity based on the cooperative nurses, and the willing people, respectively, as the determinant of the first-dose reservation in the algorithm. “PB-HW” and “PB-OC” represent the administrations for healthcare workers and other citizens with Pfizer/BioNTech vaccines, respectively. “TM-LC” and “TM-WP” represent the administrations at large sites and workplaces with Takeda/Moderna vaccines, respectively. “y.o.” stands for “years old.”

First-Dose Reservation Date	Corresponding Date of First Doses	Vaccine Distribution Category									
		PB-HW 40–44 y.o.	PB-OC 65–69 y.o.	PB-OC 40–44 y.o.	PB-OC 12–15 y.o.	TM-LC 65–69 y.o.	TM-LC 40–44 y.o.	TM-LC 12–15 y.o.	TM-WP 65–69 y.o.	TM-WP 40–44 y.o.	TM-WP 12–15 y.o.
2021/02/07	2021/02/14	-	-	-	-	-	-	-	-	-	-
2021/02/08	2021/02/15	-	-	-	-	-	-	-	-	-	-
2021/02/09	2021/02/16	-	-	-	-	-	-	-	-	-	-
2021/02/10	2021/02/17	-	-	-	-	-	-	-	-	-	-
2021/02/11	2021/02/18	-	-	-	-	-	-	-	-	-	-
2021/02/12	2021/02/19	-	-	-	-	-	-	-	-	-	-
2021/02/13	2021/02/20	-	-	-	-	-	-	-	-	-	-
2021/02/14	2021/02/21	-	-	-	-	-	-	-	-	-	-
2021/02/15	2021/02/22	Vflow	-	-	-	-	-	-	-	-	-
2021/02/16	2021/02/23	Vflow	-	-	-	-	-	-	-	-	-
2021/02/17	2021/02/24	Vflow	-	-	-	-	-	-	-	-	-
2021/02/18	2021/02/25	Vflow	-	-	-	-	-	-	-	-	-
2021/02/19	2021/02/26	Vflow	-	-	-	-	-	-	-	-	-
2021/02/20	2021/02/27	Vflow	-	-	-	-	-	-	-	-	-
2021/02/21	2021/02/28	Vflow	-	-	-	-	-	-	-	-	-
2021/02/22	2021/03/01	Vflow	-	-	-	-	-	-	-	-	-
2021/02/23	2021/03/02	Vflow	-	-	-	-	-	-	-	-	-
2021/02/24	2021/03/03	Vflow	-	-	-	-	-	-	-	-	-
2021/02/25	2021/03/04	Vflow	-	-	-	-	-	-	-	-	-
2021/02/26	2021/03/05	Vflow	-	-	-	-	-	-	-	-	-
2021/02/27	2021/03/06	Vflow	-	-	-	-	-	-	-	-	-
2021/02/28	2021/03/07	Vflow	-	-	-	-	-	-	-	-	-
2021/03/01	2021/03/08	Vflow	-	-	-	-	-	-	-	-	-
2021/03/02	2021/03/09	Vflow	-	-	-	-	-	-	-	-	-
2021/03/03	2021/03/10	Vflow	-	-	-	-	-	-	-	-	-
2021/03/04	2021/03/11	Vflow	-	-	-	-	-	-	-	-	-
2021/03/05	2021/03/12	Vflow	-	-	-	-	-	-	-	-	-
2021/03/06	2021/03/13	Vflow	-	-	-	-	-	-	-	-	-
2021/03/07	2021/03/14	Vflow	-	-	-	-	-	-	-	-	-
2021/03/08	2021/03/15	Vflow	-	-	-	-	-	-	-	-	-

2021/03/09	2021/03/16	Vflow	-	-	-	-	-	-	-	-	-
2021/03/10	2021/03/17	Vflow	-	-	-	-	-	-	-	-	-
2021/03/11	2021/03/18	Vflow	-	-	-	-	-	-	-	-	-
2021/03/12	2021/03/19	Vflow	-	-	-	-	-	-	-	-	-
2021/03/13	2021/03/20	Vflow	-	-	-	-	-	-	-	-	-
2021/03/14	2021/03/21	Vflow	-	-	-	-	-	-	-	-	-
2021/03/15	2021/03/22	Vflow	-	-	-	-	-	-	-	-	-
2021/03/16	2021/03/23	Vflow	-	-	-	-	-	-	-	-	-
2021/03/17	2021/03/24	Vflow	-	-	-	-	-	-	-	-	-
2021/03/18	2021/03/25	Vflow	-	-	-	-	-	-	-	-	-
2021/03/19	2021/03/26	Vflow	-	-	-	-	-	-	-	-	-
2021/03/20	2021/03/27	Vflow	-	-	-	-	-	-	-	-	-
2021/03/21	2021/03/28	Vflow	-	-	-	-	-	-	-	-	-
2021/03/22	2021/03/29	Vflow	-	-	-	-	-	-	-	-	-
2021/03/23	2021/03/30	Vflow	-	-	-	-	-	-	-	-	-
2021/03/24	2021/03/31	Vflow	-	-	-	-	-	-	-	-	-
2021/03/25	2021/04/01	Vflow	-	-	-	-	-	-	-	-	-
2021/03/26	2021/04/02	Vflow	-	-	-	-	-	-	-	-	-
2021/03/27	2021/04/03	Vflow	-	-	-	-	-	-	-	-	-
2021/03/28	2021/04/04	Vflow	-	-	-	-	-	-	-	-	-
2021/03/29	2021/04/05	Vstock	-	-	-	-	-	-	-	-	-
2021/03/30	2021/04/06	Vstock	-	-	-	-	-	-	-	-	-
2021/03/31	2021/04/07	Vstock	-	-	-	-	-	-	-	-	-
2021/04/01	2021/04/08	Vstock	-	-	-	-	-	-	-	-	-
2021/04/02	2021/04/09	Vstock	-	-	-	-	-	-	-	-	-
2021/04/03	2021/04/10	Vstock	-	-	-	-	-	-	-	-	-
2021/04/04	2021/04/11	Vstock	-	-	-	-	-	-	-	-	-
2021/04/05	2021/04/12	Vstock	Vflow	-	-	-	-	-	-	-	-
2021/04/06	2021/04/13	Vstock	Vflow	-	-	-	-	-	-	-	-
2021/04/07	2021/04/14	Vstock	Vflow	-	-	-	-	-	-	-	-
2021/04/08	2021/04/15	Vstock	Vflow	-	-	-	-	-	-	-	-
2021/04/09	2021/04/16	Vstock	Vflow	-	-	-	-	-	-	-	-
2021/04/10	2021/04/17	Vstock	Vflow	-	-	-	-	-	-	-	-
2021/04/11	2021/04/18	Vstock	Vflow	-	-	-	-	-	-	-	-
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2021/04/13	2021/04/20	Vflow	Vflow	-	-	-	-	-	-	-	-
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2021/04/15	2021/04/22	Vflow	Vflow	-	-	-	-	-	-	-	-
2021/04/16	2021/04/23	Vflow	Vflow	-	-	-	-	-	-	-	-
2021/04/17	2021/04/24	Vflow	Vflow	-	-	-	-	-	-	-	-
2021/04/18	2021/04/25	Vflow	Vflow	-	-	-	-	-	-	-	-
2021/04/19	2021/04/26	Vflow	Vflow	-	-	-	-	-	-	-	-

2021/04/20	2021/04/27	Vflow	Vflow	-	-	-	-	-	-	-	-
2021/04/21	2021/04/28	Vflow	Vflow	-	-	-	-	-	-	-	-
2021/04/22	2021/04/29	Vflow	Vflow	-	-	-	-	-	-	-	-
2021/04/23	2021/04/30	Vflow	Vflow	-	-	-	-	-	-	-	-
2021/04/24	2021/05/01	Vflow	Vflow	-	-	-	-	-	-	-	-
2021/04/25	2021/05/02	Vflow	Vflow	-	-	-	-	-	-	-	-
2021/04/26	2021/05/03	Vstock	Vflow	-	-	-	-	-	-	-	-
2021/04/27	2021/05/04	Vstock	Vflow	-	-	-	-	-	-	-	-
2021/04/28	2021/05/05	Vstock	Vflow	-	-	-	-	-	-	-	-
2021/04/29	2021/05/06	Vstock	Vflow	-	-	-	-	-	-	-	-
2021/04/30	2021/05/07	Vstock	Vflow	-	-	-	-	-	-	-	-
2021/05/01	2021/05/08	Vstock	Vflow	-	-	-	-	-	-	-	-
2021/05/02	2021/05/09	Vstock	Vflow	-	-	-	-	-	-	-	-
2021/05/03	2021/05/10	Vflow	Vflow	-	-	-	-	-	-	-	-
2021/05/04	2021/05/11	Vflow	Vflow	-	-	-	-	-	-	-	-
2021/05/05	2021/05/12	Vflow	Vflow	-	-	-	-	-	-	-	-
2021/05/06	2021/05/13	Vflow	Vflow	-	-	-	-	-	-	-	-
2021/05/07	2021/05/14	Vflow	Vflow	-	-	-	-	-	-	-	-
2021/05/08	2021/05/15	Vflow	Vflow	-	-	-	-	-	-	-	-
2021/05/09	2021/05/16	Vflow	Vflow	-	-	-	-	-	-	-	-
2021/05/10	2021/05/17	Vflow	Nurse	-	-	-	-	-	-	-	-
2021/05/11	2021/05/18	Vflow	Nurse	-	-	-	-	-	-	-	-
2021/05/12	2021/05/19	Vflow	Nurse	-	-	-	-	-	-	-	-
2021/05/13	2021/05/20	People	Nurse	-	-	-	-	-	-	-	-
2021/05/14	2021/05/21	People	Nurse	-	-	-	-	-	-	-	-
2021/05/15	2021/05/22	People	Nurse	-	-	-	-	-	-	-	-
2021/05/16	2021/05/23	People	Nurse	-	-	-	-	-	-	-	-
2021/05/17	2021/05/24	People	Nurse	-	-	-	-	-	-	-	-
2021/05/18	2021/05/25	People	Nurse	-	-	-	-	-	-	-	-
2021/05/19	2021/05/26	People	Nurse	-	-	-	-	-	-	-	-
2021/05/20	2021/05/27	People	Nurse	-	-	-	-	-	-	-	-
2021/05/21	2021/05/28	People	Nurse	-	-	-	-	-	-	-	-
2021/05/22	2021/05/29	People	Nurse	-	-	-	-	-	-	-	-
2021/05/23	2021/05/30	People	Nurse	-	-	-	-	-	-	-	-
2021/05/24	2021/05/31	People	Nurse	-	-	Vflow	-	-	-	-	-
2021/05/25	2021/06/01	People	Nurse	-	-	Vflow	-	-	-	-	-
2021/05/26	2021/06/02	People	Vflow	-	-	Vflow	-	-	-	-	-
2021/05/27	2021/06/03	People	Vflow	-	-	Vflow	-	-	-	-	-
2021/05/28	2021/06/04	People	Vflow	-	-	Vflow	-	-	-	-	-
2021/05/29	2021/06/05	People	Vflow	-	-	Vflow	-	-	-	-	-
2021/05/30	2021/06/06	People	Vflow	-	-	Vflow	-	-	-	-	-
2021/05/31	2021/06/07	People	Vflow	-	-	Vflow	-	-	-	-	-

2021/06/01	2021/06/08	People	Vflow	-	-	Vflow	-	-	-	-	-
2021/06/02	2021/06/09	People	Vflow	-	-	Vflow	-	-	-	-	-
2021/06/03	2021/06/10	People	Vflow	-	-	Vflow	-	-	-	-	-
2021/06/04	2021/06/11	People	Vflow	-	-	Vflow	-	-	-	-	-
2021/06/05	2021/06/12	People	Vflow	-	-	Vflow	-	-	-	-	-
2021/06/06	2021/06/13	People	Vflow	-	-	Vflow	-	-	-	-	-
2021/06/07	2021/06/14	People	Vflow	-	-	Vflow	-	-	Vflow	Vflow	-
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2021/08/26	2021/09/02	People	Vstock	Vstock	Vstock	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow
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2021/09/08	2021/09/15	People	Vstock	Vstock	Vstock	Vstock	Vstock	Vstock	Vstock	Vstock	Vflow
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2021/09/25	2021/10/02	People	Vflow	Vflow	Vflow	Vstock	Vstock	Vstock	Vstock	Vstock	Vstock
2021/09/26	2021/10/03	People	Vflow	Vflow	Vflow	Vstock	Vstock	Vstock	Vstock	Vstock	Vstock
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2021/09/29	2021/10/06	People	Vflow	Vflow	Vflow	Vstock	Vstock	Vstock	Vstock	Vstock	Vstock
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2021/10/02	2021/10/09	People	People	Vflow	Vflow	People	Vstock	Vstock	People	Vstock	Vstock
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2021/10/04	2021/10/11	People	People	Vflow	People	People	Nurse	People	People	Vstock	People

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2021/10/07	2021/10/14	People	People	Vstock	People	People	Nurse	People	People	Vstock	People
2021/10/08	2021/10/15	People	People	Vstock	People	People	Nurse	People	People	Vstock	People
2021/10/09	2021/10/16	People	People	Vstock	People	People	Nurse	People	People	Vstock	People
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2021/10/16	2021/10/23	People	People	Vstock	People	People	Vstock	People	People	Vstock	People
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2021/10/23	2021/10/30	People	People	Vstock	People	People	Vstock	People	People	Vstock	People
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2021/10/26	2021/11/02	People	People	People	People	People	People	People	People	People	People
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2021/11/02	2021/11/09	People	People	People	People	People	People	People	People	People	People
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2021/11/07	2021/11/14	People	People	People	People	People	People	People	People	People	People
2021/11/08	2021/11/15	People	People	People	People	People	People	People	People	People	People
2021/11/09	2021/11/16	People	People	People	People	People	People	People	People	People	People
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2021/11/12	2021/11/19	People	People	People	People	People	People	People	People	People	People
2021/11/13	2021/11/20	People	People	People	People	People	People	People	People	People	People
2021/11/14	2021/11/21	People	People	People	People	People	People	People	People	People	People
2021/11/15	2021/11/22	People	People	People	People	People	People	People	People	People	People

2021/11/16	2021/11/23	People	People	People	People	People	People	People	People	People	People
2021/11/17	2021/11/24	People	People	People	People	People	People	People	People	People	People
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2021/11/20	2021/11/27	People	People	People	People	People	People	People	People	People	People
2021/11/21	2021/11/28	People	People	People	People	People	People	People	People	People	People
2021/11/22	2021/11/29	People	People	People	People	People	People	People	People	People	People
2021/11/23	2021/11/30	People	People	People	People	People	People	People	People	People	People

6.2.3. Takeda/Moderna Vaccine Administrations

Regarding Takeda/Moderna vaccine administrations, Table 6-2 shows the R-squared values are 0.627, 0.367, and 0.282 with the simulated and actual smoothed daily trends of the total, first, and second doses from May 21 to November 30, 2021, respectively. The R-squared values with the actual not-smoothed curves of the total, first, and second doses are 0.698, 0.554, and 0.474, respectively.

The table also introduces the metrics with the time range by September 12, 2021, the last date with available vaccine distribution data for the Takeda/Moderna vaccines. The R-squared with actual smoothed trends are 0.661, 0.113, and 0.476 on total, first, and second doses, respectively. The R-squared with actual not-smoothed curves are 0.694, 0.327, and 0.615 on total, first, and second doses, respectively.

Figure 6-8 (a) exhibits that the simulated daily vaccination speed is faster than the actual values by early June, equivalent from mid to late July, and slower from early August, with steep decelerations in early September and early October. The deceleration timing in early September corresponds to the 7 days before the first date with no vaccine distribution data, while that in early October is 28 days later than the early one.

Figure 6-8 (b) shows the peak level of simulated daily first-dose vaccinations around the beginning of July is 84% of the vaccine distribution peak in late June, which is larger than the peak level of the actual smoothed trend by 7% and smaller than that of the actual not-smoothed curve by 5%.

Figure 6-8 (c) shows that the shape of the simulated second-dose vaccinations with Takeda/Moderna vaccines fits the simulated first-dose curve with a 4-week lag.

The complementary error oscillation trends are observed with the simulated first-dose and second-dose vaccinations in Figure 6-8 (b) and (c). The simulated first-dose speed is faster than the actual from mid-June to early July, slower from mid-July to mid-August, faster from late August to the beginning of September, and slower from early September. The simulated trend of second doses is faster than the actual from mid-July to early August, slower from mid-August to mid-September, and faster from mid-September to the beginning of October.

Table 6-3 lists the simulated determinants of first-dose reservations on Takeda/Moderna vaccine administrations. The daily administrations of Takeda/Moderna vaccines in the simulation are determined by vaccine delivery flows from the initiation dates to early and mid-September and mainly vaccine stocks from early and mid-September to early October. The simulated administrations at large sites and in workplaces with the age groups 65–69 years old and 12–15 years old mainly face the depleted willing population. Based on the corresponding reservations, the simulated determinant of vaccinations at large sites with Takeda/Moderna vaccines for the age group 40–44 years old is the number of cooperative nurses in mid-October, the vaccine stock in late October and the willing population from the end of October. The simulated determinant in workplaces for the age group 40–44 years old is the vaccine stock from mid to late October, and the willing population from the end of October.

Figure 6-9 shows that the simulated trends with Takeda/Moderna vaccines do not predict weekly oscillations and negative pulses on national holidays in the actual not-smoothed daily vaccinations.

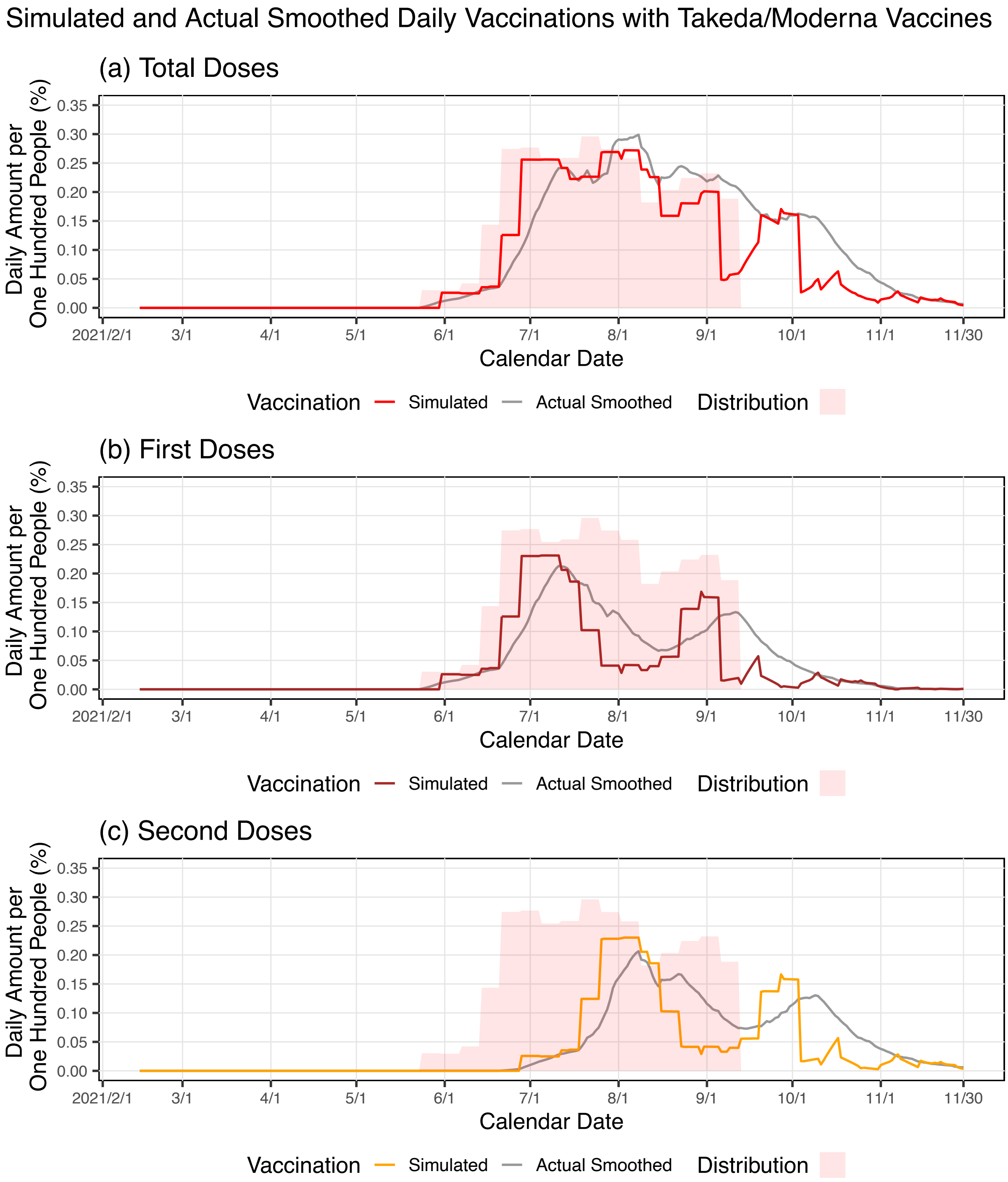
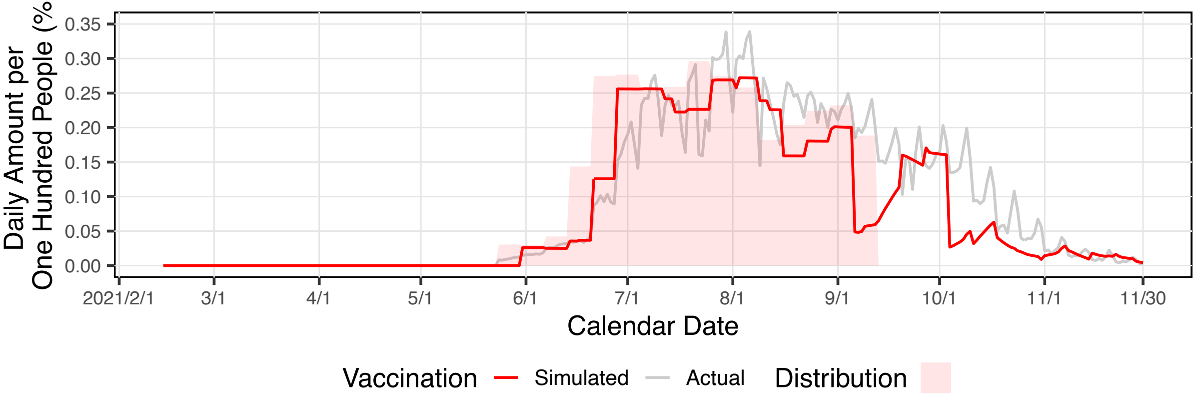


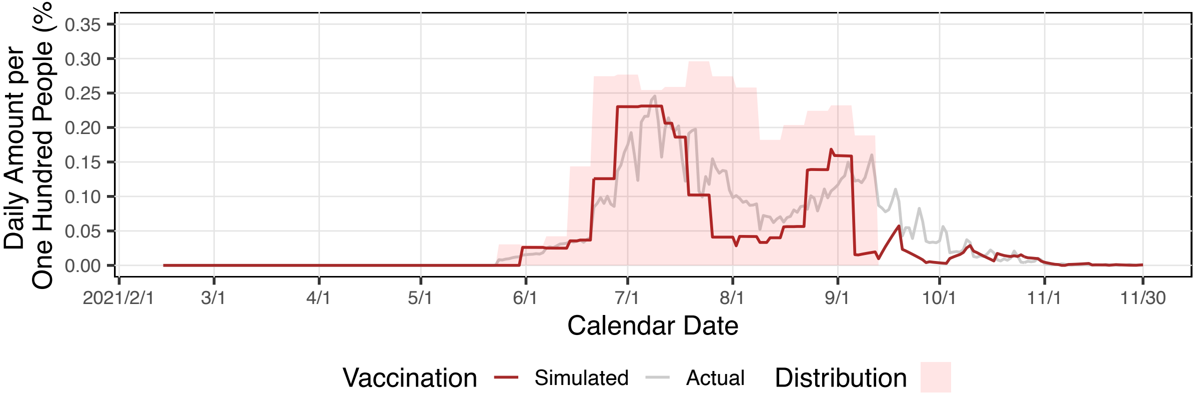
Figure 6-8 Simulated and Actual Smoothed Daily Vaccinations with Takeda/Moderna Vaccines
Simulated daily vaccination trends and actual 7-day smoothed daily vaccination trends in Japan for the primary series with Takeda/Moderna vaccines. Colored areas indicate the daily deliveries of Takeda/Moderna vaccines to vaccination sites.

