COVID-19 Network Technology-based Responsive Action (CONTRA)

Project report #1:

Requirements identification and system mapping

December 2020

The CONTRA project is funded by the Research Council of Norway, grant agreement No. 321773

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Preface

The project "COVID-19 Network Technology-based Responsive Action" (CONTRA) started in June 2020. This report summarizes the initial data collection and analysis to identify the COVID-19 vaccine distribution network characteristics in Norway. The CONTRA project aims to develop a decision support system to support public health responders to distribute the COVID-19 vaccine effectively, efficiently, sustainably, and fairly. This report mainly focuses on understanding the vaccine distribution network's potential challenges from vaccine distribution stakeholders' perspectives. Based on the information shared by stakeholders' representatives and a review of published reports by national authorities, we first map the actors in the vaccine distribution system. After that, we define the scope of the problem that the CONTRA team will address in the project's next steps. We are grateful to the professionals at public health authorities and partnered businesses who have contributed with their time and expertise, and look forward to further collaboration. The project is funded by the Research Council of Norway (agreement No. 312773).

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Abstract

The research project "COVID-19 Network Technology-based Responsive Action" (CONTRA), funded by the Research Council of Norway, commenced in June 2020. The CONTRA project develops a decision support system (DSS) based on mathematical modeling and stochastic optimization, and machine learning tools for designing a robust COVID-19 vaccine distribution network. The project follows two main objectives within two phases. In response to the on-going COVID-19 outbreak, rapid analyses will provide actionable advice to public health authorities in Norway regarding vaccine distribution and delivery to responders. This phase involved a systematic study of vaccine distribution system actors in Norway and their decision-making needs. Based on such insights, the project will develop a DSS based on mathematical models to support designing the vaccine distribution network. The DSS should contribute to the effectiveness, efficiency, equity, and sustainability of the COVID-19 vaccine distribution. The proposed solution will also support vaccine distribution in future pandemics.

The report describes the results of the first work package (WP) in the CONTRA project. The WP1 aims to identify the key actors in the vaccine distribution network in Norway, map their relation to each other, and distinguish critical decisions in the system. Moreover, the report presents an overview of related research on vaccine distribution networks, related decision support systems, and the progress in the literature about the COVID-19 pandemic. Through preliminary interviews, document review, and a workshop with multiple representatives from Norwegian public health authorities, the current vaccine distribution system is analyzed, and its actors have been mapped. This system map is the basis for further discussion both within the project team and with stakeholders. It should be noted that this map will change throughout the project due to the additional insights from other validation opportunities and the fact that the COVID-19 context is dynamic and is changing permanently. However, the system map has served as a basis for the problem definition in the CONTRA project.

Based on our findings from the stakeholder workshop and system mapping, we have decided to focus on defining and studying the central vaccine allocation problem (CVAP), which is faced by Public Health Institute (FHI). As such, the CONTRA will investigate the problem of determining

the amount of each vaccine to be shipped to every municipality. CVAP is challenged by the scarce amount of vaccines, the current immunization level, population, and priority groups in each municipality. In our project, CVAP will be formulated as a multi-objective resource allocation problem. Specifically, we will define and formulate objectives related to the following performance dimensions: efficacy (e.g., total coverage, coverage per priority group, etc.), efficiency and sustainability (e.g., logistics costs, waste), and fairness (e.g., distribution of efficacy among municipalities).

The next step in the project will be to validate the problem definition and develop the mathematical model (second work package). Moreover, two individual reports for the actors map and system map will be published in the upcoming months by project partners.

1. Introduction

1.1 About the CONTRA project

The project "COVID-19 Network Technology-based Responsive Action" (CONTRA) is funded by the *Collaborative and Knowledge-building Projects for the Fight Against Coronavirus Disease (COVID-19)* program[1] of the Research Council of Norway for the period June 2020 – December 2021.