Simulated and Actual Daily Vaccinations with Takeda/Moderna vaccines

(a) Total Doses



(b) First Doses



(c) Second Doses

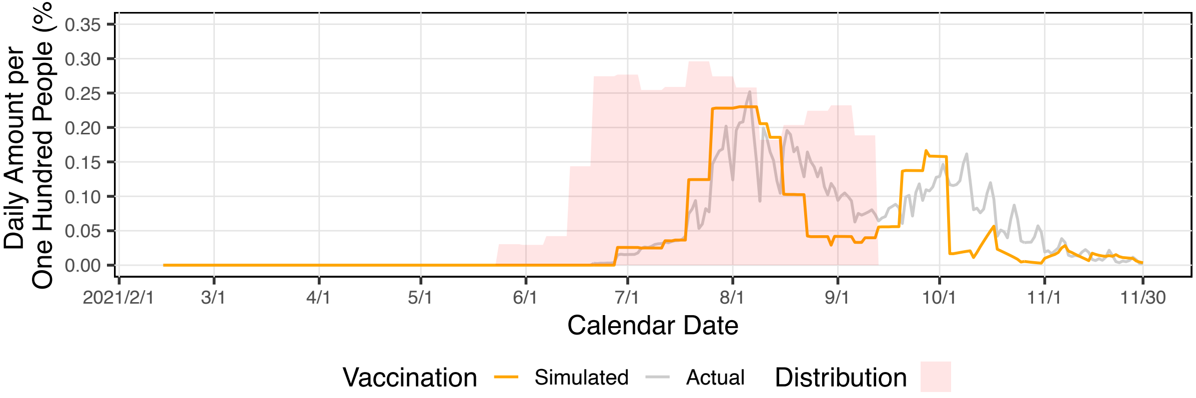


Figure 6-9 Simulated and Actual Daily Vaccinations with Takeda/Moderna Vaccines
Simulated and actual daily vaccinations in Japan for the primary series with Takeda/Moderna vaccines. Colored areas indicate the daily deliveries of Takeda/Moderna vaccines to vaccination sites.

6.3. Discussions on Determinant Assumptions of Daily Vaccination Speed

6.3.1. Willing Population

The populations willing to take the first and second doses contribute to predicting the saturations of cumulative vaccinated people. Figure 6-2 exhibits the saturation of cumulative vaccination trends in November below the threshold of cumulative distributed Pfizer/BioNTech vaccines. Table 6-3 supports that the population willing to take first doses is the simulated determinant of daily first-dose vaccinations in November.

6.3.2. Vaccine Delivery and Ceiling Effect

The assumption of the vaccine delivery ceiling effect on first-dose reservations fits the peak levels of daily vaccination trends with both the Pfizer/BioNTech and Takeda/Moderna vaccines. Figure 6-6 (b) exhibits that the model predicts the peak level of first doses with Pfizer/BioNTech vaccines in June below 50% of the maximum daily vaccine delivery speed in May. Table 6-3 endorses that the vaccine delivery constraint causes this trend in the period. Figure 6-8 (b) displays that the model also simulates that the peak level of the first doses of Takeda/Moderna vaccines is close to the actual in early July, around 84% of the maximum daily vaccine delivery speed in late June. Table 6-3 supports that the determinants of Takeda/Moderna vaccine administrations are vaccine delivery flows in the corresponding period.

6.3.3. Vaccine Stock at Vaccination Sites

The assumption of the vaccine stock constraint on first-dose reservations contributes to the fitting in the period with the low vaccine delivery speed. Figure 6-6 (b) and Table 6-3 reveal that not-reserved vaccine stocks at vaccination sites determine the well-fitting trend of first doses with Pfizer/BioNTech vaccines from August to mid-September and mid to late October in the simulation.

6.3.4. Human Resource Constraints

The assumption of human resource constraints with fully immunized cooperative healthcare workers partially fits the vaccination trend. Figure 6-6 (b) and Table 6-3 endorse that the well-fitting of daily first-dose administrations with Pfizer/BioNTech vaccines in late May can be attributed to the human resource capacity constraint, potentially with nurses.

6.3.5. System Dynamics of Vaccination Speed

The changing determinants of reservations in the simulation range validate the assumption of system dynamics on vaccination speed. Results and discussions on human resource constraints in Figure 6-6 (b), Table 6-3, and Chapter 6.3.4 implies the existing reinforcing loop of the human resource increase for daily reservations and vaccinations in the early phase of the vaccination project. Table 6-3 and discussions in Chapters 6.3.1 and 6.3.2 suggests that the vaccine deliveries and stocks at vaccination sites can be determinants of daily vaccination speed in every phase of the vaccination project. Table 6-3 shows that the model predicts the vaccine stock as the determinant of daily vaccinations in the later phase of the project. The table also exhibits that the willing population is the determinant at the end of the simulation range with all the vaccine distribution categories.

6.4. Model Limitations and Future Research Topics

6.4.1. Determinant in Human Resource Constraint

The determinant in the human resource constraint can easily change with the maximum achievable ratio of nurses to doctors. The reference input of this ratio for operations with Pfizer/BioNTech vaccines by municipalities is based on the maximum ratio among five facility types for vaccination sites in the reference [226]. If the average or smaller ratio is chosen from the reference for the simulation input, the model could output doctors as the determinant from mid to late May. The interpretation and utilization require careful attention to the variable inputs regarding human resources.

6.4.2. Initiation date

Table 6-3 exhibits that the simulated initiation dates of vaccinations deviate from the input actual dates by 5 days on Pfizer/BioNTech vaccine administrations for healthcare workers, 7 days on Takeda/Moderna vaccine administrations for the elderly at large sites, and 1 day on Takeda/Moderna vaccine administrations in workplaces. These gaps can be attributed to the model algorithm, which determines the earliest administration date by the earliest vaccine delivery dates. The algorithm needs to be refactored to improve the explainability of the initiation timings.

6.4.3. Local Peak in Mid-May with Pfizer/BioNTech First-Dose Vaccinations

Positive simulation errors exist with the step-function-like daily first-dose vaccination trend from early to mid-May. The model outputs that the administration determinants in this period are vaccine deliveries and stocks for both the operations for healthcare workers and elderly citizens.

One possible cause of this error trend is the no-limit assumption of human resource capacity on vaccinations for healthcare workers. The error decreases as the vaccinations for healthcare workers decline from mid to late May. The model might overestimate the total human resource capacity while the administrations for healthcare workers and the elderly exist in parallel.

Another possible explanation for the errors is the reporting delay of actual daily vaccination trends. Previous research suggests the potential reporting delay with the government vaccination record system [4]. If the reporting delay exists, the true first-dose curve with Pfizer/BioNTech vaccines might shift to the left.

6.4.4. Vaccination Ramp-Up with Takeda/Moderna Vaccines

The R-Squared values with the Takeda/Moderna vaccines are smaller than the Pfizer/BioNTech ones. With the faster ramp-up of the first-dose trend after June 21, 2021, the model output the complementary error oscillations of first-dose and second-dose curves with Takeda/Moderna vaccines, which degrade the R-Squared.

One of the possible causes is the excess level of the ceiling effect. The larger ceiling coefficient can cause a faster vaccination ramp-up with vaccine distributions in the simulation. The input value adopts the observed ceiling coefficient from the not-smoothed trend, oscillating with a 7-day interval. There also might be a gap in the ceiling coefficients between the two administrations of Takeda/Moderna vaccines at large sites and workplaces. The model fits the actual first-dose trend well in early and mid-June, but the deviation increases after June 21, 2021, the initiation date for many vaccination sites at workplaces [234].

However, calibrating the ceiling coefficient cannot explain the X-axis gap between the peak positions of simulated and actual first-dose vaccination trends. The actual trend shows the peak on July 8 to 9 with a two-week lag from the distribution peak from late June to early July. The lag with the simulated first-dose trend is 7 days based on the algorithm. The calibration or probabilistic distribution of human resource factors or other mechanisms might be required to consider a lag distribution between vaccine deliveries and vaccinations. This calibration might be applicable for the simulation of the Pfizer/BioNTech administrations.

6.4.5. Weekday and Holiday Effects

The model cannot explain the weekly oscillations and declines with national holidays and vacation seasons in the actual not-smoothed vaccination trends. The impacts of national holidays and vacation seasons are also observed in the actual smoothed vaccination trend. The model enhancement with the weekday effect and the holiday effect will improve the fitting to both the not-smoothed and smoothed vaccination trends.

6.4.6. Data Limitation on Takeda/Moderna Vaccine Distributions

The lack of distribution data with Takeda/Moderna vaccines after mid-September can degrade the fittings of simulated trends with lower ceilings of cumulative trends than the actual data. If the complete vaccine distribution dataset is available, the errors with the Takeda/Moderna and all the vaccine administrations might decrease.

6.5. Chapter Summary

The model predicted the actual cumulative vaccination trends with Pfizer/BioNTech and Takeda/Moderna vaccines with the 70% coverage achievement period errors (percentage errors) of 10 days (4.24%), 12 days (5.41%), and 8 days (3.23%) for the total doses, first doses, and second doses, respectively. The R-squared values were 0.943, 0.909, and 0.915 with the simulated and actual smoothed daily trends of the total, first, and second doses with all the vaccines from February 14 to November 30, 2021, respectively. The simulation results endorsed the validity of system dynamics assumptions on vaccination speed with the willing population as a demand constraint, vaccine deliveries with the ceiling effect and vaccine stocks at vaccination sites as supply constraints with vaccines, and cooperative fully immunized healthcare workers as another supply constraint with human resources. Further research will be expected to consider the updated mechanisms on initiation dates, human resource constraints on vaccinations for healthcare workers, calibration or probabilistic distribution of parameters, and weekday and holiday effects.

7. Exploring Operational Options

This chapter explores the operational options for primary-series vaccinations in Japan using the developed simulation model from resource-saving and acceleration viewpoints. In Chapter 7.1, the simulation searches for the potential to reduce excess planned recruitment of human resources. The room for acceleration with the earlier completion of vaccinations for healthcare workers is simulated in Chapter 7.2.

7.1. Reducing Excess Planned Recruitment of Human Resources

7.1.1. Objective

This subchapter explores the room for saving doctors' participation in the vaccination project for the primary series in Japan. The simulation results with the reference inputs in Chapter 6 revealed that the determinants of vaccination trends are available vaccines, cooperative nurses on the supply side, and willing people on the demand side. There might be an excess number of doctor recruitments planned by municipalities in June 2021 [226], which can be reduceable without the delay of vaccination coverage achievement. Efficient recruitment and operations with healthcare workers are significant for society to materialize their maximum professional capacities for emergency responses and routine work during pandemics.

7.1.2. Approach

This subchapter runs the developed vaccination model with multiple inputs of the doctors' participation rate pr_{doctor} and the maximum achievable ratio of nurses to doctors $maxratio_{\mathrm{NperDOP}}$ with Pfizer/BioNTech vaccines operated by local governments. The lowest doctors' participation rate determines the potential excess number of doctors with no delay on the 70% full vaccination coverage achievement in each case of maximum achievable nurse–doctor ratio. One note is that the variables of doctors in the following discussions exclude occupational physicians as the variable definitions in Chapter 5.

7.1.3. Pre-Estimation with Human Resource Balancing Equation

The potential saving number of doctors can be predicted by the following equation before the simulation, given the population ratio of nurses to doctors except for occupational physicians, the planned doctors' and nurses' participation rate pr^{*}_{doctor} and pr^{*}_{nurse}, and the maximum achievable ratio of nurses to doctors $maxratio^{*}_{\mathrm{NperDOP}}$ in the operations by local governments are known.

$$\begin{aligned}&\text{Potential Saving Number of Doctors} =\\&\quad \text{Doctors' Population} \times pr^{*}_{\mathrm{doctor}} - \text{Nurses' Population} \times pr^{*}_{\mathrm{nurse}} \div\ maxratio_{\mathrm{NperDOP}}\end{aligned}$$

The second term on the right hand of the equation implies the minimum number of doctors required to materialize the maximum nurses' capacity. Dividing this value by the doctors' population provides the corresponding lowest acceptable doctors' participation rate before the simulation. The reference inputs and the equations predict that the potential saving number of doctors is 5,550. The lowers acceptable doctors' participation rate is expected to be 19.32%, which is smaller by 1.80% than the reference participation rate of 21.12%

7.1.4. Results of Model Simulation

Table 7-1 exhibits the simulated achievement gaps of the 70% full vaccination coverage between the base case and other cases with modulated pr_{doctor} and $maxratio_{\mathrm{NperDOP}}$. The yellow cells indicate the variable combination with no simulated gap of the achievement date. The lowest acceptable doctors' participation rate decreases as $maxratio_{\mathrm{NperDOP}}$ increases.

With the reference input of 2.02 on $maxratio_{\mathrm{NperDOP}}$, the lowest acceptable doctors' participation rate is expected to be 17%, which is smaller by 4.12% than the base case input. The corresponding potential saving number of doctors is 12,680. These simulated values are larger than the estimation with the human resource equations without the simulation.

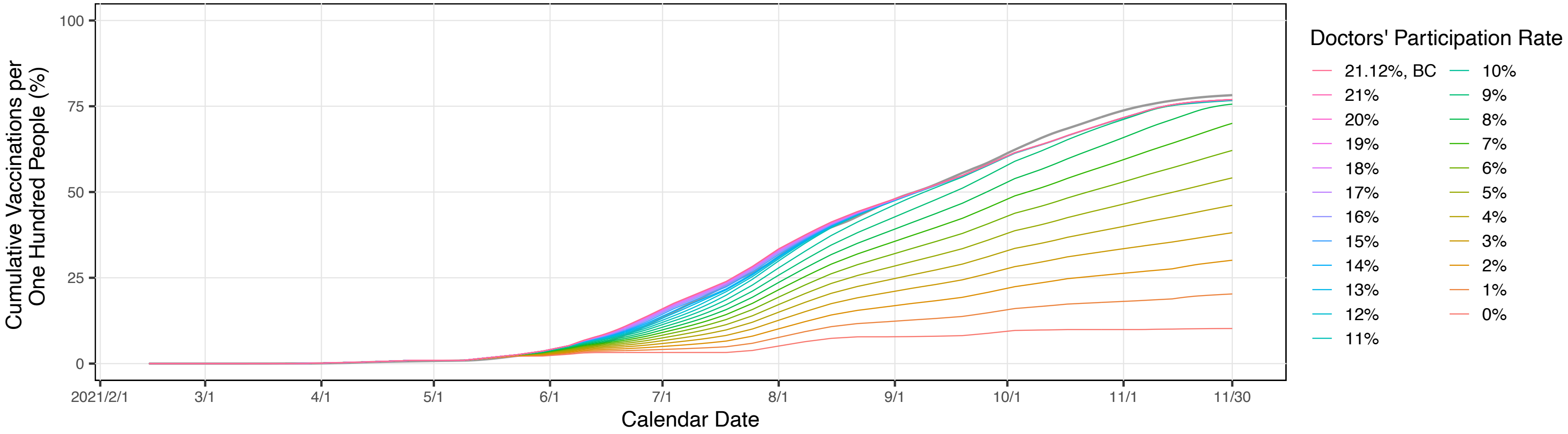
Figure 7-1 exhibits the cumulative and daily second-dose vaccination trends with the multiple inputs with pr_{doctor} and the reference input of 2.02 with $maxratio_{\mathrm{NperDOP}}$. The figure shows that the simulated trends surge and converge to the reference case as pr_{doctor} increases.

Table 7-1 Gap in Simulated Achievement Dates by Doctors' Participation Rate and Nurse–Doctor Ratio
The gaps with simulated achievement dates of the 70% full vaccination coverage between the reference simulation and other cases with multiple combinations of the doctors' participation rate pr_{doctor} and the maximum achievable ratio of nurses to doctors $maxratio_{\text{NperDOP}}$ for operations by local governments with Pfizer/BioNTech vaccines. The yellow cells show the gaps of 0 days from the reference simulation. "Ref." stands for the base case in the simulation. The values on the Potential Saving Number of Doctors column show the product of the doctors' population by the doctors' participation rate gap between the simulation and reference inputs. The $maxratio_{\text{NperDOP}}$ of 5.33 corresponds to the input value for operations with Takeda/Moderna vaccines.

Doctors' Participation Rate $\boldsymbol{pr}_{\textbf{doctor}}$	Potential Saving Number of Doctors	Saving Number Gap between Simulation and Equation	Maximum Achievable Ratio of Nurses to Doctors $\boldsymbol{maxratio}_{\textbf{NperDOP}}$							
			0	1	2	Ref. 2.02	3	4	5	5.33
Ref. 21.12%	-	(5,550)	-	1	0	Ref.	0	0	0	0
21%	370	(5,180)	-	1	0	0	0	0	0	0
20%	3,450	(2,100)	-	1	0	0	0	0	0	0
19%	6,530	980	-	1	0	0	0	0	0	0
18%	9,610	4,060	-	3	0	0	0	0	0	0
17%	12,680	7,130	-	9	0	0	0	0	0	0
16%	15,760	10,210	-	17	1	1	0	0	0	0
15%	18,840	13,290	-	26	1	1	0	0	0	0
14%	21,920	16,370	-	-	1	1	0	0	0	0
13%	25,000	19,450	-	-	1	1	0	0	0	0
12%	28,080	22,530	-	-	1	1	0	0	0	0
11%	31,160	25,610	-	-	1	1	1	0	0	0
10%	34,230	28,680	-	-	1	1	1	0	0	0
9%	37,310	31,760	-	-	3	2	1	0	0	0
8%	40,390	34,840	-	-	17	15	1	1	0	0
7%	43,470	37,920	-	-	-	34	1	1	0	0
6%	46,550	41,000	-	-	-	-	3	1	1	1
5%	49,630	44,080	-	-	-	-	26	1	1	1
4%	52,710	47,160	-	-	-	-	-	17	1	1
3%	55,790	50,240	-	-	-	-	-	-	26	17
2%	58,860	53,310	-	-	-	-	-	-	-	-
1%	61,940	56,390	-	-	-	-	-	-	-	-
0%	65,020	59,470	-	-	-	-	-	-	-	-

Simulated Second–Dose Vaccinations and Doctors' Participation Rate with Maximum Achievable Nurse–Doctor Ratio of 2.02

(a) Cumulative Vaccinations



(b) Daily Vaccinations

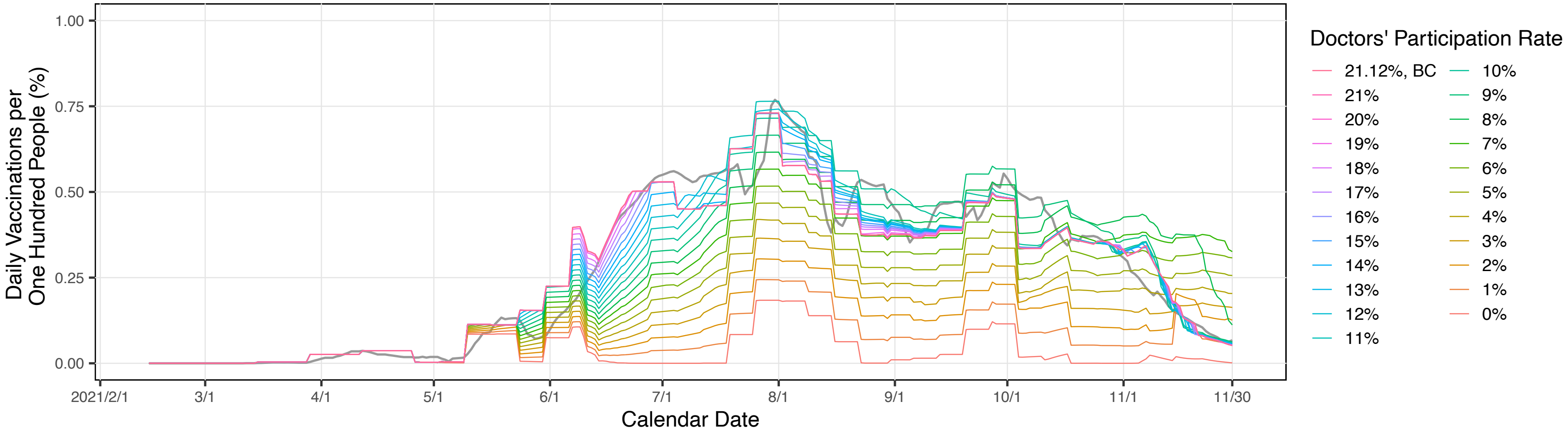


Figure 7-1 Simulated Second-Dose Vaccinations and Doctors' Participation Rate with Maximum Achievable Nurse–Doctor Ratio of 2.02
Simulated second-dose cumulative and daily vaccination trends with the multiple inputs with the doctors' participation rate and the reference input of 2.02 with the maximum achievable ratio of nurses to doctors. "21.12%, BC" stands for the base case input of the doctors' participation rate. Grey lines on the backgrounds indicate the actual vaccination trends.

7.1.5. Discussions

There is a gap of 7,130 and 2.32% with the potential saving number of doctors and the lowest acceptable participation rate, respectively, between the simulated values and the estimation with the equations on human resource balancing. Considering the simulated determinant trends in Chapter 6, these differences are attributed to the supply-side capacity gap between vaccines and human resources.

The simulation suggests that 37,920 doctors, 12.32% of the population, might be released from the recruitment plan without vaccination delay by considering vaccine bottlenecks and achieving $maxratio_{\mathrm{NperDOP}}$ of 5.33 on average, like the JSDF vaccination site with Takeda/Moderna vaccines, and considering vaccine bottlenecks.

These results and discussions demonstrate the criticality of synchronizing capacities on human resources and vaccines, besides the effectiveness of operational excellence on sites for vaccinations, to materialize fewer resource allocations for the project. With the simulation model and vaccine procurement schedules at a national scale, a government or project management office will be able to propose optimal numbers of healthcare workers' recruitment to cooperative organizations.

7.1.6. Limitations

The number of potentially saving healthcare workers is sensitive to the input values of the daily vaccination productivity and the weekly proportion of working days. The larger the productivity, the fewer the potential saving healthcare workers get. The smaller the weekly proportion of working days, the more potential saving healthcare workers get. Therefore, the exact numbers of simulated potential saving healthcare workers should be carefully interpreted.

7.2. Acceleration by Early Immunity Development for Healthcare Workers

7.2.1. Objective

This subchapter explores the impact of earlier vaccine procurement and distribution to solve the human resource constraints in mid to late May. The model simulation predicts that the administration determinant of first-dose vaccinations for the elderly with Pfizer/BioNTech vaccines is human resource capacity from May 17 to June 1, 2021 (cf. Table 6-3 in Chapter 6.2). In most of the period before the depletion of willing people, the administration determinant is vaccine deliveries and stocks. Human resource capacity is determined by the number of healthcare workers who have experienced the immunity development period after the second dose. One of the minimum interventions for this bottleneck is to complete the vaccinations for healthcare workers with Pfizer/BioNTech vaccines earlier.

7.2.2. Approach

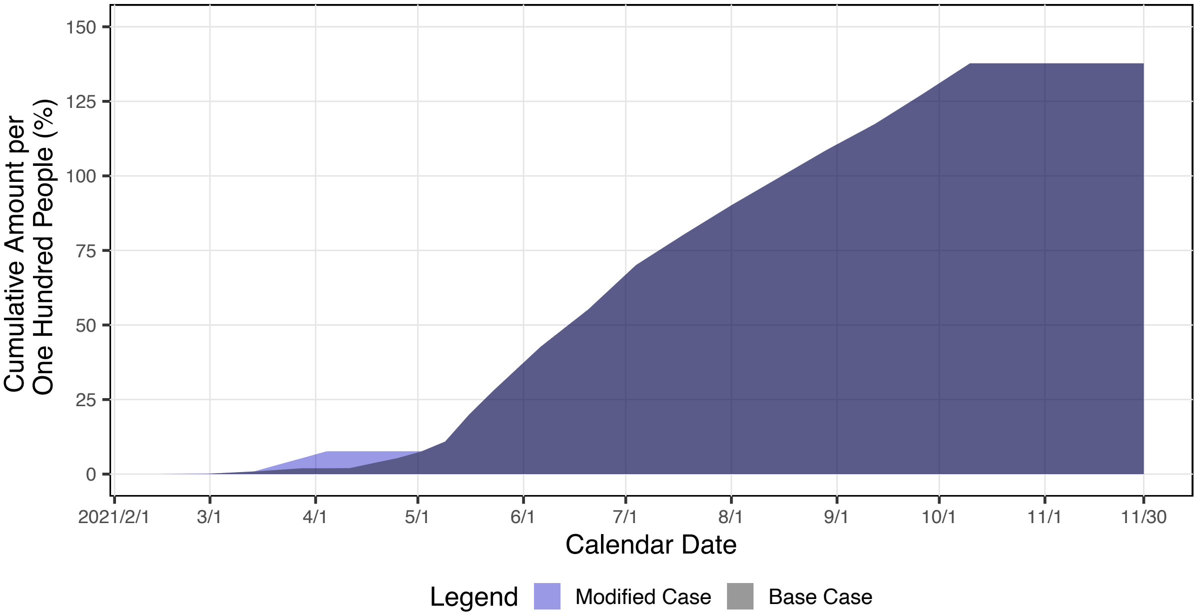
This exploration assumes that the 9.65 million doses of Pfizer/BioNTech vaccines are delivered from February 15 to April 5 without increasing the total delivered Pfizer/BioNTech vaccines in the simulation time range. The first date of vaccinations with the human resource constraint is on May 17, which is 35 days after April 5. It takes 7 days from a reservation to a first dose, 21 days from a first to a second dose, and 7 days for immunity development after a second dose of Pfizer/BioNTech vaccines. Therefore, this simulation assumes the last delivery date of Pfizer/BioNTech vaccines for healthcare workers is April 5.

The daily deliveries of all the Pfizer/BioNTech vaccines from April 6 to May 2 are added to the daily deliveries 28 days before from March 9 to April 4, respectively. The delivered amount of vaccines on April 5 is equal to the actual total delivered amount of Pfizer/BioNTech vaccines for the primary series of healthcare workers minus the cumulative amount of modified vaccine deliveries by April 4. No vaccine delivery is assumed after April 6 for healthcare workers. On May 3, vaccine distributions with Pfizer/BioNTech vaccines are initiated for the elderly and other citizens. Figure 7-2 exhibits the assumed and actual vaccine distribution trends: the latter is the base-case input of the simulation.

Other simulation inputs are the same as the base case in Chapter 6.

Modified and Base−Case Distributions of Pfizer/BioNTech Vaccines

(a) Cumulative Distribution



(b) Daily Distribution

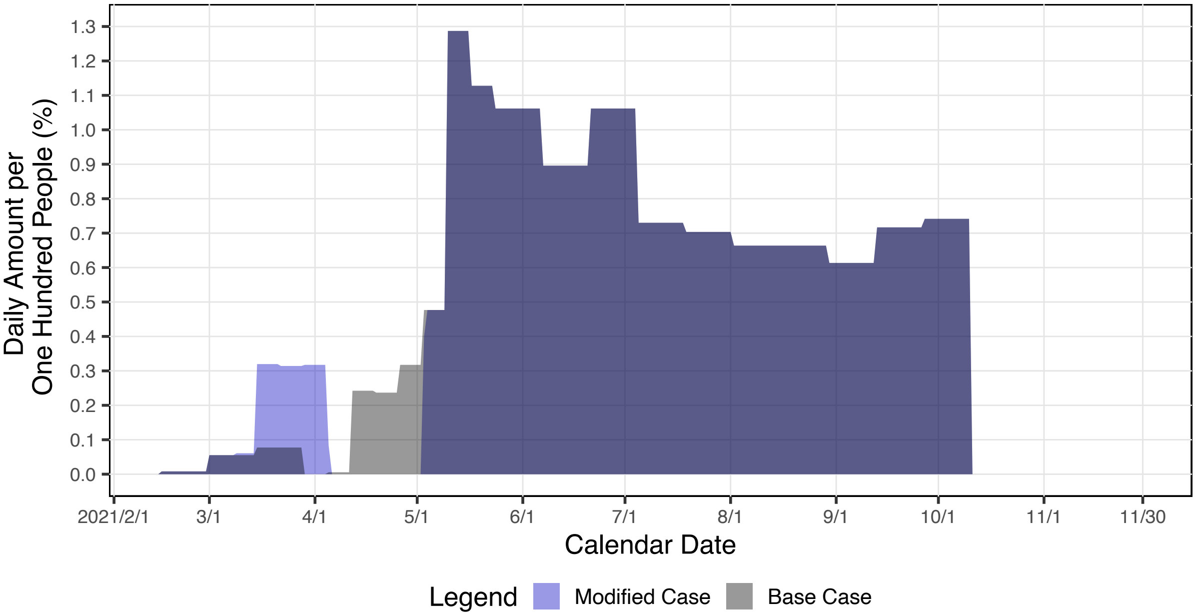


Figure 7-2 Modified and Reference Vaccine Distributions with Pfizer/BioNTech Vaccines
Modified vaccine distribution with Pfizer/BioNTech vaccines to accelerate vaccinations for healthcare workers, compared with the base-case distribution trend.

7.2.3. Results of Model Simulation

Figure 7-3 exhibits the simulated cumulative vaccination and deviation trends with the modified Pfizer/BioNTech vaccine distributions. The modified distribution case outputs a faster first-dose ramp-up by the beginning of May, a slower pace in early to mid-May, and faster after mid-May. The second-dose curve fits the shifted first-dose trend.

Table 7-2 lists the deviations of coverage achievement periods between modified and base-case Pfizer/BioNTech vaccine distributions. The modified case reaches 70% vaccination coverage earlier by 4 days, 3 days, and 3 days on total doses, first doses, and second doses, respectively. The corresponding percentage deviations are -1.63%, -1.28%, and -1.17%, respectively.

Figure 7-4 shows the daily vaccination trends with the modified and base cases. The first-dose daily vaccination speed with the modified distribution is faster than the base case from mid-March to early April, slower from mid-April to early May, faster from mid to late May, equivalent from June to August, and slightly faster from early September to the end of October. The second-dose trend fits the shifted first-dose curve.

Table 7-3 indicates that the simulated determinants of first-dose vaccinations are vaccine deliveries or willing populations by early September. The administrations with Pfizer/BioNTech vaccines are determined by vaccine constraints from mid-September to late September and late October and by the depleted willing people to the end of November. The operations with Takeda/Moderna vaccines are mainly determined by not-reserved vaccine stocks at sites from mid-September to late September and late October and by the depleted willing people to the end of November. The model predicts that the determinant with Takeda/Moderna vaccines for the age group of 40–44 years old in mid-October is human resource constraints.

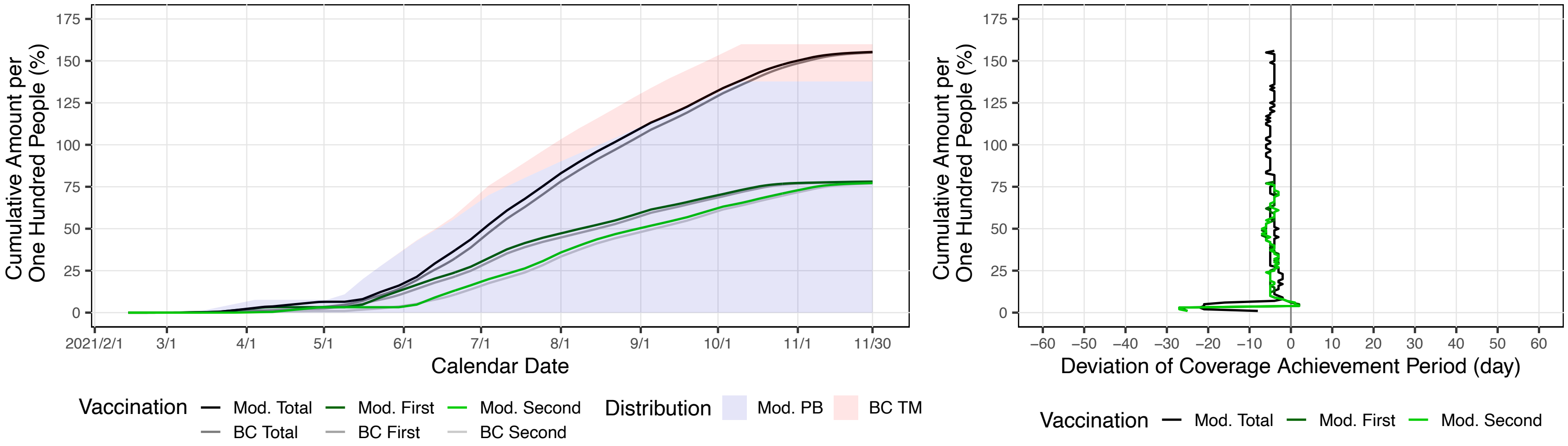
Table 7-2 Deviations of Coverage Achievement Periods between Modified and Base-Case Vaccine Distributions
Simulated deviations of coverage achievement periods with all the vaccines between modified and base-case Pfizer/BioNTech vaccine distributions. The percentage deviation is a deviation divided by the corresponding base-case achievement period. For the dose round "Total," the deviations in the Coverage Period columns correspond to the achievement periods of 20%, 80%, and 140% coverages. For the other dose rounds "First" and "Second," the deviations in these columns correspond to the achievement periods of 10%, 40%, and 70% coverages. The start dates of the achievement periods are the authorization date of the Pfizer/BioNTech vaccine on February 14, 2021.

Deviation Metrics	Dose Round	Range (Corresponding Vaccination Coverage)	20%/10% Coverage Period	80%/40% Coverage Period	140%/70% Coverage Period
Deviation (day)	Total	-22 to -2 days (at 3% and 8% coverages)	-2 days	-4 days	-4 days
	First	-27 to 2 days (at 3% and 4% coverages)	-5 days	-5 days	-3 days
	Second	-27 to 2 days (at 2% and 4% coverages)	-5 days	-4 days	-3 days
Percentage Deviation (%)	Total	-31.43% to -1.43% (at 2% and 154% coverages)	-1.75%	-2.34%	-1.63%
	First	-38.46% to 2.30% (at 1% and 4% coverages)	-4.72%	-3.16%	-1.28%
	Second	-29.07% to 1.85% (at 1% and 4% coverages)	-3.94%	-2.21%	-1.17%

Simulated Cumulative Vaccinations and Deviations with Modified and Base–Case Vaccine Distributions

(a) Cumulative Vaccinations

(b) Deviation of Coverage Achievement Period



(c) Percentage Deviation of Cumulative Vaccination

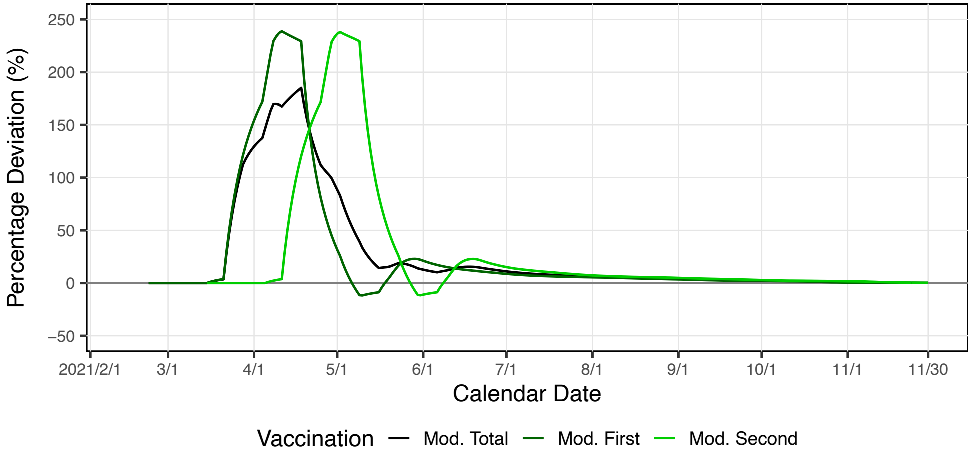
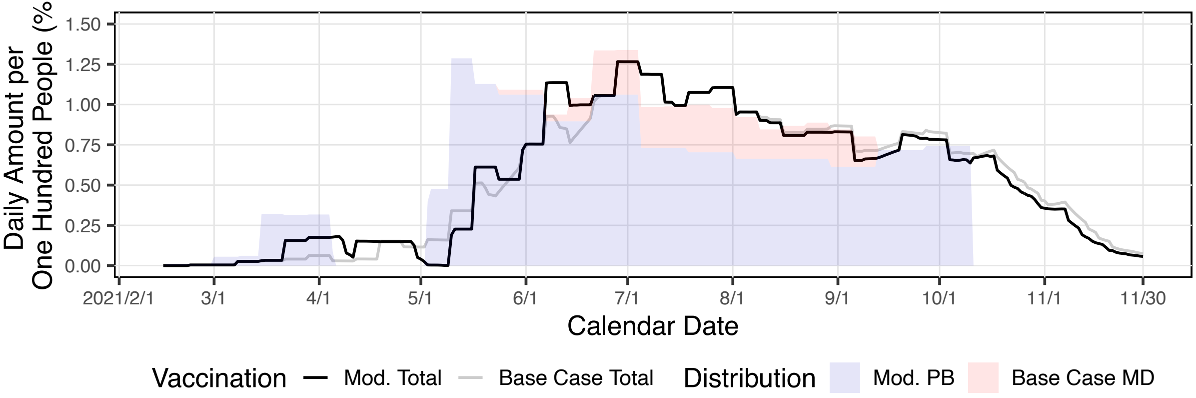


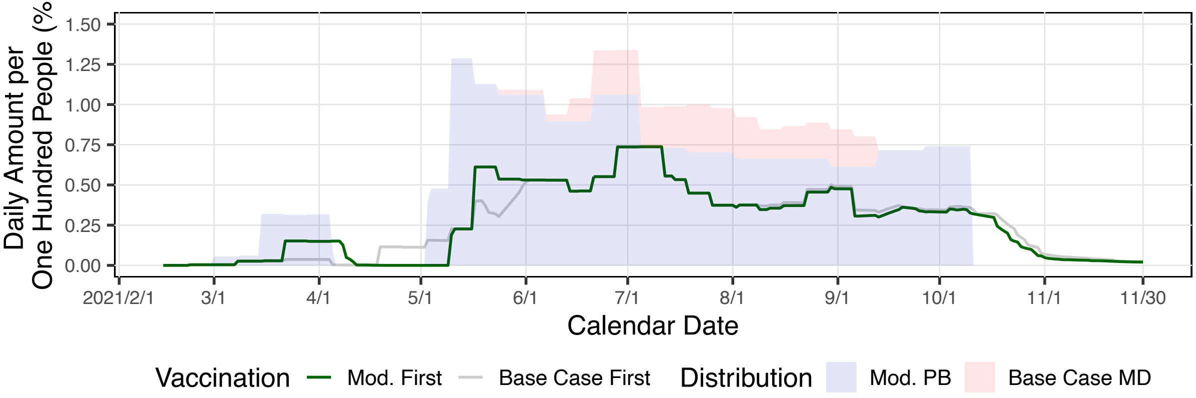
Figure 7-3 Simulated Cumulative Vaccinations and Deviations with Modified and Base-Case Vaccine Distributions
(a) Simulated cumulative vaccinations in Japan for the primary series with modified/base-case Pfizer/BioNTech and base-case Takeda/Moderna vaccine distributions. (b) Deviations of coverage achievement period between the cases of the modified and base-case distributions. (c) Percentage deviations of cumulative vaccinations. "Mod.," "BC," "PB," and "TM" stand for "Modified Case," "Base Case," "Pfizer/BioNTech," and "Takeda/Moderna," respectively.