The goal of the CONTRA project is to contribute to the effectiveness, efficiency, equity, and sustainability of the COVID-19 response. It aims to develop a generic decision support system (DSS) for pandemic responders as they attempt to enhance the resilience and responsiveness of national (i.e., in-country) vaccine supply chains. The objective of this project is to develop a DSS based on mathematical modeling and stochastic optimization (for supply uncertainty) as well as machine learning tools (for demand uncertainty) for designing a robust vaccine distribution network. We aim to learn from the current situation, the disease spread data, best practices, and strategies involved in Norway's response to COVID-19 to propose a generic methodology that can support supply chain decision-makers in public health response in both high- and low-income countries. Achieving this goal entails integrating knowledge and methods from different disciplines to conduct a systematic analysis of current practices and needs of decision-makers, identifying the parameters and decision variables of the COVID-19 vaccine supply chain problem, translating the characteristics of low-income countries to constraints, and developing tool support for collaborative information synthesis.

The project is led by the Centre for Integrated Emergency Management (CIEM) at the University of Agder (UiA), in collaboration with the following partners:

- Centre for Artificial Intelligence (CAIR) at UiA,
- School of Business and Law at UiA,
- Norwegian Centre for Transportation Research (TØI),

[1] https://www.forskningsradet.no/en/call-for-proposals/2020/covid-19-emergency-call-proposals-collaborative-and-knowledge-building-projects-for-the-fight-against-coronavirus-disease-covid-19/

- Research Center of the Access-To-Medicines (ATM) at the Katholieke Universiteit Leuven (KU Leuven),
- Industrial Engineering Department at the Ozyegin University (OU)
- Agens AS - developing the methodology and software for DSS

The project encompasses an interdisciplinary team of experts in disaster management, logistics, health system design, operations management, socio-technical systems, and computer science. End-user involvement is secured through a broad representation of core stakeholders of vaccine distribution in the project stakeholders' reference group (cf. Appendix A).

1.2 Aim and scope of report

The report describes the results of the first work package (WP) in the CONTRA project. The WP1 aims to identify the key actors in the vaccine distribution network in Norway, map their relation to each other, and distinguish critical decisions in the system. Moreover, the report presents an overview of related research on vaccine distribution networks, related decision support systems, and the progress in the literature about the COVID-19 pandemic. Based on the experts' insights and the literature gaps, this report introduces the scope and boundaries of the problem that the CONTRA project will try to address over the next months.

Several logistics challenges in the in-country vaccine distribution network can be recognized. Challenges range from locating storage facilities and administering points to allocating transportation means and vaccines to different facilities. However, the vaccine allocation-transportation problem stands in the center of the distribution network as representatives from public health authorities shared with us. The centrality is because (1) vaccines have to be allocated based on different (and conflicting criteria), (2) the impact of vaccine allocation on other decisions in the system is huge, and (3) the vaccine transportation can be complex depending on the size of allocated vaccines and the final destination. The CONTRA project will, therefore, focus on the COVID-19 vaccine allocation-transportation problem in the in-country distribution network. This choice means that the CONTRA project will not specifically cover some logistics challenges such as storing and/or administering vaccines.

We acknowledge that the focus of system mapping and problem identification conducted at WP1 has been on the Norwegian practice. However, we argue that the literature review has provided an additional basis for comparison with developments in other contexts. Furthermore, to account for divergences between the context of Norway and other countries as well as uncertainties in the distribution system, the project will investigate multiple scenarios in later stages. As documented in this report, the problem that CONTRA aims to investigate can be seen as a basis for possible adaption in many other countries, including middle- and low-income contexts.

1.3 Structure of the report

Section 2 provides a brief review of related research about vaccine distribution and the COVID-19 pandemic. The methods used for data collection and system mapping are presented in Section 3. Section 4 includes the findings. We conclude the report and point to further steps in the project in Section 5.

2. Related research

2.1 Vaccine distribution

Several researchers have analyzed the vaccine allocation and distribution in general and pandemic vaccine distribution in particular. Lee et al. (2011) explored the effect of introducing a new vaccine on the design and structure of the vaccine supply chain. The study considered the whole vaccine supply chain, including storage location, refrigerator, freezer, transport vehicle, warehouse, and clinics. The results demonstrated that additional transport and storage capacity is required to accommodate the new vaccine. In a similar study, Brown et al. (2014) explained that the restructuring of the downstream supply chain could significantly impact the cost and availability of the new vaccine. Re-designing the vaccine supply chain is also addressed by Shittu et al. (2016) by analyzing the effect of variation in supply and demand of vaccine on storage capacity in Nigeria. Their results confirm that the introduction of three more vaccine hub could reduce cold storage requirements. By taking Mozambique as a case study, Lee et al. (2016) explored the impact of re-designing the decades-old vaccine supply chain on the availability and cost of the vaccine. The results showed that by re-designing the distribution system, the availability of the vaccine could be increased, and logistics costs could be decreased compared to the existing system.

Lemmens et al. (2016) conduct a systematic literature review on the design of vaccine supply chains. Their study asserts that very few studies have considered uncertainties (through for instance scenario analysis (Portnoy et al., 2015)) when developing models to address the problem characteristics. Lemmens et al. (2016) also contend that while the efficiency and effectiveness criteria are essential in vaccine supply chains, such networks should account for sustainability, too. As such, Lemmens et al. (2016) suggest that the preferences of different stakeholders have to be taken into account for obtaining a set of economic, technological, and value key performance indicators that need to be satisfied by design. Moreover, a recent study confirms that considering multiple objectives, including the equity criterion, in vaccine supply chain models is of stakeholders' interest (Baharmand et al., working paper).

In the pandemic vaccine distribution, identifying and setting the priority group is an essential element. For instance, some researchers (Uscher-Pines et al. 2006; Buccieri and Gaetz, 2013; Davila-Payan et al. 2014; Huang et al. 2017; Govindan et al., 2020) made priority groups based on susceptibility, while Li et al. (2018) considered the factor exposure in setting the priority group. And finally, some studies (see Medlock and Galvani, 2009; Lee et al. 2012; Arazet al. 2012; Chen et al. 2020) combined both susceptibility and exposure to prioritize the people in vaccine allocation and distribution. Arora et al. (2010) explained that the vaccine's transshipment could reduce the excess supply in one county by transferring it to the region with a shortage of vaccine. A study by Fitzgerald et al. (2016) explained that formalized agreements between public health departments and pharmacies should be established to improve the pandemic vaccine supply chain's efficiency and effectiveness.

2.2 COVID-19 related research

The research related to COVID-19 is limited. Among the few, Govindan et al. (2020) developed a decision support system by applying the Mamdani fuzzy inference system (FIS). Their study's objective is to manage demand in the healthcare system and reduce the impact of the COVID-19 pandemic. They applied two criteria to set the priority groups. First, they divided the population into four categories based on their immune system (very sensitive, sensitive, slightly sensitive, and normal). Secondly, they used two factors that are age and pre-existing diseases, to classify them further. Their proposed decision support system extracted the information from the system to classify the recipients and then informed them about the kind of services they would get from health care workers. Finally, the real data was used to check the proposed decision support model. The results obtained from the simulation confirmed that the decision support system was authentic. Chen et al. (2020) addressed the issue of the optimal allocation design for the COVID-19 vaccine. They took New York City as a case study and grouped the population first into seven compartments. Then each compartment was further classified into five age-groups. They tested static and dynamic policies. Results demonstrated that the oldest group of the population should be prioritized over the younger group to mitigate the death rates. However, if the objective is to reduce the infected numbers, the younger people should be preferred. Appendix B presents different scenarios based on the literature review.