Simulated Daily Vaccinations with Modified and Base−Case Vaccine Distributions

(a) Total Doses



(b) First Doses



(c) Second Doses

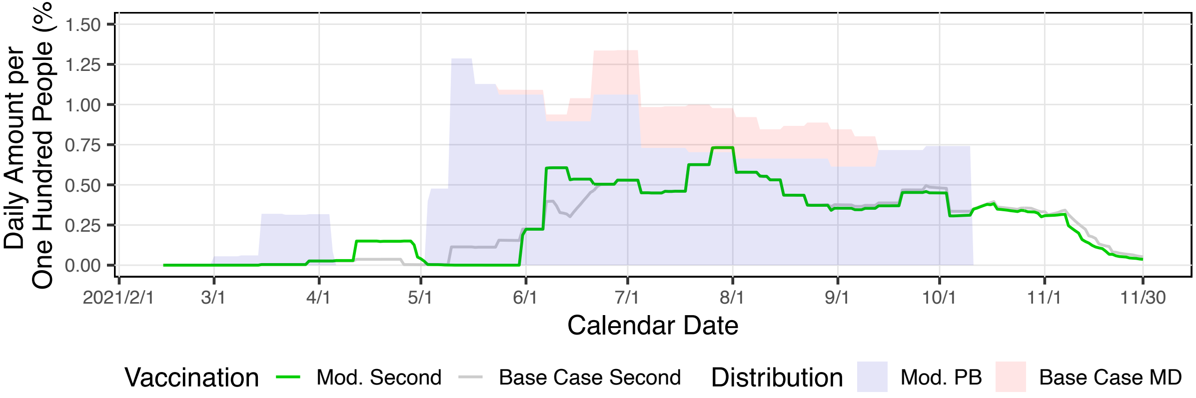


Figure 7-4 Simulated Daily Vaccinations with Modified and Base-Case Vaccine Distributions
Simulated daily vaccination trends in Japan for the primary series with modified/base-case Pfizer/BioNTech and base-case Takeda/Moderna vaccine distributions. Colored areas indicate the daily deliveries of Pfizer/BioNTech and Takeda/Moderna vaccines. “Mod.” stands for “Modified Case.”

Table 7-3 Simulated Determinants of First-Dose Reservations with Modified Pfizer/BioNTech Vaccine Distributions

The simulated determinants of first-dose reservations $rsvflow1$ with modified Pfizer/BioNTech vaccine distributions each time step by vaccine distribution category with the examples of age groups. The Corresponding Date column lists the dates 7 days after the values of the First-Dose Reservation Date, which indicates the time steps with the values in $rsvflow1$. "Vflow," "Vstock," "Nurse," and "People" stand for the vaccine inflows, vaccine stocks, human resource capacity based on the cooperative nurses, and the willing people as the determinant of the first-dose reservation in the algorithm, respectively. "PB-HW" and "PB-OC" represent the administrations for healthcare workers and other citizens with Pfizer/BioNTech vaccines, respectively. "TM-LC" and "TM-WP" represent the administrations at large sites and workplaces with Takeda/Moderna vaccines, respectively. "y.o." stands for "years old."

First-Dose Reservation Date	Corresponding Date of First Doses	Vaccine Distribution Category PB-HW 40–44 y.o.	PB-OC 65–69 y.o.	PB-OC 40–44 y.o.	PB-OC 12–15 y.o.	TM-LC 65–69 y.o.	TM-LC 40–44 y.o.	TM-LC 12–15 y.o.	TM-WP 65–69 y.o.	TM-WP 40–44 y.o.	TM-WP 12–15 y.o.
2021/02/07	2021/02/14	-	-	-	-	-	-	-	-	-	-
2021/02/08	2021/02/15	-	-	-	-	-	-	-	-	-	-
2021/02/09	2021/02/16	-	-	-	-	-	-	-	-	-	-
2021/02/10	2021/02/17	-	-	-	-	-	-	-	-	-	-
2021/02/11	2021/02/18	-	-	-	-	-	-	-	-	-	-
2021/02/12	2021/02/19	-	-	-	-	-	-	-	-	-	-
2021/02/13	2021/02/20	-	-	-	-	-	-	-	-	-	-
2021/02/14	2021/02/21	-	-	-	-	-	-	-	-	-	-
2021/02/15	2021/02/22	Vflow	-	-	-	-	-	-	-	-	-
2021/02/16	2021/02/23	Vflow	-	-	-	-	-	-	-	-	-
2021/02/17	2021/02/24	Vflow	-	-	-	-	-	-	-	-	-
2021/02/18	2021/02/25	Vflow	-	-	-	-	-	-	-	-	-
2021/02/19	2021/02/26	Vflow	-	-	-	-	-	-	-	-	-
2021/02/20	2021/02/27	Vflow	-	-	-	-	-	-	-	-	-
2021/02/21	2021/02/28	Vflow	-	-	-	-	-	-	-	-	-
2021/02/22	2021/03/01	Vflow	-	-	-	-	-	-	-	-	-
2021/02/23	2021/03/02	Vflow	-	-	-	-	-	-	-	-	-
2021/02/24	2021/03/03	Vflow	-	-	-	-	-	-	-	-	-
2021/02/25	2021/03/04	Vflow	-	-	-	-	-	-	-	-	-
2021/02/26	2021/03/05	Vflow	-	-	-	-	-	-	-	-	-
2021/02/27	2021/03/06	Vflow	-	-	-	-	-	-	-	-	-
2021/02/28	2021/03/07	Vflow	-	-	-	-	-	-	-	-	-
2021/03/01	2021/03/08	Vflow	-	-	-	-	-	-	-	-	-
2021/03/02	2021/03/09	Vflow	-	-	-	-	-	-	-	-	-
2021/03/03	2021/03/10	Vflow	-	-	-	-	-	-	-	-	-
2021/03/04	2021/03/11	Vflow	-	-	-	-	-	-	-	-	-
2021/03/05	2021/03/12	Vflow	-	-	-	-	-	-	-	-	-
2021/03/06	2021/03/13	Vflow	-	-	-	-	-	-	-	-	-
2021/03/07	2021/03/14	Vflow	-	-	-	-	-	-	-	-	-
2021/03/08	2021/03/15	Vflow	-	-	-	-	-	-	-	-	-

2021/03/09	2021/03/16	Vflow	-	-	-	-	-	-	-	-	-
2021/03/10	2021/03/17	Vflow	-	-	-	-	-	-	-	-	-
2021/03/11	2021/03/18	Vflow	-	-	-	-	-	-	-	-	-
2021/03/12	2021/03/19	Vflow	-	-	-	-	-	-	-	-	-
2021/03/13	2021/03/20	Vflow	-	-	-	-	-	-	-	-	-
2021/03/14	2021/03/21	Vflow	-	-	-	-	-	-	-	-	-
2021/03/15	2021/03/22	Vflow	-	-	-	-	-	-	-	-	-
2021/03/16	2021/03/23	Vflow	-	-	-	-	-	-	-	-	-
2021/03/17	2021/03/24	Vflow	-	-	-	-	-	-	-	-	-
2021/03/18	2021/03/25	Vflow	-	-	-	-	-	-	-	-	-
2021/03/19	2021/03/26	Vflow	-	-	-	-	-	-	-	-	-
2021/03/20	2021/03/27	Vflow	-	-	-	-	-	-	-	-	-
2021/03/21	2021/03/28	Vflow	-	-	-	-	-	-	-	-	-
2021/03/22	2021/03/29	Vflow	-	-	-	-	-	-	-	-	-
2021/03/23	2021/03/30	Vflow	-	-	-	-	-	-	-	-	-
2021/03/24	2021/03/31	Vflow	-	-	-	-	-	-	-	-	-
2021/03/25	2021/04/01	Vflow	-	-	-	-	-	-	-	-	-
2021/03/26	2021/04/02	Vflow	-	-	-	-	-	-	-	-	-
2021/03/27	2021/04/03	Vflow	-	-	-	-	-	-	-	-	-
2021/03/28	2021/04/04	Vflow	-	-	-	-	-	-	-	-	-
2021/03/29	2021/04/05	Vflow	-	-	-	-	-	-	-	-	-
2021/03/30	2021/04/06	Vflow	-	-	-	-	-	-	-	-	-
2021/03/31	2021/04/07	Vflow	-	-	-	-	-	-	-	-	-
2021/04/01	2021/04/08	Vflow	-	-	-	-	-	-	-	-	-
2021/04/02	2021/04/09	People	-	-	-	-	-	-	-	-	-
2021/04/03	2021/04/10	People	-	-	-	-	-	-	-	-	-
2021/04/04	2021/04/11	People	-	-	-	-	-	-	-	-	-
2021/04/05	2021/04/12	People	-	-	-	-	-	-	-	-	-
2021/04/06	2021/04/13	People	-	-	-	-	-	-	-	-	-
2021/04/07	2021/04/14	People	-	-	-	-	-	-	-	-	-
2021/04/08	2021/04/15	People	-	-	-	-	-	-	-	-	-
2021/04/09	2021/04/16	People	-	-	-	-	-	-	-	-	-
2021/04/10	2021/04/17	People	-	-	-	-	-	-	-	-	-
2021/04/11	2021/04/18	People	-	-	-	-	-	-	-	-	-
2021/04/12	2021/04/19	People	-	-	-	-	-	-	-	-	-
2021/04/13	2021/04/20	People	-	-	-	-	-	-	-	-	-
2021/04/14	2021/04/21	People	-	-	-	-	-	-	-	-	-
2021/04/15	2021/04/22	People	-	-	-	-	-	-	-	-	-
2021/04/16	2021/04/23	People	-	-	-	-	-	-	-	-	-
2021/04/17	2021/04/24	People	-	-	-	-	-	-	-	-	-
2021/04/18	2021/04/25	People	-	-	-	-	-	-	-	-	-
2021/04/19	2021/04/26	People	-	-	-	-	-	-	-	-	-

2021/04/20	2021/04/27	People	-	-	-	-	-	-	-	-	-
2021/04/21	2021/04/28	People	-	-	-	-	-	-	-	-	-
2021/04/22	2021/04/29	People	-	-	-	-	-	-	-	-	-
2021/04/23	2021/04/30	People	-	-	-	-	-	-	-	-	-
2021/04/24	2021/05/01	People	-	-	-	-	-	-	-	-	-
2021/04/25	2021/05/02	People	-	-	-	-	-	-	-	-	-
2021/04/26	2021/05/03	People	-	-	-	-	-	-	-	-	-
2021/04/27	2021/05/04	People	-	-	-	-	-	-	-	-	-
2021/04/28	2021/05/05	People	-	-	-	-	-	-	-	-	-
2021/04/29	2021/05/06	People	-	-	-	-	-	-	-	-	-
2021/04/30	2021/05/07	People	-	-	-	-	-	-	-	-	-
2021/05/01	2021/05/08	People	-	-	-	-	-	-	-	-	-
2021/05/02	2021/05/09	People	-	-	-	-	-	-	-	-	-
2021/05/03	2021/05/10	People	Vflow	-	-	-	-	-	-	-	-
2021/05/04	2021/05/11	People	Vflow	-	-	-	-	-	-	-	-
2021/05/05	2021/05/12	People	Vflow	-	-	-	-	-	-	-	-
2021/05/06	2021/05/13	People	Vflow	-	-	-	-	-	-	-	-
2021/05/07	2021/05/14	People	Vflow	-	-	-	-	-	-	-	-
2021/05/08	2021/05/15	People	Vflow	-	-	-	-	-	-	-	-
2021/05/09	2021/05/16	People	Vflow	-	-	-	-	-	-	-	-
2021/05/10	2021/05/17	People	Vflow	-	-	-	-	-	-	-	-
2021/05/11	2021/05/18	People	Vflow	-	-	-	-	-	-	-	-
2021/05/12	2021/05/19	People	Vflow	-	-	-	-	-	-	-	-
2021/05/13	2021/05/20	People	Vflow	-	-	-	-	-	-	-	-
2021/05/14	2021/05/21	People	Vflow	-	-	-	-	-	-	-	-
2021/05/15	2021/05/22	People	Vflow	-	-	-	-	-	-	-	-
2021/05/16	2021/05/23	People	Vflow	-	-	-	-	-	-	-	-
2021/05/17	2021/05/24	People	Vflow	-	-	-	-	-	-	-	-
2021/05/18	2021/05/25	People	Vflow	-	-	-	-	-	-	-	-
2021/05/19	2021/05/26	People	Vflow	-	-	-	-	-	-	-	-
2021/05/20	2021/05/27	People	Vflow	-	-	-	-	-	-	-	-
2021/05/21	2021/05/28	People	Vflow	-	-	-	-	-	-	-	-
2021/05/22	2021/05/29	People	Vflow	-	-	-	-	-	-	-	-
2021/05/23	2021/05/30	People	Vflow	-	-	-	-	-	-	-	-
2021/05/24	2021/05/31	People	Vflow	-	-	Vflow	-	-	-	-	-
2021/05/25	2021/06/01	People	Vflow	-	-	Vflow	-	-	-	-	-
2021/05/26	2021/06/02	People	Vflow	-	-	Vflow	-	-	-	-	-
2021/05/27	2021/06/03	People	Vflow	-	-	Vflow	-	-	-	-	-
2021/05/28	2021/06/04	People	Vflow	-	-	Vflow	-	-	-	-	-
2021/05/29	2021/06/05	People	Vflow	-	-	Vflow	-	-	-	-	-
2021/05/30	2021/06/06	People	Vflow	-	-	Vflow	-	-	-	-	-
2021/05/31	2021/06/07	People	Vflow	-	-	Vflow	-	-	-	-	-

2021/06/01	2021/06/08	People	Vflow	-	-	Vflow	-	-	-	-	-
2021/06/02	2021/06/09	People	Vflow	-	-	Vflow	-	-	-	-	-
2021/06/03	2021/06/10	People	Vflow	-	-	Vflow	-	-	-	-	-
2021/06/04	2021/06/11	People	Vflow	-	-	Vflow	-	-	-	-	-
2021/06/05	2021/06/12	People	Vflow	-	-	Vflow	-	-	-	-	-
2021/06/06	2021/06/13	People	Vflow	-	-	Vflow	-	-	-	-	-
2021/06/07	2021/06/14	People	Vflow	-	-	Vflow	-	-	Vflow	Vflow	-
2021/06/08	2021/06/15	People	Vflow	-	-	Vflow	-	-	Vflow	Vflow	-
2021/06/09	2021/06/16	People	Vflow	-	-	Vflow	-	-	Vflow	Vflow	-
2021/06/10	2021/06/17	People	Vflow	Vflow	Vflow	Vflow	Vflow	-	Vflow	Vflow	-
2021/06/11	2021/06/18	People	Vflow	Vflow	Vflow	Vflow	Vflow	-	Vflow	Vflow	-
2021/06/12	2021/06/19	People	Vflow	Vflow	Vflow	Vflow	Vflow	-	Vflow	Vflow	-
2021/06/13	2021/06/20	People	Vflow	Vflow	Vflow	Vflow	Vflow	-	Vflow	Vflow	-
2021/06/14	2021/06/21	People	Vflow	Vflow	Vflow	Vflow	Vflow	-	Vflow	Vflow	-
2021/06/15	2021/06/22	People	Vflow	Vflow	Vflow	Vflow	Vflow	-	Vflow	Vflow	-
2021/06/16	2021/06/23	People	Vflow	Vflow	Vflow	Vflow	Vflow	-	Vflow	Vflow	-
2021/06/17	2021/06/24	People	Vflow	Vflow	Vflow	Vflow	Vflow	-	Vflow	Vflow	-
2021/06/18	2021/06/25	People	Vflow	Vflow	Vflow	Vflow	Vflow	-	Vflow	Vflow	-
2021/06/19	2021/06/26	People	Vflow	Vflow	Vflow	Vflow	Vflow	-	Vflow	Vflow	-
2021/06/20	2021/06/27	People	Vflow	Vflow	Vflow	Vflow	Vflow	-	Vflow	Vflow	-
2021/06/21	2021/06/28	People	Vflow	Vflow	Vflow	Vflow	Vflow	-	Vflow	Vflow	-
2021/06/22	2021/06/29	People	Vflow	Vflow	Vflow	Vflow	Vflow	-	Vflow	Vflow	-
2021/06/23	2021/06/30	People	Vflow	Vflow	Vflow	Vflow	Vflow	-	Vflow	Vflow	-
2021/06/24	2021/07/01	People	Vflow	Vflow	Vflow	Vflow	Vflow	-	Vflow	Vflow	-
2021/06/25	2021/07/02	People	Vflow	Vflow	Vflow	Vflow	Vflow	-	Vflow	Vflow	-
2021/06/26	2021/07/03	People	Vflow	Vflow	Vflow	Vflow	Vflow	-	Vflow	Vflow	-
2021/06/27	2021/07/04	People	Vflow	Vflow	Vflow	Vflow	Vflow	-	Vflow	Vflow	-
2021/06/28	2021/07/05	People	Vflow	Vflow	Vflow	Vflow	Vflow	-	Vflow	Vflow	-
2021/06/29	2021/07/06	People	Vflow	Vflow	Vflow	Vflow	Vflow	-	Vflow	Vflow	-
2021/06/30	2021/07/07	People	Vflow	Vflow	Vflow	Vflow	Vflow	-	Vflow	Vflow	-
2021/07/01	2021/07/08	People	Vflow	Vflow	Vflow	Vflow	Vflow	-	Vflow	Vflow	-
2021/07/02	2021/07/09	People	Vflow	Vflow	Vflow	Vflow	Vflow	-	Vflow	Vflow	-
2021/07/03	2021/07/10	People	Vflow	Vflow	Vflow	Vflow	Vflow	-	Vflow	Vflow	-
2021/07/04	2021/07/11	People	Vflow	Vflow	Vflow	Vflow	Vflow	-	Vflow	Vflow	-
2021/07/05	2021/07/12	People	Vflow	Vflow	Vflow	Vflow	Vflow	-	Vflow	Vflow	-
2021/07/06	2021/07/13	People	Vflow	Vflow	Vflow	Vflow	Vflow	-	Vflow	Vflow	-
2021/07/07	2021/07/14	People	Vflow	Vflow	Vflow	Vflow	Vflow	-	Vflow	Vflow	-
2021/07/08	2021/07/15	People	Vflow	Vflow	Vflow	Vflow	Vflow	-	Vflow	Vflow	-
2021/07/09	2021/07/16	People	Vflow	Vflow	Vflow	Vflow	Vflow	-	Vflow	Vflow	-
2021/07/10	2021/07/17	People	Vflow	Vflow	Vflow	Vflow	Vflow	-	Vflow	Vflow	-
2021/07/11	2021/07/18	People	Vflow	Vflow	Vflow	Vflow	Vflow	-	Vflow	Vflow	-
2021/07/12	2021/07/19	People	Vflow	Vflow	Vflow	Vflow	Vflow	-	Vflow	Vflow	-

2021/07/13	2021/07/20	People	Vflow	Vflow	Vflow	Vflow	Vflow	-	Vflow	Vflow	-
2021/07/14	2021/07/21	People	Vflow	Vflow	Vflow	Vflow	Vflow	-	Vflow	Vflow	-
2021/07/15	2021/07/22	People	Vflow	Vflow	Vflow	Vflow	Vflow	-	Vflow	Vflow	-
2021/07/16	2021/07/23	People	Vflow	Vflow	Vflow	Vflow	Vflow	-	Vflow	Vflow	-
2021/07/17	2021/07/24	People	Vflow	Vflow	Vflow	Vflow	Vflow	-	Vflow	Vflow	-
2021/07/18	2021/07/25	People	Vflow	Vflow	Vflow	Vflow	Vflow	-	Vflow	Vflow	-
2021/07/19	2021/07/26	People	Vflow	Vflow	Vflow	Vflow	Vflow	-	Vflow	Vflow	-
2021/07/20	2021/07/27	People	Vflow	Vflow	Vflow	Vflow	Vflow	-	Vflow	Vflow	-
2021/07/21	2021/07/28	People	Vflow	Vflow	Vflow	Vflow	Vflow	-	Vflow	Vflow	-
2021/07/22	2021/07/29	People	Vflow	Vflow	Vflow	Vflow	Vflow	-	Vflow	Vflow	-
2021/07/23	2021/07/30	People	Vflow	Vflow	Vflow	Vflow	Vflow	-	Vflow	Vflow	-
2021/07/24	2021/07/31	People	Vflow	Vflow	Vflow	Vflow	Vflow	-	Vflow	Vflow	-
2021/07/25	2021/08/01	People	Vflow	Vflow	Vflow	Vflow	Vflow	-	Vflow	Vflow	-
2021/07/26	2021/08/02	People	Vflow	Vflow	Vflow	Vflow	Vflow	-	Vflow	Vflow	-
2021/07/27	2021/08/03	People	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow
2021/07/28	2021/08/04	People	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow
2021/07/29	2021/08/05	People	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow
2021/07/30	2021/08/06	People	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow
2021/07/31	2021/08/07	People	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow
2021/08/01	2021/08/08	People	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow
2021/08/02	2021/08/09	People	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow
2021/08/03	2021/08/10	People	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow
2021/08/04	2021/08/11	People	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow
2021/08/05	2021/08/12	People	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow
2021/08/06	2021/08/13	People	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow
2021/08/07	2021/08/14	People	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow
2021/08/08	2021/08/15	People	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow
2021/08/09	2021/08/16	People	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow
2021/08/10	2021/08/17	People	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow
2021/08/11	2021/08/18	People	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow
2021/08/12	2021/08/19	People	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow
2021/08/13	2021/08/20	People	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow
2021/08/14	2021/08/21	People	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow
2021/08/15	2021/08/22	People	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow
2021/08/16	2021/08/23	People	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow
2021/08/17	2021/08/24	People	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow
2021/08/18	2021/08/25	People	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow
2021/08/19	2021/08/26	People	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow
2021/08/20	2021/08/27	People	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow
2021/08/21	2021/08/28	People	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow
2021/08/22	2021/08/29	People	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow
2021/08/23	2021/08/30	People	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow

2021/08/24	2021/08/31	People	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow
2021/08/25	2021/09/01	People	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow
2021/08/26	2021/09/02	People	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow
2021/08/27	2021/09/03	People	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow
2021/08/28	2021/09/04	People	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow
2021/08/29	2021/09/05	People	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow	Vflow
2021/08/30	2021/09/06	People	Vflow	Vflow	Vflow	Vstock	Vstock	Vstock	Vstock	Vstock	Vflow
2021/08/31	2021/09/07	People	Vflow	Vflow	Vflow	Vstock	Vstock	Vstock	Vstock	Vstock	Vflow
2021/09/01	2021/09/08	People	Vflow	Vflow	Vflow	Vstock	Vstock	Vstock	Vstock	Vstock	Vflow
2021/09/02	2021/09/09	People	Vflow	Vflow	Vflow	Vstock	Vstock	Vstock	Vstock	Vstock	Vflow
2021/09/03	2021/09/10	People	Vflow	Vflow	Vflow	Vstock	Vstock	Vstock	Vstock	Vstock	Vflow
2021/09/04	2021/09/11	People	Vflow	Vflow	Vflow	Vstock	Vstock	Vstock	Vstock	Vstock	Vflow
2021/09/05	2021/09/12	People	Vflow	Vflow	Vflow	Vstock	Vstock	Vstock	Vstock	Vstock	Vflow
2021/09/06	2021/09/13	People	Vflow	Vflow	Vflow	Vstock	Vstock	Vstock	Vstock	Vstock	Vflow
2021/09/07	2021/09/14	People	Vflow	Vflow	Vflow	Vstock	Vstock	Vstock	Vstock	Vstock	Vflow
2021/09/08	2021/09/15	People	Vflow	Vflow	Vflow	Vstock	Vstock	Vstock	Vstock	Vstock	Vflow
2021/09/09	2021/09/16	People	Vflow	Vflow	Vflow	Vstock	Vstock	Vstock	Vstock	Vstock	Vflow
2021/09/10	2021/09/17	People	Vflow	Vflow	Vflow	Vstock	Vstock	Vstock	Vstock	Vstock	Vflow
2021/09/11	2021/09/18	People	Vflow	Vflow	Vflow	Vstock	Vstock	Vstock	Vstock	Vstock	Vflow
2021/09/12	2021/09/19	People	Vflow	Vflow	Vflow	Vstock	Vstock	Vstock	Vstock	Vstock	Vflow
2021/09/13	2021/09/20	People	Vflow	Vflow	Vflow	Vstock	Vstock	Vstock	Vstock	Vstock	Vstock
2021/09/14	2021/09/21	People	Vflow	Vflow	Vflow	Vstock	Vstock	Vstock	Vstock	Vstock	Vstock
2021/09/15	2021/09/22	People	Vflow	Vflow	Vflow	Vstock	Vstock	Vstock	Vstock	Vstock	Vstock
2021/09/16	2021/09/23	People	Vflow	Vflow	Vflow	Vstock	Vstock	Vstock	Vstock	Vstock	Vstock
2021/09/17	2021/09/24	People	People	Vflow	Vflow	People	Vstock	Vstock	People	Vstock	Vstock
2021/09/18	2021/09/25	People	People	Vflow	Vflow	People	Vstock	Vstock	People	Vstock	Vstock
2021/09/19	2021/09/26	People	People	Vflow	Vflow	People	Vstock	Vstock	People	Vstock	Vstock
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2021/09/21	2021/09/28	People	People	Vflow	Vflow	People	Vstock	Vstock	People	Vstock	Vstock
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2021/09/24	2021/10/01	People	People	Vflow	Vflow	People	Vstock	Vstock	People	Vstock	Vstock
2021/09/25	2021/10/02	People	People	Vflow	Vflow	People	Vstock	Vstock	People	Vstock	Vstock
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2021/09/27	2021/10/04	People	People	Vflow	Vflow	People	Vstock	Vstock	People	Vstock	Vstock
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2021/10/03	2021/10/10	People	People	Vflow	People	People	Nurse	People	People	Vstock	People
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2021/10/05	2021/10/12	People	People	Vflow	People	People	Nurse	People	People	Vstock	People
2021/10/06	2021/10/13	People	People	Vflow	People	People	Nurse	People	People	Vstock	People
2021/10/07	2021/10/14	People	People	Vflow	People	People	Nurse	People	People	Vstock	People
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2021/10/09	2021/10/16	People	People	Vflow	People	People	Nurse	People	People	Vstock	People
2021/10/10	2021/10/17	People	People	Vflow	People	People	Vstock	People	People	Vstock	People
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2021/10/24	2021/10/31	People	People	People	People	People	People	People	People	People	People
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2021/10/30	2021/11/06	People	People	People	People	People	People	People	People	People	People
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2021/11/14	2021/11/21	People	People	People	People	People	People	People	People	People	People
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2021/11/16	2021/11/23	People	People	People	People	People	People	People	People	People	People
2021/11/17	2021/11/24	People	People	People	People	People	People	People	People	People	People
2021/11/18	2021/11/25	People	People	People	People	People	People	People	People	People	People
2021/11/19	2021/11/26	People	People	People	People	People	People	People	People	People	People
2021/11/20	2021/11/27	People	People	People	People	People	People	People	People	People	People
2021/11/21	2021/11/28	People	People	People	People	People	People	People	People	People	People
2021/11/22	2021/11/29	People	People	People	People	People	People	People	People	People	People
2021/11/23	2021/11/30	People	People	People	People	People	People	People	People	People	People

7.2.4. Discussions

The simulation with the modified distribution inputs of Pfizer/BioNTech vaccines predicts no human resource constraints by September, as expected.

The simulation implies that the administration of COVID-19 vaccines has effectively conquered the human resource constraints in Japan. The model with the faster vaccine deliveries outputs the achievement dates 3–5 days earlier than the base case with the WHO full vaccination coverage targets. These deviations can be interpreted as the potential room for accelerating vaccinations with better human resource management.

The model suggests that much faster vaccinations and earlier coverage achievements might be materialized by faster vaccine distributions with earlier procurements and earlier vaccine authorizations by the national government in Japan.

7.2.5. Limitation

Table 7-3 displays that there is a period with human resource constraints as the simulated first-dose reservation determinant in early October with Takeda/Moderna vaccine administrations. This output can be counter-intuitive because there might be sufficient human resources in society in October. This output can be attributed to the algorithm of human resource allocation between the vaccination for the elderly and other citizens with Pfizer/BioNTech vaccines (vdc = 3) and the vaccinations at large sites with Takeda/Moderna vaccines (vdc = 4). The algorithm can allocate almost all the human resources to one operation side when the other side has comparatively small vaccine delivery flows and vaccine stocks for second-dose reservations. Pfizer/BioNTech vaccines are distributed in early October, while Takeda/Moderna vaccines are not. There might be room for improving the human resource allocation algorithm to enhance the model's explainability.

7.3. Chapter Summary

This chapter explored room for improvement in the vaccination project in Japan with the developed simulation model. Regarding the resource-saving viewpoint, the model suggested that the thousands of healthcare worker recruitments can be avoided without a vaccination delay due to the tight capacity constraints on vaccine supplies. The simulation also demonstrated the potential to save over 20 thousand healthcare worker recruitments with no vaccination delay by modified operations in vaccination sites with the maximum achievable nurse–doctor ratio of 3 or more with Pfizer/BioNTech vaccines. For accelerating the vaccination speed and achieving earlier coverage, the model predicted that limited chances exist with human resource management. The simulation implied that earlier vaccine authorizations, earlier procurements, and faster distributions by the national government were essential to materialize more immediate vaccination coverage for citizens in Japan.

8. Limitations and Future Research Topics

This research has the following limitations and potential topics for future explorations.

(1) Vaccine Authorization and Procurement

Vaccine authorization and procurement mechanisms are not discussed in detail, while this research found these upstream factors were the most critical bottlenecks of the vaccination project in Japan. The academic discussions on these topics require more comprehensive reviews of public documents and interviews to consider the decision-making processes behind the phenomena.

Regarding vaccine authorization, it is inevitable to consider the uncertainties of vaccine safety, the balance of risks and benefits, and citizens' attitudes. The latecomer advantage is critical for citizens' safety if the risks of new vaccines are significant. Vaccine hesitancy and risk-aversive culture might prioritize the latecomer advantage and increase citizens' willingness to take vaccines. In contrast, the pioneering advantage of vaccine authorization might be critical in the global competition of vaccine procurement. More advanced discussions on vaccination projects could handle these tradeoffs of key processes from the comprehensive management viewpoint.

(2) Regional Heterogeneity of Operational Factors

This research did not measure and simulate the regional heterogeneity on both the demand and supply side with the vaccination trends and mechanisms in Japan.

On the demand side, the willingness proportion to take vaccine shots can vary by prefecture or municipality. The regional heterogeneity of disease spreads might demand governments prioritize regions by allocating a limited amount of vaccines. On the supply side, the number of healthcare workers per unit population and other operational constraints can vary by region. The regional heterogeneity on the supply side can also be an operational bottleneck in the vaccination project.

The developed vaccination model in this research can be easily applied to analyzing and predicting regional vaccination trends by inputting parameters by region if sufficient datasets and computing capacities are available.

(3) Integration with Epidemiology and Economics Models

The developed model outputs of vaccination coverage trends can be utilized as inputs for epidemiology models and economic models to strategize a comprehensive policy portfolio against pandemics in a real-time manner.

9. Conclusions

This research analyzed the performance and mechanisms of COVID-19 vaccination projects in Japan with three steps: international comparisons of project performance in 49 countries, model development and validation of vaccination trends, and exploration of operational improvement of the project in Japan.

The research quantitatively compared the COVID-19 vaccination coverages, speed, and trends in 49 countries. Despite the slowest vaccine authorization, Japan became the 13th earliest country to achieve 70% full vaccination coverage on October 18, 2021, by the 3rd shortest period from the initial vaccine authorization to the achievement date, 247 days. Japan ranked 11th with the average–maximum speed ratio of 0.363 with many weekend vaccinations. Comparing the top 11 countries with average–maximum speed ratio, daily vaccination trends revealed that Japan experienced a slow pace in the first 80 days from mid-February to early May. This research found the daily distribution ceiling effect on first-dose vaccinations in the early phase of the project in Japan: the 48.03% and 88.76% ceiling of daily distributions of the Pfizer/BioNTech and Takeda/Moderna vaccines, respectively. The daily vaccination trends in Japan also suggested another potential bottleneck of vaccinations in mid to late May 2021.

The system dynamics model of vaccination trends has been developed with four major operational factors: willing people to take vaccine shots, daily vaccine deliveries to sites, not-reserved vaccine stocks at sites, and human resource capacities with healthcare workers. The model predicted the actual 7-day smoothed vaccination trends with the R-squared of 0.943, 0.909, and 0.915 for the total, first, and second doses with Pfizer/BioNTech and Takeda/Moderna vaccines from February 14 to November 30, 2021. Regarding the cumulative vaccination trends of these two vaccines, the 70% coverage achievement period errors (percentage errors) are 10 days (4.24%), 12 days (5.41%), and 8 days (3.23%) for the total, first, and second doses, respectively. The simulation results validated the system dynamics assumptions on the vaccination mechanism: acceleration with increasing fully immunized healthcare workers as human resource capacities in the early phase, vaccine deliveries and stocks as major bottlenecks, and deceleration with depleted willing people and vaccines.

Room for operational improvement in Japan was explored with the developed simulation model for resource-saving and acceleration purposes. This research estimated that thousands of planned healthcare worker recruitments could be omitted with no vaccination delay due to the limited vaccine supplies. The model also demonstrated the potential savings of over 20 thousand healthcare worker recruitments without vaccination delay by a modified team structure in sites with the nurse–doctor ratio of 3 or more with Pfizer/BioNTech vaccines. For achieving earlier coverage, the model predicted limited opportunities with human resource management, only shortening the 70% full vaccination coverage period by 3 days. This result implied that earlier vaccine authorizations, earlier procurements, and faster distributions by the national government were essential for earlier vaccination coverage for citizens in Japan.

Through the discussions, this research proposed the performance management viewpoints and tools for model-based project planning and management applicable to future pandemics and public emergency responses by practitioners.

References

[1] World Health Organization Regional Office for Europe, "Coronavirus disease (COVID-19) pandemic," *WHO Europe*, 2023. https://www.who.int/europe/emergencies/situations/covid-19 (accessed May 07, 2023).

[2] The United Nations, "WHO chief declares end to COVID-19 as a global health emergency," *UN News*, May 05, 2023. https://news.un.org/en/story/2023/05/1136367 (accessed May 07, 2023).

[3] World Health Organization, "COVID-19 - Landscape of novel coronavirus candidate vaccine development worldwide," Mar. 30, 2023. https://www.who.int/publications/m/item/draft-landscape-of-covid-19-candidate-vaccines (accessed Apr. 09, 2023).

[4] T. Kayano *et al.*, "Number of averted COVID-19 cases and deaths attributable to reduced risk in vaccinated individuals in Japan," *Lancet Reg. - West. Pac.*, vol. 28, no. 100571, 2022, doi: 10.1016/j.

[5] W. Mimura, C. Ishiguro, M. Maeda, F. Murata, and H. Fukuda, "Effectiveness of messenger RNA vaccines against infection with SARS-CoV-2 during the periods of Delta and Omicron variant predominance in Japan: the Vaccine Effectiveness, Networking, and Universal Safety (VENUS) study," *Int. J. Infect. Dis.*, vol. 125, pp. 58–60, Dec. 2022, doi: 10.1016/j.ijid.2022.10.001.

[6] T. Yamaguchi *et al.*, "Safety monitoring of COVID-19 vaccines in Japan-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/)," *Lancet Reg. Health - West. Pac.*, vol. 23, p. 100442, 2022, doi: 10.1016/j.

[7] Q. Niu *et al.*, "Public Opinion and Sentiment Before and at the Beginning of COVID-19 Vaccinations in Japan: Twitter Analysis," *JMIR Infodemiology*, vol. 2, no. 1, Jun. 2022, doi: 10.2196/32335.

[8] R. Kobayashi *et al.*, "Evolution of Public Opinion on COVID-19 Vaccination in Japan: Large-Scale Twitter Data Analysis," *J. Med. Internet Res.*, vol. 24, no. 12, Dec. 2022, doi: 10.2196/41928.

[9] Kosaka M, Hashimoto T, Ozaki A, Tanimoto T, and Kami M., "Delayed COVID-19 vaccine roll-out in Japan," *The Lancet*, vol. 397, no. 10292, p. 2334, Jun. 2021, doi: 10.1016/S0140-6736(21)01220-4.

[10] M. K. Looi, "Covid-19: Extended emergency and Olympic concerns overshadow Japan's accelerated vaccine rollout," *BMJ*, vol. 373, p. n1546, Jun. 2021, doi: 10.1136/bmj.n1546.

[11] A. P. Liff, "Japan in 2021: Covid-19 (again), the Olympics, and a new administration," *Asian Surv.*, vol. 62, no. 1, pp. 29–42, Feb. 2022, doi: 10.1525/as.2022.62.1.03.

[12] The Headquarters for the Promortion of Administrative Reform Cabinet Secretariat, "今後の円滑なワクチン接種に向けた課題の整理、取りまとめ," Nov. 08, 2021. https://www.gyoukaku.go.jp/review/aki/R03/img/1_7torimatome.pdf (accessed Sep. 07, 2022).

[13] The Headquarters for the Promortion of Administrative Reform Cabinet Secretariat, "今後の円滑なワクチン接種に向けた課題の整理, 内閣官房行政改革推進本部事務局説明資料," Nov. 08, 2021. https://www.gyoukaku.go.jp/review/aki/R03/img/1_1gyoukaku.pdf (accessed Sep. 07, 2021).

[14] Ministry of Health, Labour and Welfare of Japan, “医薬品、医療機器等の品質、有効性及び安全性の確保等に関する法律等の一部を改正する法律案（令和 4 年 3 月 1 日提出）,” *Ministry of Health, Labour and Welfare of Japan*, Mar. 01, 2022. https://www.mhlw.go.jp/stf/topics/bukyoku/soumu/houritu/208.html (accessed Apr. 05, 2023).

[15] M. Ujiie, “Establishment of an emergency regulatory approval system in Japan in response to the COVID-19 pandemic and challenges in developing domestically produced vaccines,” *Glob. Health Med.*, vol. 4, no. 2, pp. 144–145, Apr. 2022, doi: 10.35772/ghm.2022.01023.

[16] Director General for Pharmaceutical Safety and Environmental Health Bureau, “医薬品、医療機器等の品質、有効性及び安全性の確保等に関する法律等の一部を改正する法律等の公布について,” May 20, 2022. https://www.mhlw.go.jp/content/11120000/000940763.pdf (accessed Apr. 05, 2023).

[17] Ministry of Finance, “社会保障,” Nov. 07, 2022. Accessed: Feb. 07, 2023. [Online]. Available: https://www.mof.go.jp/about_mof/councils/fiscal_system_council/sub-of_fiscal_system/proceedings/material/zaiseia20221107/01.pdf

[18] Board of Audit of Japan, “新型コロナウイルス感染症に係るワクチン接種事業の実施状況等,” Mar. 2023, Accessed: Apr. 05, 2023. [Online]. Available: https://www.jbaudit.go.jp/pr/kensa/result/5/pdf/050329_point.pdf

[19] D. Fujii and T. Nakata, “COVID-19 and output in Japan,” *Jpn. Econ. Rev.*, vol. 72, no. 4, pp. 609–650, Oct. 2021, doi: 10.1007/s42973-021-00098-4.

[20] Y. Furuse, “Simulation of future COVID-19 epidemic by vaccination coverage scenarios in Japan,” *J. Glob. Health*, vol. 11, pp. 1–11, 2021, doi: 10.7189/jogh.11.05025.

[21] Y. Tokuda and T. Kuniya, “Prediction of COVID-19 cases during Tokyo’s Olympic and Paralympic Games,” *J. Gen. Fam. Med.*, vol. 22, no. 4, pp. 171–172, Jul. 2021, doi: 10.1002/jgf2.465.

[22] H. Nomoto, K. Hayakawa, and N. Ohmagari, “Impact of prioritized vaccinations for the elderly on the COVID-19 pandemic in Japan,” *Glob. Health Med.*, vol. 4, no. 2, pp. 129–132, Apr. 2022, doi: 10.35772/ghm.2022.01015.

[23] H. Yasuda, F. Ito, K. ichi Hanaki, and K. Suzuki, “COVID-19 pandemic vaccination strategies of early 2021 based on behavioral differences between residents of Tokyo and Osaka, Japan,” *Arch. Public Health*, vol. 80, no. 1, Dec. 2022, doi: 10.1186/s13690-022-00933-z.

[24] M. Sasanami, M. Fujimoto, T. Kayano, K. Hayashi, and H. Nishiura, “Projecting the COVID-19 immune landscape in Japan in the presence of waning immunity and booster vaccination,” *J. Theor. Biol.*, vol. 559, Feb. 2023, doi: 10.1016/j.jtbi.2022.111384.

[25] H. Nishiura, “資料３–３　西浦先生提出資料,” Jun. 09, 2021. https://www.mhlw.go.jp/content/10900000/000790389.pdf (accessed Apr. 05, 2023).

[26] D. Fujii and T. Nakata, “資料３–５　仲田先生提出資料　コロナ感染と経済活動の中・長期見通し,” Jun. 02, 2021. https://www.mhlw.go.jp/content/10900000/000787730.pdf (accessed Apr. 05, 2023).

[27] S. Kurahashi, “外出・会食モデル　ワクチン接種モデル,” Feb. 2021. https://www.covid19-ai.jp/ja-

jp/presentation/2021_rq3_countermeasures_simulation/articles/article051/ (accessed Apr. 05, 2023).

[28] Y. Ohsawa, H. Daisuke, T. Maekawa, Y. Mochizuki, T. Yamada, and S. Hayakawa, “自粛の段階的解除とワクチン接種戦略 Stay with Your Community の応用,” Mar. 02, 2021. https://www.covid19-ai.jp/ja-jp/presentation/2021_rq3_countermeasures_simulation/articles/article049/ (accessed Apr. 05, 2023).

[29] T. Unemi, “ワクチン接種の優先順に関するシミュレーション結果,” Mar. 09, 2021. https://www.covid19-ai.jp/ja-jp/presentation/2021_rq3_countermeasures_simulation/articles/article046/ (accessed Apr. 05, 2023).

[30] Mitsubishi Research Institute Inc., “医療および検査リソースの最適化シミュレーション　ワクチン接種による効果検討 #3,” Mar. 23, 2021. https://www.covid19-ai.jp/ja-jp/presentation/2021_rq3_countermeasures_simulation/articles/article015/ (accessed Apr. 05, 2023).

[31] A. Chiba, “ワクチン普及後の行動制限解除,” Aug. 24, 2021. https://www.covid19-ai.jp/ja-jp/presentation/2021_rq3_countermeasures_simulation/articles/article117/ (accessed Apr. 05, 2023).

[32] D. Fujii, K. Machi, and T. Nakata, “ワクチン接種完了後の世界：コロナ感染と経済の長期見通し,” Aug. 31, 2021. https://www.covid19-ai.jp/ja-jp/presentation/2021_rq3_countermeasures_simulation/articles/article125/ (accessed Apr. 05, 2023).