3. Methods

3.1 Preliminary interviews

We conducted interviews with representatives of the Directorate for Civil Protection (DSB), Ministry of Health and Care Services (HOD), Institute of Public Health (FHI), the County Governor for Vestfold and Telemark, and the Directorate for Civil Protection (DSB). The representatives were chosen for their knowledge of their organization’s role in distributing vaccines in Norway. Unstructured interviews were conducted so that we could explore, on an ad hoc basis, different aspects of the subject under analysis and follow up information on other key actors to invite to the system mapping workshop, as well as any useful resources such as contacts or documents (Stanton et al., 2013). Two of the researchers were present at all interviews. The interviews were conducted online, due to the pandemic situation, in August and September of 2020.

3.2 Document analysis

As a result of interviews, the following documents were retrieved reviewed to help map actors and actor relations for vaccine distribution in Norway:

- National plan for the health system's preparedness for a pandemic, emergencies prepared by the Ministry of Health and Care Services (HOD) (Nasjonal helseberedskapsplan, 2018).
- Review of experiences of the response to influenza A (H1N1) epidemic in Norway 2009 issued by the Directorate for Civil Protection (DSB, 2009)
- Plan for national preparedness in the event of an influenza pandemic, issued by the Institute of Public Health (FHI, 2014).
- Guidelines for mass vaccination against pandemic influenza I municipalities and regional health units, issued by the Institute of Public Health (FHI, 2016)
- Plan for regional preparedness in the south-east region of Norway (Helse Sør-Øst, 2020)

These documents also gave insight into guiding principles for the organization of vaccine distribution and emergency response in Norway. They will be summarized in a later report.

3.3 Workshop

On October 13th, 2020, a virtual workshop was held[2] led by Catherine Decouttere and Nico Vandaele of the ATM team of KU Leuven and connected the project team to a diverse set of Norwegian COVID-19 vaccine system stakeholders. It was technically supported by Agens[3], making use of Miro[4] to collect the information provided by the stakeholders as they spoke. Doing a group model building workshop online is not apparent. Therefore we organized according to a format with four consecutive brainstorm sessions. For each brainstorm session, we had the same structure: a short brief of the content, a list of guiding questions, time to brainstorm, and a debrief. The debrief was led by moderators and had a rolling sequence of the stakeholders to kick-off, taking into account their position with respect to the topic of the respective brainstorm. We followed the principle of information saturation for each debrief. Each additional stakeholder only adds elements that were not already mentioned in the Miro system. The format is shown in table 1:

[2] https://contrauia.wpengine.com/workshop1/
[3] https://agens.no/
[4] Miro is an online visual collaboration platform for teamwork accessible at http://miro.no

Table 1. Detailed workshop format and setup

Start	Finish	Activity	Theme	Coach
10.00	10.10	Opening	Welcome	Hossein, Ross
10.10	10.30	Introduction	Participants, goal and setup	Nico, Catherine
10.30	11.30	Brainstorm #1: 15-10-35	Covid19 System: Supply Side	Nico, Catherine
11.30	11.45	Break	Coffee	
11.45	12.45	Brainstorm #2: 15-10-35	Covid19 System: Demand Side	Nico, Catherine
12.45	13.30	Break	Lunch	
13.30	14.30	Brainstorm #3:15-10-35	Covid19 System: Supply meets Demand?	Nico, Catherine
14.30	14.45	Break	Coffee	
14.15	15.15	Brainstorm #4: 15-10-35	Decision Maker, Decision Support and Data	Nico, Catherine
15.45	16.00	Closing	Wrap-up & Next steps	Hossein, Ross

Now we review the content-wise aspects of the four brainstorming sessions very briefly:

1. Brainstorm #1 - Covid19 system: the supply side

Starting from a generic immunization system map, the Covid19 perspective and the Norwegian setting, the following questions were presented:

   a. Where do I see my role?
   b. Given my role and contribution, what are the major challenges, problems, bottlenecks I foresee?
   c. Are there any other challenges, problems, bottlenecks in the system beyond my role?
   d. Can you share the source of your thoughts? Experience? Reports? References?