[33] T. Kuniya, D. Fujii, and N. Taisuke, “ワクチン配分戦略,” Oct. 18, 2022. https://www.covid19-ai.jp/ja-jp/presentation/2022_rq1_simulations_for_infection_situations/articles/article390/ (accessed Apr. 05, 2023).

[34] S. Sunohara *et al.*, “Effective vaccine allocation strategies, balancing economy with infection control against COVID-19 in Japan,” *PLoS ONE*, vol. 16, no. 9 September, Sep. 2021, doi: 10.1371/journal.pone.0257107.

[35] E. Mathieu *et al.*, “A global database of COVID-19 vaccinations,” *Nat. Hum. Behav.*, vol. 5, no. 7, pp. 947–953, Jul. 2021, doi: 10.1038/s41562-021-01122-8.

[36] Z. Chen *et al.*, “Global diversity of policy, coverage, and demand of COVID-19 vaccines: a descriptive study,” *BMC Med.*, vol. 20, no. 1, Dec. 2022, doi: 10.1186/s12916-022-02333-0.

[37] B. Rosen, R. Waitzberg, and A. Israeli, “Israel’s rapid rollout of vaccinations for COVID-19,” *Isr. J. Health Policy Res.*, vol. 10, no. 1, Dec. 2021, doi: 10.1186/s13584-021-00440-6.

[38] O. Tubi, “Infrastructural capital in the Israeli vaccination campaign against COVID-19,” *Soc. Sci. Med.*, vol. 303, Jun. 2022, doi: 10.1016/j.socscimed.2022.115022.

[39] G. W. Warren and R. Lofstedt, “COVID-19 vaccine rollout management and communication in Europe: one year on,” *J. Risk Res.*, vol. 25, no. 9, pp. 1098–1117, 2022, doi: 10.1080/13669877.2021.2001674.

[40] F. Oliani *et al.*, “Italy’s rollout of COVID-19 vaccinations: The crucial contribution of the first experimental mass vaccination site in Lombardy,” *Vaccine*, vol. 40, no. 10, pp. 1397–1403, Mar. 2022, doi: 10.1016/j.vaccine.2022.01.059.

[41] F. Raciborski, M. Jankowski, M. Gujski, J. Pinkas, and P. Samel-Kowalik, “Changes in attitudes towards the covid-19 vaccine and the willingness to get vaccinated among adults in poland: Analysis of serial, cross-sectional, representative surveys, january–april 2021,” *Vaccines*, vol. 9, no. 8, Aug. 2021, doi: 10.3390/vaccines9080832.

[42] I. Nozaki, M. Hachiya, and C. Ikeda, “COVID-19 vaccination program in Cambodia: Achievements and remaining challenges,” *Glob. Health Med.*, p. 2023.01002, 2023, doi: 10.35772/ghm.2023.01002.

[43] C. Marcela Vélez, “COVID-19 and vaccination in Latin America and the Caribbean: challenges, needs and opportunities,” UNESCO Office Montevideo and Regional Bureau for Science in Latin America and the Caribbean, 2021. Accessed: Feb. 11, 2023. [Online]. Available: www.unesco.org/open-access/terms-use-ccbysa-sp

[44] Y. Yang, S. Vinayavekhin, R. Phaal, E. O’sullivan, and N. Leelawat, “Strategic Roadmapping Framework for Disaster Response: Case of COVID-19 Pandemic Vaccine Rollout Program in the UK,” *J. Disaster Res.*, vol. 18, no. 1, pp. 11–20, Jan. 2023, doi: 10.20965/jdr.2023.p0011.

[45] H. Rahmandad, T. Y. Lim, and J. Sterman, “Behavioral dynamics of COVID-19: estimating underreporting, multiple waves, and adherence fatigue across 92 nations,” *Syst. Dyn. Rev.*, vol. 37, no. 1, pp. 5–31, Jan. 2021, doi: 10.1002/sdr.1673.

[46] Z. LaJoie, T. Usherwood, S. Sampath, and V. Srivastava, “A COVID-19 model incorporating variants, vaccination, waning immunity, and population behavior,” *Sci. Rep.*, vol. 12, no. 1, Dec. 2022, doi: 10.1038/s41598-022-24967-z.

[47] S. Moore, E. M. Hill, M. J. Tildesley, L. Dyson, and M. J. Keeling, “Vaccination and non-pharmaceutical interventions for COVID-19: a mathematical modelling study,” *Lancet Infect. Dis.*, vol. 21, no. 6, pp. 793–802, Jun. 2021, doi: 10.1016/S1473-3099(21)00143-2.

[48] Y. Liu *et al.*, “Optimising health and economic impacts of COVID-19 vaccine prioritisation strategies in the WHO European Region: a mathematical modelling study,” *Lancet Reg. Health - Eur.*, vol. 12, Jan. 2022, doi: 10.1016/j.lanepe.2021.100277.

[49] Jung Eun Kim, Heejin Choi, Yongin Choi, and Chang Hyeong Lee, “The economic impact of COVID-19 interventions: Amathematical modelingapproach,” 2019. doi: 10.3389/fpubh.2022.993745.

[50] Ministry of Health, Labour and Welfare of Japan, “新型コロナワクチンの接種実績｜厚生労働省,” *Ministry of Health Labour, and Welfare of Japan*, 2023. https://www.mhlw.go.jp/stf/seisakunitsuite/bunya/vaccine_sesshujisseki.html (accessed Mar. 13, 2023).

[51] Prime Minister’s Office of Japan, “新型コロナワクチンについて | 首相官邸ホームページ,” *Prime Minister’s Office of Japan*, Apr. 13, 2023. https://www.kantei.go.jp/jp/headline/kansensho/vaccine.html (accessed Apr. 15, 2023).

[52] Ministry of Health, Labour and Welfare of Japan, “新型コロナワクチンの有効性・安全性について｜厚生労働省,” *Ministry of Health Labour, and Welfare of Japan*, Feb. 09, 2023.

https://www.mhlw.go.jp/stf/seisakunitsuite/bunya/vaccine_yuukousei_anzensei.html (accessed Feb. 09, 2023).

[53] Ministry of Internal Affairs and Communications, "令和 4 年 1 月 1 日住民基本台帳年齢階級別人口（都道府県別）（総計）." Aug. 09, 2022. Accessed: Mar. 14, 2023. [Online]. Available: https://www.e-stat.go.jp/stat-search/files?page=1&layout=datalist&toukei=00200241&tstat=000001039591&cycle=7&year=20220&month=0&tclass1=000001039601&stat_infid=000032224635&result_back=1&cycle_facet=tclass1%3Acycle&tclass2val=0&metadata=1&data=1

[54] Ministry of Internal Affairs and Communications, "令和 2 年国勢調査 人口等基本集計結果 結果の概要." Nov. 30, 2021. Accessed: Apr. 07, 2023. [Online]. Available: https://www.stat.go.jp/data/kokusei/2020/kekka/pdf/outline_01.pdf

[55] Cabinet Office, "「国民の祝日」について," *Government of Japan*, 2023. https://www8.cao.go.jp/chosei/shukujitsu/gaiyou.html (accessed Mar. 20, 2023).

[56] P. C. Siqueira, J. P. Cola, T. Comerio, C. M. M. Sales, and E. L. Maciel, "Herd immunity threshold for SARS-CoV-2 and vaccination effectiveness in Brazil," *J. Bras. Pneumol. Publicacao Of. Soc. Bras. Pneumol. E Tisilogia*, vol. 48, no. 2, p. e20210401, May 2022, doi: 10.36416/1806-3756/e20210401.

[57] Y. Liu, A. A. Gayle, A. Wilder-Smith, and J. Rocklöv, "The reproductive number of COVID-19 is higher compared to SARS coronavirus," *J. Travel Med.*, vol. 27, no. 2, Mar. 2020, doi: 10.1093/jtm/taaa021.

[58] WHO Team of Immunization Vaccines and Biologicals, "Strategy to Achieve Global Covid-19 Vaccination by mid-2022," Oct. 2021. Accessed: Apr. 12, 2023. [Online]. Available: https://cdn.who.int/media/docs/default-source/immunization/covid-19/strategy-to-achieve-global-covid-19-vaccination-by-mid-2022.pdf?sfvrsn=5a68433c_5&download=true

[59] Australian Government Department of Foreign Affairs and Trade, "The G20 | Australian Government Department of Foreign Affairs and Trade," 2023. https://www.dfat.gov.au/trade/organisations/g20 (accessed Apr. 06, 2023).

[60] Organization for Economic Co-operation and Development, "List of OECD Member countries-Ratification of the Convention on the OECD," 2023. https://www.oecd.org/about/document/ratification-oecd-convention.htm (accessed Apr. 06, 2023).

[61] European Medicines Agency, "The European regulatory system for medicines," Dec. 2017. Accessed: Apr. 06, 2023. [Online]. Available: https://www.ema.europa.eu/en/documents/leaflet/european-regulatory-system-medicines-european-medicines-agency-consistent-approach-medicines_en.pdf

[62] European Medicines Agency, "Authorisation of medicines," 2023. https://www.ema.europa.eu/en/about-us/what-we-do/authorisation-medicines (accessed Apr. 11, 2023).

[63] European Medicines Agency, "COVID-19 vaccines: authorized," *European Medicines Agency*, 2023. https://www.ema.europa.eu/en/human-regulatory/overview/public-health-threats/coronavirus-disease-covid-19/treatments-vaccines/vaccines-covid-19/covid-19-vaccines-authorised (accessed Apr. 10, 2023).

[64] M. M. Higdon *et al.*, "A Systematic Review of Coronavirus Disease 2019 Vaccine Efficacy and Effectiveness Against Severe Acute Respiratory Syndrome Coronavirus 2 Infection and Disease," *Open Forum Infect. Dis.*, vol. 9, no. 6, Jun. 2022, doi: 10.1093/ofid/ofac138.

[65] Z. Hu *et al.*, "Effectiveness of inactivated COVID-19 vaccines against severe illness in B.1.617.2 (Delta) variant–infected patients in Jiangsu, China," *Int. J. Infect. Dis.*, vol. 116, pp. 204–209, Mar. 2022, doi: 10.1016/j.ijid.2022.01.030.

[66] World Health Organization, "The Novavax vaccine against COVID-19: What you need to know," Sep. 28, 2022. https://www.who.int/news-room/feature-stories/detail/the-novavax-vaccine-against-covid-19-what-you-need-to-know (accessed Apr. 10, 2023).

[67] Novavax, "Novavax and Serum Institute of India Receive Emergency Use Authorization for COVID-19 Vaccine in Indonesia," *Novavax News & Media*, Nov. 01, 2021. https://ir.novavax.com/2021-11-01-Novavax-and-Serum-Institute-of-India-Receive-Emergency-Use-Authorization-for-COVID-19-Vaccine-in-Indonesia (accessed Feb. 10, 2023).

[68] Takeda Pharmaceutical Company Limited, "Takeda Submits New Drug Application for Novavax' COVID-19 Vaccine Candidate in Japan," Dec. 16, 2021. https://www.takeda.com/ja-jp/announcements/takeda-submits-new-drug-application-for-novavax-covid-19-vaccine-candidate-in-japan (accessed Apr. 10, 2023).

[69] Reuters, "Indonesia approves first home-grown COVID vaccine for emergency use - media," *Reuters*, Sep. 28, 2022. https://www.reuters.com/world/asia-pacific/indonesia-approves-first-home-grown-covid-vaccine-emergency-use-media-2022-09-28/ (accessed Feb. 10, 2023).

[70] Reuters, "Indonesia gives emergency use approval to home-grown COVID-19 vaccine Inavac," *Reuters*, Nov. 04, 2022. https://www.reuters.com/business/healthcare-pharmaceuticals/indonesia-gives-emergency-use-approval-home-grown-covid-19-vaccine-inavac-2022-11-04/ (accessed Feb. 10, 2023).

[71] SK bioscience, "SK bioscience and GSK Announce Biologics License Application Approval of SKYCovione^{TM} in Republic of Korea," Jun. 29, 2022. https://www.skbioscience.com/en/news/news_01_01?mode=view&id=132& (accessed Feb. 09, 2023).

[72] Takeda Pharmaceutical Company Limited, "Start of a Japanese Clinical Study of TAK-919, Moderna's COVID-19 Vaccine Candidate," Jan. 21, 2021. https://www.takeda.com/ja-jp/announcements/japanese-clinical-study-tak-919 (accessed Apr. 10, 2023).

[73] S. Widianto and R. Liu, "A Chinese mRNA COVID vaccine is approved for the first time - in Indonesia," *Reuters*, Sep. 30, 2022. https://www.reuters.com/business/healthcare-pharmaceuticals/indonesia-drug-agency-approves-chinas-walvax-mrna-vaccine-emergency-use-2022-09-29/ (accessed Apr. 12, 2023).

[74] Serum Institute of India Pvt. Ltd., "COVISHIELD FAQs - Serum Institute Of India.," Jul. 05, 2021. https://www.seruminstitute.com/health_faq_covishield.php#faq1 (accessed Apr. 10, 2023).

[75] Bharat Biotech International Limited, "Bharat Biotech's iNCOVACC world's first Intra Nasal vaccine receives approval for emergency use in India," *Bharat Biotech International Limited Press Release*, Sep. 06, 2022. https://www.bharatbiotech.com/images/press/Bharat-

Biotech-iNCOVACC-Worlds-First-Intra-Nasal-Vaccine-Receives-Approval.pdf (accessed Feb. 10, 2023).

[76] The Gamaleya National Center of Epidemiology and Microbiology and Russian Direct Investment Fund, "ABOUT SPUTNIK LIGHT," 2023. https://sputnikvaccine.com/about-vaccine/sputnik-light/ (accessed Apr. 11, 2023).

[77] European Medicines Agency, "Jcovden (previously COVID-19 Vaccine Janssen) | European Medicines Agency," 2023. https://www.ema.europa.eu/en/medicines/human/EPAR/jcovden-previously-covid-19-vaccine-janssen (accessed Apr. 10, 2023).

[78] Medicago Inc, "Medicago and GSK announce the approval by Health Canada of COVIFENZ®, an Adjuvanted Plant-Based COVID-19 Vaccine | Medicago," Feb. 24, 2022. https://medicago.com/en/press-release/covifenz/ (accessed Apr. 10, 2023).

[79] Takeda Pharmaceutical Company Limited, "Takeda Announces Approval of Moderna's COVID-19 Vaccine in Japan," May 21, 2021. https://www.takeda.com/newsroom/newsreleases/2021/takeda-announces-approval-of-modernas-covid-19-vaccine-in-japan/ (accessed Feb. 10, 2023).

[80] Takeda Pharmaceutical Company Limited, "Takeda Announces Approval of Nuvaxovid® COVID-19 Vaccine for Primary and Booster Immunization in Japan," Apr. 19, 2022. https://www.takeda.com/newsroom/newsreleases/2022/takeda-announces-approval-of-nuvaxovid-covid-19-vaccine-for-primary-and-booster-immunization-in-japan (accessed Feb. 10, 2023).

[81] Reuters Staff, "China gives its first COVID-19 vaccine approval to Sinopharm | Reuters," *Reuters*, Dec. 30, 2020. https://www.reuters.com/article/us-health-coronavirus-vaccine-china-idUSKBN29505P (accessed Feb. 10, 2023).

[82] Reuters Staff, "China approves Sinovac Biotech COVID-19 vaccine for general public use," *Reuters*, Feb. 06, 2021. https://www.reuters.com/article/us-health-coronavirus-vaccine-sinovac-idUSKBN2A60AY (accessed Feb. 10, 2023).

[83] Reuters Staff, "China approves two more domestic COVID-19 vaccines for public use," *Reuters*, Feb. 25, 2021. https://www.reuters.com/article/us-health-coronavirus-china-vaccine-idUSKBN2AP1MW (accessed Feb. 10, 2023).

[84] Reuters Staff, "China IMCAS's COVID-19 vaccine obtained emergency use approval in China," *Reuters*, Mar. 15, 2021. https://www.reuters.com/article/health-coronavirus-china-vaccine/…19-vaccine-obtained-emergency-use-approval-in-china-idUSL4N2LD3BZ (accessed Feb. 10, 2023).

[85] Reuters Staff, "Kangtai Biological's COVID-19 vaccine gets emergency use approval in China," *Reuters*, May 14, 2021. https://www.reuters.com/article/us-health-coronavirus-vaccine-kan…vid-19-vaccine-gets-emergency-use-approval-in-china-idUSKBN2CV1F6 (accessed Feb. 10, 2023).

[86] Reuters, "China builds new plant for IMBCAMS COVID-19 vaccine -state media," *Reuters*, Jun. 09, 2021. https://www.reuters.com/world/asia-pacific/china-builds-new-plant-imbcams-covid-19-vaccine-state-media-2021-06-09/ (accessed Apr. 09, 2023).

[87] Reuters, A. Ahmed, and K. N. Das, "India approves AstraZeneca and local COVID vaccines, roll out seen soon World Business Legal Markets EM," Jan. 02, 2021.

https://www.reuters.com/world/india/india-approves-astrazeneca-local-covid-vaccines-roll-out-seen-soon-2021-01-03/ (accessed Feb. 10, 2023).

[88] N. Turak, "India becomes 60th country to authorize use of Russia's Sputnik V vaccine," *CNBC*, Apr. 14, 2021. https://www.cnbc.com/2021/04/14/covid-india-authorizes-use-of-russias-sputnik-v-vaccine.html (accessed Feb. 10, 2023).

[89] France 24, "India approves Moderna's Covid-19 vaccine for emergency use," *AFP*, Jun. 29, 2021. https://www.france24.com/en/live-news/20210629-india-approves-moderna-s-covid-19-vaccine-for-emergency-use (accessed Feb. 10, 2023).

[90] Reuters, "India approves J&J vaccine; no delivery timeline yet," *Reuters*, Aug. 07, 2021. https://www.reuters.com/world/india/india-approves-jj-covid-19-vaccine-emergency-use-2021-08-07/ (accessed Apr. 12, 2023).

[91] Reuters, "India gives emergency approval for world's first COVID-19 DNA vaccine," *Reuters*, Aug. 20, 2021. https://www.reuters.com/business/healthcare-pharmaceuticals/india-approves-zydus-cadilas-covid-19-vaccine-emergency-use-2021-08-20/ (accessed Feb. 10, 2023).

[92] Novavax, "Novavax and Serum Institute of India Receive Emergency Use Authorization for COVID-19 Vaccine in India," *Novavax News & Media*, Dec. 28, 2021. https://ir.novavax.com/2021-12-28-Novavax-and-Serum-Institute-of-India-Receive-Emergency-Use-Authorization-for-COVID-19-Vaccine-in-India (accessed Feb. 10, 2023).

[93] Biological E. Limited, "CORBEVAX GETS DCGI APPROVAL," *Biological E. Limited*, Dec. 28, 2021. https://www.biologicale.com/news.html (accessed Feb. 10, 2023).

[94] Hindustan Times, "DCGI grants emergency use permission to single-dose Sputnik Light Covid vaccine," *Hindustan Times*, Feb. 06, 2021. https://www.hindustantimes.com/india-news/dcgi-grants-emergency-use-permission-to-single-dose-sputnik-light-covid-vaccine-101644166721390.html (accessed Feb. 10, 2023).

[95] HDT bio corp., "HDT Bio's COVID-19 Vaccine Wins Regulatory Approval in India," *Press Release*, Jun. 29, 2022. https://www.hdt.bio/news-blog/hdt-bios-covid-19-vaccine-wins-regulatory-approval-in-india (accessed Feb. 10, 2023).

[96] S. Widianto, "Indonesia approves China's Sinovac vaccine as infections surge," *Reuters*, Jan. 11, 2021. https://www.reuters.com/article/us-health-coronavirus-indonesia/indonesia-approves-chinas-sinovac-vaccine-as-infections-surge-idUSKBN29G0RP (accessed Feb. 10, 2023).

[97] Reuters Staff, "Indonesia approves AstraZeneca vaccine for emergency use," *Reuters*, Mar. 08, 2021. https://www.reuters.com/article/us-health-coronavirus-indonesia/i…esia-approves-astrazeneca-vaccine-for-emergency-use-idUSKBN2B10BE (accessed Feb. 10, 2023).

[98] Reuters, "Indonesia approves Sinopharm COVID-19 vaccine for emergency use," *Reuters*, Apr. 29, 2021. https://www.reuters.com/world/asia-pacific/indonesia-approves-sinopharm-covid-19-vaccine-emergency-use-2021-04-30/ (accessed Feb. 10, 2023).

[99] Reuters, "Indonesia authorises Moderna's COVID-19 vaccine for emergency use," *Reuters*, Jul. 01, 2021. https://www.reuters.com/business/healthcare-pharmaceuticals/indonesia-authorises-modernas-covid-19-vaccine-emergency-use-2021-07-02/ (accessed Feb. 10, 2023).

[100] Reuters Staff, “Indonesia approves Pfizer COVID-19 vaccine for emergency use,” *Reuters*, Jul. 15, 2021. https://www.reuters.com/article/health-coronavirus-indonesia-pfizer/indonesia-approves-pfizer-covid-19-vaccine-for-emergency-use-idUSL4N2OR2HT (accessed Feb. 15, 2023).

[101] Reuters, “Indonesia approves Russia’s Sputnik V vaccine for emergency use,” *Reuters*, Aug. 25, 2021. https://www.reuters.com/world/asia-pacific/indonesia-approves-russias-sputnik-v-vaccine-emergency-use-2021-08-25/ (accessed Feb. 10, 2023).

[102] Reuters, “Indonesia approves J&J, Cansino COVID-19 vaccines for emergency use,” *Reuters*, Sep. 07, 2021. https://www.reuters.com/world/asia-pacific/indonesia-approves-jj-cansino-covid-19-vaccines-emergency-use-2021-09-07/ (accessed Feb. 10, 2023).

[103] Reuters, “Indonesia approves COVID-19 vaccine of China’s Zhifei unit,” *Retuers*, Oct. 07, 2021. https://www.reuters.com/world/asia-pacific/indonesia-approves-covid-19-vaccine-chinas-zhifei-unit-2021-10-07/ (accessed Feb. 10, 2023).

[104] Shenzhen Kangtai Biological Products Co Ltd, “BioKangtai’s adenovirus vector COVID-19 vaccine obtained EUA in Indonesia,” *Cision PR Newswire*, Nov. 03, 2021. https://www.prnewswire.com/news-releases/biokangtais-adenovirus-vector-covid-19-vaccine-obtained-eua-in-indonesia-301415162.html (accessed Feb. 10, 2023).

[105] The Israel Ministry of Health, “Vaccines - Corona Traffic Light Model (Ramzor) Website,” 2023. https://corona.health.gov.il/en/vaccine-for-covid/ (accessed Feb. 11, 2023).

[106] Pfizer Inc., “Real-World Evidence Confirms High Effectiveness of Pfizer-BioNTech COVID-19 Vaccine and Profound Public Health Impact of Vaccination One Year After Pandemic Declared | Pfizer,” Mar. 11, 2021. https://www.pfizer.com/news/press-release/press-release-detail/real-world-evidence-confirms-high-effectiveness-pfizer (accessed Feb. 17, 2023).

[107] J. Bryne, “Israel’s health ministry has given Moderna’s COVID-19 vaccine the green light,” *William Reed Ltd*, Jan. 05, 2021. https://www.biopharma-reporter.com/Article/2021/01/05/Israel-s-health-ministry-has-given-Moderna-s-COVID-19-vaccine-the-green-light (accessed Feb. 11, 2023).

[108] Israel Ministry of Health, “Vaccination with the AstraZeneca Vaccine to Start This Thursday (21/10/2021),” Oct. 18, 2021. https://www.gov.il/en/departments/news/18102021-01 (accessed Feb. 11, 2023).

[109] Novavax, “Novavax Nuvaxovid^{TM} COVID-19 Vaccine Now Available in Israel for Individuals Aged 12 and Older,” Sep. 16, 2022. https://ir.novavax.com/2022-09-16-Novavax-Nuvaxovid-TM-COVID-19-Vaccine-Now-Available-in-Israel-for-Individuals-Aged-12-and-Older (accessed Feb. 11, 2023).

[110] R. Krimly, “Coronavirus: Saudi Arabia approves Pfizer-BioNTech COVID-19 vaccine for use,” *Al Arabiya News*, Dec. 10, 2020. https://english.alarabiya.net/coronavirus/2020/12/10/Coronavirus-Saudi-Arabia-approves-Pfizer-COVID-19-vaccine-for-use (accessed Feb. 10, 2023).

[111] Reuters Staff, “Saudi Arabia approves AstraZeneca’s COVID vaccine, state TV reports,” *Reuters*, Feb. 18, 2021. https://www.reuters.com/article/us-health-coronavirus-vaccine-saudi-idUSKBN2AI1PU (accessed Feb. 10, 2023).

[112] Reuters, “Saudi Arabia approves Moderna’s COVID vaccine -state news agency | Reuters,” *Reuters*, Jul. 09, 2021. https://www.reuters.com/business/healthcare-

pharmaceuticals/saudi-arabia-approves-modernas-covid-vaccine-state-news-agency-2021-07-09/ (accessed Feb. 10, 2023).

[113] D. Al-Khudair, “Saudi Arabia approves Sinovac and Sinopharm vaccines,” *Arab News*, Aug. 25, 2021. https://www.arabnews.com/node/1916756/saudi-arabia (accessed Apr. 09, 2023).

[114] Singapore Health Sciences Authority, “HSA Grants Interim Authorisation for First COVID-19 Vaccine in Singapore,” Dec. 14, 2020. https://www.hsa.gov.sg/announcements/press-release/interimauth-firstcovid19vaccine (accessed Feb. 11, 2023).

[115] Singapore Health Sciences Authority, “HSA Grants Interim Authorisation for Moderna COVID-19 Vaccine in Singapore,” Feb. 03, 2021. https://www.hsa.gov.sg/announcements/press-release/hsa-grants-interim-authorisation-for-moderna-covid-19-vaccine-in-singapore (accessed Feb. 11, 2023).

[116] Singapore Health Sciences Authority, “HSA Grants Interim Authorisation for Sinovac-CoronaVac Vaccine in Singapore Review of Data from Sinovac,” Oct. 23, 2021. https://www.hsa.gov.sg/announcements/press-release/interimauth-sinovac (accessed Feb. 11, 2023).

[117] Singapore Health Sciences Agency, “HSA Grants Interim Authorisation for Nuvaxovid COVID-19 Vaccine by Novavax in Singapore,” Feb. 14, 2022. https://www.hsa.gov.sg/announcements/press-release/interimauth-nuvaxovid (accessed Feb. 11, 2023).

[118] L. Jeong-yeo, “South Korea approves special import of Pfizer vaccine,” Feb. 03, 2021. http://www.koreaherald.com/view.php?ud=20210203001122 (accessed Feb. 09, 2023).

[119] S. Cha, “South Korea to approve AstraZeneca as first COVID-19 vaccine, including for elderly,” *Reuters*, Feb. 10, 2021. https://www.reuters.com/article/us-health-coronavirus-southkorea-astraze-idUSKBN2AA0E8 (accessed Feb. 09, 2023).

[120] Korea Ministry of Food and Drug Safety, “MFDS Grants Marketing Authorization for Janssen COVID-19 Vaccine [Press Release, April 7, 2021],” Apr. 08, 2021. https://www.mfds.go.kr/eng/brd/m_64/view.do?seq=66&srchFr=&s…0&itm_seq_2=0&multi_itm_seq=0&company_cd=&company_nm=&page=1 (accessed Feb. 09, 2023).

[121] K. Han-joo, “Moderna COVID-19 vaccine gets final nod in S. Korea | Yonhap News Agency,” *Yonhap News Agency*, May 21, 2021. https://en.yna.co.kr/view/AEN20210521005500320 (accessed Feb. 09, 2023).

[122] Reuters, “S.Korea authorises Novavax COVID-19 vaccine, imports Pfizer pills | Reuters,” *Reuters*, Jan. 12, 2022. https://www.reuters.com/business/healthcare-pharmaceuticals/skorea-authorises-use-novavax-covid-19-vaccine-2022-01-12/ (accessed Feb. 10, 2023).

[123] Reuters Staff, “Turkey grants emergency authorization to Sinovac’s CoronaVac: Anadolu,” *Reuters*, Jan. 13, 2021. https://www.reuters.com/article/us-health-coronavirus-turkey-vaccine/turkey-grants-emergency-authorization-to-sinovacs-coronavac-anadolu-idUSKBN29I29F (accessed Feb. 10, 2023).

[124] Reuters Staff, “Turkey begins administering Pfizer/BioNTech COVID-19 shots,” *Reuters*, Apr. 02, 2021. https://www.reuters.com/article/us-health-coronavirus-turkey-idUKKBN2BP0VN (accessed Feb. 10, 2023).

[125] Reuters Staff, “Turkey grants emergency authorization to Russia’s Sputnik V vaccine,” *Reuters*, Apr. 30, 2021. https://www.reuters.com/article/idUSI7N2LY01F (accessed Feb. 10, 2023).

[126] Reuters, “Turkey’s domestic COVID-19 vaccine receives emergency use authorisation-minister,” *Reuters*, Dec. 22, 2021. https://www.reuters.com/world/europe/turkeys-domestic-covid-19-vaccine-receives-emergency-use-authorisation-minister-2021-12-22/ (accessed Feb. 10, 2023).

[127] Department of Health and Aged Care Australian Government, “Approved COVID-19 vaccines | Australian Government Department of Health and Aged Care,” Jan. 30, 2022. https://www.health.gov.au/our-work/covid-19-vaccines/approved-vaccines (accessed Feb. 09, 2023).

[128] Department of Health and Aged Care, “Comirnaty (Pfizer) Approval for Use in Australia,” *Australian Government*, Feb. 01, 2023. https://www.health.gov.au/our-work/covid-19-vaccines/approved-vaccines/pfizer (accessed Feb. 09, 2023).

[129] Department of Health and Aged Care, “Vaxzevria (AstraZeneca) Approval for Use in Australia,” *Australian Government*, Feb. 01, 2023. https://www.health.gov.au/our-work/covid-19-vaccines/approved-vaccines/astrazeneca (accessed Feb. 09, 2023).

[130] Therapeutic Goods Administration Department of Health and Aged Care, “COVID-19 vaccine: Janssen Provisional approval,” *Australian Government*, Apr. 05, 2022. https://www.tga.gov.au/node/289166 (accessed Feb. 09, 2023).

[131] COVID-19 vaccine: Janssen Provisional approval, “Spikevax (Moderna) Approval for Use in Australia,” *Australian Government*, Feb. 07, 2023. https://www.health.gov.au/our-work/covid-19-vaccines/approved-vaccines/moderna (accessed Feb. 09, 2023).

[132] Department of Health and Aged Care, “Nuvaxovid (Novavax) Approval for Use in Australia Dose schedule Primary course,” *Australian Government*, Jan. 19, 2023. https://www.health.gov.au/our-work/covid-19-vaccines/approved-vaccines/novavax (accessed Feb. 09, 2023).

[133] New Zealand Medicines and Medical Devices Safety Authority, “Approval status of COVID-19 vaccines applications received by Medsafe,” Feb. 07, 2023. https://medsafe.govt.nz/COVID-19/status-of-applications.asp (accessed Feb. 11, 2023).

[134] Pfizer New Zealand Limited, “NEW ZEALAND DATA SHEET for COMIRNATY,” *New Zealand Gazette*, Nov. 18, 2022. https://medsafe.govt.nz/profs/Datasheet/c/comirnatyinj.pdf (accessed Feb. 11, 2023).

[135] Janssen-Cilag (New Zealand) Ltd, “COVID-19 VACCINE JANSSEN® Ad26.COV2.S DATA SHEET,” *New Zealand Gazette*, Jul. 19, 2022. https://medsafe.govt.nz/profs/Datasheet/c/COVID19VaccineJansseninj.pdf (accessed Feb. 11, 2023).

[136] AstraZeneca, “NEW ZEALAND DATA SHEET for VAXZEVRIA,” *New Zealand Gazette*, Nov. 17, 2022. https://medsafe.govt.nz/profs/Datasheet/c/Covid19VaccineAstraZenecainj.pdf (accessed Feb. 11, 2023).

[137] Biocelect New Zealand Ltd, “New Zealand Data Sheet for NUVAXOVID,” *New Zealand Gazette*, Oct. 21, 2022. https://medsafe.govt.nz/profs/Datasheet/n/Nuvaxovidinj.pdf (accessed Feb. 11, 2023).

[138] Medsafe Ministry of Health, “Provisional Consent to the Distribution of a New Medicine, SPIKEVAX,” *New Zealand Gazette*, Jun. 17, 2022. https://gazette.govt.nz/notice/id/2022-go2432 (accessed Feb. 11, 2023).

[139] Belgium Federal Public Service Health Food Chain Safety and Environment, “Vaccination | Coronavirus COVID-19,” 2023. https://www.info-coronavirus.be/en/vaccination/#faq (accessed Feb. 09, 2023).

[140] Ministry of Health of the Czech Republic, “Information about available vaccines in the Czech Republic · Covid Portál,” Jan. 30, 2023. https://covid.gov.cz/en/situations/vaccines/information-about-available-vaccines-czech-republic (accessed Feb. 09, 2023).

[141] Danish Medicines Agency, “General information on COVID-19 vaccines,” 2023. https://laegemiddelstyrelsen.dk/en/news/themes/general-information-on-covid-19-vaccines/#idE395811A956C4500B182EEE600E19965 (accessed Apr. 08, 2023).

[142] The Estonia Government Communication Unit, “COVID-19 vaccines | Kriis,” Oct. 27, 2022. https://www.kriis.ee/en/sickness-health-vaccinations/vaccines-and-vaccinations/covid-19-vaccines (accessed Feb. 09, 2023).

[143] Finland Ministry of Social Affairs and Health, “COVID-19 vaccines - Ministry of Social Affairs and Health,” Feb. 03, 2023. https://stm.fi/en/covid-19-vaccines (accessed Feb. 09, 2023).

[144] Germany Federal Ministry of Health, “Current information on coronavirus vaccination,” Dec. 31, 2022. https://www.bundesgesundheitsministerium.de/en/coronavirus/faq-covid-19-vaccination.html (accessed Feb. 09, 2023).

[145] Russian Direct Investment Fund, “HUNGARY BECOMES THE FIRST COUNTRY IN EU TO AUTHORIZE THE SPUTNIK V VACCINE,” *Press Release, Russian Direct Investment Fund*, Jan. 21, 2021. https://sputnikvaccine.com/newsroom/pressreleases/hungary-becomes-the-first-country-in-eu-to-authorize-the-sputnik-v-vaccine-/ (accessed Feb. 09, 2023).

[146] AP News, “Hungary first in EU to approve Chinese COVID-19 vaccine | AP News,” *AP News*, Jan. 29, 2021. https://apnews.com/article/europe-coronavirus-pandemic-china-coronavirus-vaccine-hungary-a598b6170a1ca9eb120ac4b87e73636c (accessed Feb. 09, 2023).

[147] Reuters, “Hungary approves new Chinese vaccine, and CoviShield for emergency use | Reuters,” *Reuters*, Mar. 22, 2021. https://www.reuters.com/business/healthcare-pharmaceuticals/hungary-approves-new-chinese-vaccine-covishield-emergency-use-2021-03-22/ (accessed Feb. 09, 2023).

[148] Iceland Directorate of Health and Iceland Department of Civil Protection and Emergency Management, “Official information about COVID-19 in Iceland,” 2023. https://www.covid.is/covid-19-vaccine (accessed Feb. 11, 2023).

[149] Ireland Health Service Executive, “COVID-19 vaccines - HSE.ie,” Oct. 21, 2022. https://www2.hse.ie/screening-and-vaccinations/covid-19-vaccine/vaccine-types/ (accessed Feb. 09, 2023).

[150] Government of the Netherlands, “Which COVID-19 vaccine do I need and how can I get one? | Coronavirus Covid-19 | Government.nl,” 2023. https://www.government.nl/topics/coronavirus-covid-19/dutch-vaccination-programme/making-an-appointment-for-vaccination (accessed Feb. 09, 2023).

[151] Norwegian Institute of Public Health, “Development and approval of coronavirus vaccine,” Sep. 19, 2022. https://www.fhi.no/en/id/vaccines/coronavirus-immunisation-programme/development-of-covid-19-vaccine/ (accessed Feb. 11, 2023).

[152] The Guardian, “Russia approves Sputnik V Covid vaccine despite testing safety concerns,” *The Guardian*, Aug. 11, 2020. https://www.theguardian.com/world/2020/aug/11/russia-approves-coronavirus-vaccine-despite-testing-safety-concerns-vladimir-putin (accessed Feb. 10, 2023).

[153] CNBC, “Russia approves second Covid-19 vaccine after preliminary trials,” *CNBC*, Oct. 14, 2020. https://www.cnbc.com/2020/10/14/russia-approves-second-covid-19-vaccine-after-preliminary-trials-.html (accessed Feb. 10, 2023).

[154] P. Ivanova, “Russia approves its third COVID-19 vaccine, CoviVac,” Feb. 20, 2021. https://www.reuters.com/article/us-health-coronavirus-russia-vaccine-idUSKBN2AK07H (accessed Feb. 20, 2023).

[155] Reuters, “Russia authorises single-dose Sputnik Light COVID vaccine for use -RDIF,” *Reuters*, May 06, 2021. https://www.reuters.com/business/healthcare-pharmaceuticals/russia-says-argentina-approves-sputnik-light-standalone-booster-vaccine-2021-12-06/ (accessed Feb. 10, 2023).

[156] Interfax, “Russian Health Ministry registers EpiVacCorona-N coronavirus vaccine,” *Interfax News Agency*, Aug. 26, 2021. https://interfax.com/newsroom/top-stories/72554/ (accessed Aug. 26, 2023).

[157] Russian Direct Investment Fund, “KAZAKHSTAN BECOMES THE FIRST COUNTRY OUTSIDE RUSSIA TO AUTHORIZE SPUTNIK M VACCINE FOR ADOLESCENTS,” *Press Release, Russian Direct Investment Fun*, Feb. 22, 2022. https://sputnikvaccine.com/newsroom/pressreleases/kazakhstan-becomes-the-first-country-outside-russia-to-authorize-sputnik-m-vaccine-for-adolescents-/ (accessed Apr. 12, 2023).

[158] Russian Direct Investment Fund, “SPUTNIK V APPROVED FOR USE IN SLOVAKIA,” *Press Release, Russian Direct Investment Fund*, Mar. 01, 2021. https://sputnikvaccine.com/newsroom/pressreleases/sputnik-v-approved-for-use-in-slovakia/ (accessed Apr. 12, 2023).

[159] Swiss Medic Swiss Agency for Therapeutic Products, “Current status of authorisations for combating COVID-19,” 2023. https://www.swissmedic.ch/swissmedic/en/home/news/coronavirus-covid-19/stand-zl-bekaempfung-covid-19.html (accessed Feb. 11, 2023).

[160] GOV.UK, “regulatory approval of covid-19 vaccine - Search - GOV.UK,” 2023. https://www.gov.uk/search/all?keywords=regulatory+approval+of+covid-19+vaccine&order=relevance (accessed Feb. 09, 2023).

[161] Pfizer Inc. and BioNTech SE, “Pfizer and BioNTech Achieve First Authorization in the World for a Vaccine to Combat COVID-19,” *Science Products Stories Newsroom*, Dec. 02, 2020. https://www.pfizer.com/news/press-release/press-release-detail/pfizer-and-biontech-achieve-first-authorization-world (accessed Feb. 10, 2023).

[162] UK Medicines and Healthcare products Regulatory Agency, “Oxford University/AstraZeneca COVID-19 vaccine approved,” *GOV.UK*, Dec. 30, 2020.

https://www.gov.uk/government/news/oxford-universityastrazeneca-covid-19-vaccine-approved (accessed Feb. 09, 2023).

[163] UK Medicines and Healthcare products Regulatory Agency, “Moderna vaccine becomes third COVID-19 vaccine approved by UK regulator,” *GOV.UK*, Jan. 08, 2021. https://www.gov.uk/government/news/moderna-vaccine-becomes-third-covid-19-vaccine-approved-by-uk-regulator (accessed Feb. 10, 2023).

[164] UK Medicines and Healthcare products Regulatory Agency, “One-dose Janssen COVID-19 vaccine approved by the MHRA,” *GOV.UK*, May 28, 2021. https://www.gov.uk/government/news/one-dose-janssen-covid-19-vaccine-approved-by-the-mhra (accessed Feb. 10, 2023).

[165] UK Medicines and Healthcare products Regulatory Agency, “Novavax COVID-19 vaccine Nuvaxovid approved by MHRA,” *GOV.UK*, Feb. 03, 2022. https://www.gov.uk/government/news/novavax-covid-19-vaccine-nuvaxovid-approved-by-mhra (accessed Feb. 10, 2023).

[166] UK Medicines and Healthcare products Regulatory Agency, “Valneva COVID-19 vaccine approved by MHRA,” *GOV.UK*, Apr. 14, 2022. https://www.gov.uk/government/news/valneva-covid-19-vaccine-approved-by-mhra (accessed Feb. 09, 2023).

[167] Government of Canada, “COVID-19 Vaccines: Authorized vaccines - Canada.ca,” Aug. 05, 2022. https://www.canada.ca/en/health-canada/services/drugs-health-products/covid19-industry/drugs-vaccines-treatments/vaccines.html (accessed Feb. 09, 2023).

[168] Health Canada, “Comirnaty (tozinameran),” *COVID-19 vaccines and treatments portal*, Jan. 26, 2023. https://covid-vaccine.canada.ca/comirnaty/product-details (accessed Feb. 09, 2023).

[169] Health Canada, “SPIKEVAX (elasomeran),” *COVID-19 vaccines and treatments portal*, Jan. 26, 2023. https://covid-vaccine.canada.ca/covid-19-vaccine-moderna/product-details (accessed Feb. 10, 2023).

[170] Health Canada, “Vaxzevria (ChAdOx1-S [recombinant]),” *COVID-19 vaccines and treatments portal*, Jan. 26, 2023. https://covid-vaccine.canada.ca/vaxzevria/product-details (accessed Feb. 10, 2023).

[171] Health Canada, “Health Canada authorizes AstraZeneca and Verity Pharmaceuticals Inc./Serum Institute of India COVID-19 vaccines,” *Statement*, Feb. 26, 2021. https://www.canada.ca/en/health-canada/news/2021/02/health-canada-authorizes-astrazeneca-and-verity-pharmaceuticals-incserum-institute-of-india-covid-19-vaccines.html (accessed Apr. 10, 2023).

[172] Health Canada, “JCOVDEN (Ad26.COV2.S [recombinant]),” *COVID-19 vaccines and treatments portal*, Jan. 26, 2023. https://covid-vaccine.canada.ca/jcovden/product-details (accessed Feb. 09, 2023).

[173] Health Canada, “NUVAXOVID,” *COVID-19 vaccines and treatments portal*, Feb. 07, 2023. https://covid-vaccine.canada.ca/nuvaxovid/product-details (accessed Feb. 09, 2023).

[174] Health Canada, “Covifenz (virus-like particles (VLP) of SARS-CoV-2 spike protein),” *COVID-19 vaccines and treatments portal*, Jun. 17, 2022. https://covid-vaccine.canada.ca/covifenz/product-details (accessed Feb. 09, 2023).

[175] Reuters, "Costa Rica authorizes Pfizer's COVID-19 vaccine - health ministry," *Reuters*, Dec. 15, 2020. https://www.reuters.com/business/healthcare-pharmaceuticals/costa-rica-authorizes-pfizers-covid-19-vaccine-health-ministry-2020-12-16/ (accessed Feb. 11, 2023).

[176] Reuters, "After weighing guidance, Costa Rica to use AstraZeneca vaccine," *Reuters*, Apr. 08, 2021. https://www.reuters.com/business/healthcare-pharmaceuticals/after-weighing-guidance-costa-rica-use-astrazeneca-vaccine-2021-04-08/ (accessed Feb. 11, 2023).

[177] Gobierno de México, "Cofepris emite autorización para uso de emergencia a vacuna Sinopharm," *Comunicado a la población 29/2021*, Aug. 26, 2021. https://www.gob.mx/cofepris/articulos/cofepris-emite-autorizacion-para-uso-de-emergencia-a-vacuna-sinopharm?idiom=es (accessed Feb. 09, 2023).

[178] U.S. Food and Drug Administration, "COVID-19 Vaccines | FDA," Mar. 14, 2023. https://www.fda.gov/emergency-preparedness-and-response/coronavirus-disease-2019-covid-19/covid-19-vaccines (accessed Apr. 09, 2023).

[179] U.S. Food and Drug Administration, "FDA Takes Key Action in Fight Against COVID-19 By Issuing Emergency Use Authorization for First COVID-19 Vaccine," *FDA News Release*, Dec. 11, 2020. https://www.fda.gov/news-events/press-announcements/fda-takes-key-action-fight-against-covid-19-issuing-emergency-use-authorization-first-covid-19 (accessed Feb. 09, 2023).

[180] U.S. Food and Drug Administration, "FDA Takes Additional Action in Fight Against COVID-19 By Issuing Emergency Use Authorization for Second COVID-19 Vaccine," *FDA News Release*, Dec. 18, 2020. https://www.fda.gov/news-events/press-announcements/fda-takes-additional-action-fight-against-covid-19-issuing-emergency-use-authorization-second-covid (accessed Feb. 09, 2023).

[181] U.S. Food and Drug Administration, "FDA Issues Emergency Use Authorization for Third COVID-19 Vaccine," *FDA News Release*, Feb. 27, 2021. FDA Issues Emergency Use Authorization for Third COVID- 19 Vaccine (accessed Feb. 09, 2023).

[182] U.S. Food and Drug Administration, "Coronavirus (COVID-19) Update: FDA Authorizes Emergency Use of Novavax COVID-19 Vaccine, Adjuvanted," *FDA News Release*, Jul. 13, 2022. https://www.fda.gov/news-events/press-announcements/coronavirus-covid-19-update-fda-authorizes-emergency-use-novavax-covid-19-vaccine-adjuvanted (accessed Feb. 09, 2023).

[183] Ministerio de Salud de la Provincia del Neuquén, "Campaña de vacunación contra el coronavirus," *Ministerio de Salud de la Provincia del Neuquén*, 2023. https://www.saludneuquen.gob.ar/campana-de-vacunacion-contra-el-coronavirus/ (accessed Feb. 09, 2023).

[184] Dirección de Control de Enfermedades Inmunoprevenibles, "Actualización de los Lineamientos Técnicos Campaña Nacional de Vacunación contra la COVID-19," *Ministerio de Salud Argentina*, Oct. 07, 2021. https://bancos.salud.gob.ar/sites/default/files/2021-10/LT%20COVID-19%20unificado%20Octubre.pdf (accessed Feb. 09, 2023).

[185] Xinhua Global Service, "Argentina starts nationwide rollout of China's Sinovac vaccine," *Xinhua English News*, Mar. 05, 2021. http://www.xinhuanet.com/english/2021-03/05/c_139786862.htm (accessed Feb. 10, 2023).

[186] Ministerio de Salud Argentina, "Resolución 2711 / 2021 VACUNA SPIKEVAX-AUTORIZASE," *Boletín Nacional del 05-Oct-2021*, Oct. 05, 2021.

https://www.argentina.gob.ar/normativa/nacional/resolución-2711-2021-354895 (accessed Apr. 10, 2023).

[187] Reuters, “Russia says Argentina approves Sputnik Light as standalone and booster vaccine,” *Reuters*, Dec. 06, 2021. https://www.reuters.com/business/healthcare-pharmaceuticals/russia-says-argentina-approves-sputnik-light-standalone-booster-vaccine-2021-12-06/ (accessed Feb. 10, 2023).

[188] J. Mcgeever and P. Fonseca, “Brazil clears emergency use of Sinovac, AstraZeneca vaccines, shots begin,” *Reuters*, Jan. 17, 2021. https://www.reuters.com/article/us-health-coronavirus-brazil/bra…izes-emergency-use-of-sinovac-astrazeneca-vaccines-idUSKBN29M0M3 (accessed Feb. 09, 2023).

[189] Reuters Staff, “Brazil approves Pfizer’s COVID-19 shot, but has none to use,” *Reuters*, Feb. 23, 2021. https://www.reuters.com/article/us-health-coronavirus-brazil/brazil-approves-pfizers-covid-19-shot-but-has-none-to-use-idUSKBN2AN19Q (accessed Feb. 10, 2023).

[190] Reuters Staff, “Brazil health regulator approves emergency use of Johnson & Johnson COVID-19 vaccine,” *Reuters*, Mar. 31, 2021. https://www.reuters.com/article/us-health-coronavirus-brazil-janssen/brazil-health-regulator-approves-emergency-use-of-johnson-johnson-covid-19-vaccine-idUSKBN2BN33V (accessed Feb. 09, 2023).

[191] Agência Nacional de Vigilância Sanitária - Anvisa, “OMS aprova o uso emergencial da vacina da Sinopharm,” *Ministério da Saúde*, May 07, 2021. https://www.gov.br/anvisa/pt-br/assuntos/noticias-anvisa/2021/oms-aprova-a-entrada-da-vacina-da-sinopharm-no-consorcio-internacional-covax-facility (accessed Feb. 10, 2023).

[192] J. McGeever and L. Paraguassu, “Brazil’s Anvisa approves Russian Sputnik V vaccine, with conditions,” *Reuters*, Jun. 04, 2021. https://www.reuters.com/world/americas/brazil-health-regulator-technical-staff-recommend-conditions-any-approval-2021-06-04/ (accessed Feb. 10, 2023).

[193] F. Cambero and N. A. Ramos Miranda, “Chilean health regulator approves Pfizer-BioNTech vaccine for emergency use,” *Reuters*, Dec. 16, 2020. https://www.reuters.com/article/health-coronavirus-chile-vaccine-idUSKBN28Q2EZ (accessed Feb. 11, 2023).

[194] A. Laing and F. Cambero, “Chile regulator greenlights Sinovac COVID-19 vaccine for emergency use,” *Reuters*, Jan. 20, 2021. https://www.reuters.com/business/healthcare-pharmaceuticals/chile-regulator-greenlights-sinovac-covid-19-vaccine-emergency-use-2021-01-20/ (accessed Feb. 11, 2023).

[195] Aislinn Laing and N. A. Ramos Miranda, “Chile health regulator approves AstraZeneca COVID-19 vaccine for emergency use Professional Ski Delivery,” *Reuters*, Jan. 27, 2021. https://www.reuters.com/article/us-health-coronavirus-chile-astrazeneca-idUSKBN29W1SQ (accessed Feb. 11, 2023).

[196] F. Cambero, “Chilean health regulator approves CanSino COVID-19 vaccine for emergency use,” *Reuters*, Apr. 07, 2021. https://www.reuters.com/business/healthcare-pharmaceuticals/chilean-health-regulator-approves-cansino-covid-19-vaccine-emergency-use-2021-04-07/ (accessed Feb. 11, 2023).

[197] Reuters, “Chile approves J&J’s COVID-19 vaccine for emergency use,” *Reuters*, Jun. 10, 2021. https://www.reuters.com/world/americas/chile-approves-jjs-covid-19-vaccine-emergency-use-2021-06-10/ (accessed Feb. 11, 2023).

[198] Reuters, “Chile approves emergency use of Sputnik-V coronavirus vaccine,” *Reuters*, Jul. 21, 2021. https://www.reuters.com/world/americas/chile-approves-emergency-use-sputnik-v-coronavirus-vaccine-2021-07-21/ (accessed Feb. 11, 2023).

[199] Agencia Informativa Latinoamericana S.A., “Chile aprueba vacuna Moderna para uso de emergencia contra Covid-19,” *Chile aprueba vacuna Moderna para uso de emergencia contra Covid-19 - Prensa Latina*, Feb. 02, 2022. https://www.prensa-latina.cu/2022/02/02/chile-aprueba-vacuna-moderna-para-uso-de-emergencia-contra-covid-19 (accessed Feb. 11, 2023).

[200] Reuters Staff, “Colombia regulator approves Pfizer-BioNTech vaccine for emergency use,” *Reuters*, Jan. 05, 2021. https://www.reuters.com/article/us-health-coronavirus-colombia-vaccine-idUSKBN29B02M (accessed Feb. 11, 2023).

[201] Medicamentos y productos biológicos - Instituto Nacional de Vigilancia de Medicamentos y Alimentos - República de Colombia, “Invima otorgó visto bueno para la importación de la vacuna CoronaVac desarrollada por la farmacéutica Sinovac Life Sciences Co. Ltd.,” *GOV.CO*, Feb. 03, 2021. https://www.invima.gov.co/en/invima-otorgo-visto-bueno-para-la-importacion-de-la-vacuna-coronavac-desarrollada-por-la-farmaceutica-sinovac-life-sciences-co-ltd (accessed Feb. 11, 2023).

[202] Reuters Staff, “Colombia approves emergency use of AstraZeneca coronavirus vaccine,” *Reuters*, Feb. 23, 2021. https://www.reuters.com/article/us-health-coronavirus-colombia/colombia-approves-emergency-use-of-astrazeneca-coronavirus-vaccine-idUSKBN2AO01A (accessed Feb. 11, 2023).

[203] Reuters Staff, “Colombia grants emergency use for J&J coronavirus vaccine,” *Reuters*, Mar. 25, 2021. https://www.reuters.com/article/us-health-coronavirus-colombia/col…bia-grants-emergency-use-for-jj-coronavirus-vaccine-idUSKBN2BI03Z (accessed Feb. 11, 2023).

[204] Instituto Nacional de Vigilancia de Medicamentos y Alimentos - República de Colombia, “Invima otorgó Autorización Sanitaria de Uso de Emergencia a la vacuna desarrollada por la farmacéutica Moderna Switzerland GmbH,” *GOV.CO*, Jun. 25, 2021. https://www.invima.gov.co/en/web/guest/invima-otorgo-autorizacion-sanitaria-de-uso-de-emergencia-a-la-vacuna-desarrollada-por-la-farmaceutica-moderna-switzerland-gmbh?redirect=%2Fen%2Fweb%2Fguest%2Fnoticias (accessed Feb. 11, 2023).

[205] R. Salud, “Colombia aprueba otra vacuna para el coronavirus: Zifivax, desarrollada en China,” *El Espectador*, Jan. 27, 2022. https://www.elespectador.com/salud/colombia-aprueba-otra-vacuna-para-el-coronavirus-zifivax-desarrollada-en-china/ (accessed Feb. 11, 2023).

[206] Immunization Office of Japan, “資料１　新型コロナウイルスワクチンの接種体制確保について　新型コロナウイルスワクチンの接種体制確保に係る自治体説明会（第６回）,” *Ministry of Health, Labour and Welfare of Japan*, May 25, 2021. https://www.mhlw.go.jp/content/10906000/000784020.pdf (accessed Sep. 07, 2023).

[207] Immunization Office of Japan, “資料１　新型コロナウイルスワクチンの接種体制確保について　新型コロナウイルスワクチンの接種体制確保に係る自治体説明会（第８回）,” *Ministry of Health, Labour and WelFare of Japan*, Sep. 22, 2021. https://www.mhlw.go.jp/content/10906000/000834746.pdf (accessed Mar. 13, 2023).

[208] Cabinet Public Affairs Office of Japan, “新型コロナワクチンの接種スケジュールについて,” *Prime Minister’s Office of Japan*, Mar. 13, 2023. https://www.kantei.go.jp/jp/headline/kansensho/vaccine_supply.html (accessed Mar. 13, 2023).

[209] Immunization Office of Japan, “資料３　各ワクチンの取扱いについて②　新型コロナウイルスワクチンの接種体制確保に係る自治体説明会（第６回）,” *Ministry of Health Labour and Welfare of Japan*, May 25, 2021. https://www.mhlw.go.jp/content/10906000/000783966.pdf (accessed Apr. 16, 2023).

[210] T. Yoda and H. Katsuyama, “Willingness to receive covid-19 vaccination in japan,” *Vaccines*, vol. 9, no. 1, pp. 1–8, Jan. 2021, doi: 10.3390/vaccines9010048.

[211] M. Machida *et al.*, “Acceptance of a covid-19 vaccine in japan during the covid-19 pandemic,” *Vaccines*, vol. 9, no. 3, pp. 1–11, 2021, doi: 10.3390/vaccines9030210.

[212] R. Okubo, T. Yoshioka, S. Ohfuji, T. Matsuo, and T. Tabuchi, “Covid-19 vaccine hesitancy and its associated factors in japan,” *Vaccines*, vol. 9, no. 6, Jun. 2021, doi: 10.3390/vaccines9060662.

[213] S. Nomura *et al.*, “Reasons for being unsure or unwilling regarding intention to take COVID-19 vaccine among Japanese people: A large cross-sectional national survey,” *Lancet Reg. Health - West. Pac.*, vol. 14, Sep. 2021, doi: 10.1016/j.lanwpc.2021.100223.

[214] Institute of Global Health Innovation, “Global attitudes towards a COVID-19 vaccine,” Imperial College London, May 2021. Accessed: Apr. 17, 2023. [Online]. Available: https://www.imperial.ac.uk/media/imperial-college/institute-of-global-health-innovation/GlobalVaccineInsights_ICL-YouGov-Covid-19-Behaviour-Tracker_20210520_v2.pdf

[215] Ministry of Defense and Japan Self Defense Force, “防衛省・自衛隊：時系列でみる大規模接種センターの運営実績,” *Ministry of Defense, Japan Self Defense Force*, 2023. https://www.mod.go.jp/j/approach/defense/covid/arcive01/timeline.html (accessed Feb. 26, 2023).

[216] NHK, “全日空 新型コロナワクチンの職域接種 開始（6/13）,” *NHK (Japan Broadcasting Corporation)*, Jun. 13, 2021. https://www3.nhk.or.jp/news/special/coronavirus/vaccine/japan_2021half/#mokuji26 (accessed Apr. 19, 2023).

[217] Ministry of Health, Labour and Welfare of Japan, “新型コロナウイルス感染症に係る予防接種の実施に関する手引き（３．１版）,” *Ministry of Health, Labour and Welfare of Japan*, Jun. 04, 2021. https://www.mhlw.go.jp/content/000800809.pdf (accessed Apr. 19, 2023).

[218] Medical Professions Division, Dental Health Division, and Immunization Office, “事務連絡　新型コロナウイルス感染症に係るワクチン接種のための筋肉内注射の歯科医師による実施について,” *Ministry of Health, Labour and Welfare of Japan*, Apr. 26, 2021. https://www.mhlw.go.jp/content/000773564.pdf (accessed Dec. 31, 2022).

[219] Director General of Health Policy Bureau, Director General of Health Service Bureau, and Director General of Pharmaceutical Safety and Environmental Health Bureau, “新型コロナ

ウイルス感染症のワクチン接種を推進するための各医療関係職種の専門性を踏まえた対応の在り方等について," *Ministry of Health, Labour and Welfare of Japan*, Jun. 04, 2021. https://www.mhlw.go.jp/content/000788723.pdf (accessed Dec. 31, 2022).

[220] Public Administration Statistics Office, Ministry of Health, Labour and Welfare of Japan, "Report on Public Health Administration and Services, Fiscal Year 2020 (衛生行政報告例)." Feb. 01, 2023. Accessed: Mar. 13, 2023. [Online]. Available: https://www.e-stat.go.jp/stat-search/files?page=1&query=衛生行政報告%20看護師都道府県%E3%80%80年齢&layout=dataset&cycle=7&stat_infid=000032156336&metadata=1&data=1

[221] Health Statistics Office, Ministry of Health, Labour and Welfare of Japan, "Statistics of Physicians, Dentists and Pharmacists, Fiscal Year 2020（医師・歯科医師・薬剤師統計）." Mar. 17, 2022. Accessed: Mar. 13, 2023. [Online]. Available: https://www.e-stat.go.jp/stat-search/files?page=1&layout=datalist&toukei=00450026&tstat=000001135683&cycle=7&tclass1=000001163706&tclass2=000001163708&cycle_facet=cycle&tclass3val=0&metadata=1&data=1

[222] Health Statistics Office, Ministry of Health, Labour and Welfare of Japan, "Survey of Medical Institutions, Summary, 2020（医療施設(静態・動態)調査(確定数)・病院報告の概況）." Apr. 27, 2022. Accessed: Apr. 19, 2023. [Online]. Available: https://www.mhlw.go.jp/toukei/saikin/hw/iryosd/20/dl/09gaikyo02.pdf

[223] Fire and Disaster Management Agency, "令和３年版　救急救助の現況," Ministry of Internal Affairs and Communications of Japan, Tokyo, Japan, Dec. 2021. Accessed: Apr. 19, 2023. [Online]. Available: https://www.fdma.go.jp/publication/rescue/items/kkkg_r03_01_kyukyu.pdf

[224] Immunization Office of Japan, "事務連絡　新型コロナワクチンの職域接種の開始について," *Ministry of Health, Labour and Welfare of Japan*, Jun. 01, 2021. https://www.mhlw.go.jp/content/000786973.pdf (accessed Dec. 31, 2022).

[225] Y. Matsumoto, "都道府県別 産業医活動における実態調査分析," *Japan Medical Associations*, May 31, 2020. https://www.sangyo-doctors.gr.jp/common/pdf/01/doc01.pdf (accessed Mar. 13, 2023).

[226] Ministry of Health, Labour and Welfare of Japan, "市町村における予防接種実施計画の作成等の状況（令和３年6月14日時点）," *Ministry of Health, Labour and Welfare of Japan*, Jun. 14, 2021. https://www.mhlw.go.jp/content/000807294.pdf (accessed Mar. 20, 2023).

[227] Ministry of Defense and Japan Self Defense Force, "防衛省・自衛隊：データで見る自衛隊大規模接種センター," *Ministry of Defense, Japan Self Defense Force*, 2023. https://www.mod.go.jp/j/approach/defense/covid/arcive01/figure.html (accessed Feb. 26, 2023).

[228] National Institute of Infectious Diseases of Japan, "新型コロナワクチンについて（2021年8月5日現在）," *National Institute of Infectious Diseases of Japan*, Aug. 13,

2021. https://www.niid.go.jp/niid/ja/diseases/ka/corona-virus/2019-ncov/2484-idsc/10569-covid19-53.html (accessed Apr. 21, 2023).

[229] F. P. Polack *et al.*, “Safety and Efficacy of the BNT162b2 mRNA Covid-19 Vaccine,” *N. Engl. J. Med.*, vol. 383, no. 27, pp. 2603–2615, Dec. 2020, doi: 10.1056/nejmoa2034577.

[230] U.S. Food and Drug Administration, “Emergency Use Authorization (EUA) for an Unapproved Product Review Memorandum | Moderna COVID-19 Vaccine EUA FDA review memorandum,” *U.S. Food and Drug Administration Report*, Dec. 21, 2021. https://fda.report/media/144673/Moderna+COVID-19+Vaccine+review+memo.pdf (accessed Apr. 21, 2023).

[231] Immunization Office of Japan, “資料１　新型コロナウイルスワクチンの接種体制確保について　新型コロナウイルスワクチンの接種体制確保に係る自治体説明会（第４回）,” *Ministry of Health, Labour and Welfare of Japan*, Mar. 12, 2021. https://www.mhlw.go.jp/content/10906000/000752530.pdf (accessed Apr. 22, 2023).

[232] Immunization Office of Japan, “事務連絡　武田／モデルナ社ワクチンの接種体制について,” *Ministry of Health, Labour and Welfare of Japan*, May 24, 2021. https://www.mhlw.go.jp/content/000784140.pdf (accessed Dec. 31, 2022).

[233] Immunization Office of Japan, “資料１　新型コロナウイルスワクチンの接種体制確保について　新型コロナウイルスワクチンの接種体制確保に係る自治体説明会（第９回）,” *Ministry of Health, Labour and Welfare of Japan*, Nov. 17, 2021. https://www.mhlw.go.jp/content/10906000/000855688.pdf (accessed Mar. 22, 2023).

[234] NHK, “ワクチン「職域接種」が本格化（6/21）,” *NHK (Japan Broadcasting Corporation)*, Jun. 21, 2021. https://www3.nhk.or.jp/news/special/coronavirus/vaccine/japan_2021half/#mokuji17 (accessed May 02, 2023).