2. Brainstorm #2 - Covid19 system: the demand side

   Starting from the WHO priority guidelines as the base case, meaning first nurses, social workers; second elderly, people with comorbidities and specific local risks; third additional priorities (police, civil servants), the following questions were presented:

   a. Is the base case feasible/relevant for Norway?
   b. How are these populations characterized?

- Physical: size, location, accessibility
- Human behavior: willingness, hesitancy, vulnerability
- Societal aspects: transmission in school, pubs, work, travel, etc.

c. What is the heterogeneity with respect to time and geography for these populations?

d. Is there a need for a diversified approach, e.g., to improve the willingness to vaccinate?

3. Brainstorm #3 - Covid19 system: supply meets demand

Starting from the in-country supply system and the Norwegian setting, we continued the following questions:

a. Where does the supply system meets demand: nurses? Elderly, comorbidities, local risk, priority 'X'?
b. What are the physical constraints? Doses vs. patients (volume)? Cold chain (freeze, fridge, ambient, etc.)?
c. Goals concerning balance supply and demand?
d. If demand is smaller than supply (hesitancy, no-show, etc.), what are the action options? Recall? Lateral shipments?
e. What are the action options if demand is more significant than supply (time-phased shortage, etc.)? Allocation? Geographical priorities?
f. For balancing demand and supply under uncertainties, what are the action options? Pooling? Postponement? Immediate shipment?

For this purpose, the stakeholders used a schematic supply and demand visuals, as shown in Figure 1.

4. Brainstorm #4 - Covid19 system: supply and demand related decision making

Starting from the in-country supply system, demand system, and the connection between supply and demand, we presented the following questions:

a. Where is the decision-maker positioned?

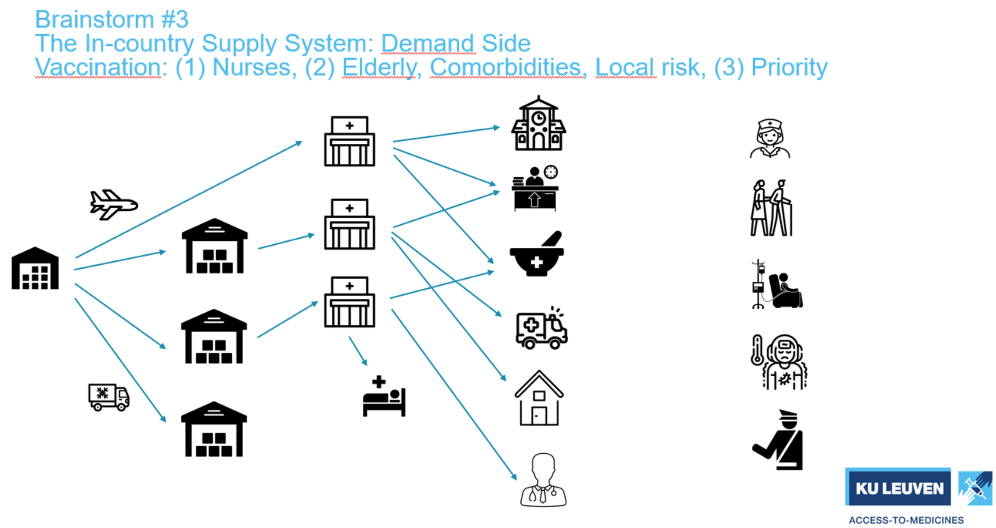


Figure 1. Schematic representation of supply- and demand-side key elements

b. Is it a single person or a group?

c. Where is the control nexus: national, regional, municipal, etc.?

d. Essential links with subsystems, stakeholders, etc.?

a. What are the supply system performance metrics needed for Covid19?

   a. Which ones are already there? SYSVAK?

   b. Which ones are new? Specific populations?

b. Where can we track these?

   a. What do you want to see on the dashboard?

   b. Do you know data sources to serve this?

c. With respect to the current/new metrics: timely, efficient, feasible, etc.?

d. Think about:

   a. What can be decided? What's the degree of decision freedom?

   b. What's the objective? Can we measure his?

   c. What are the limitations? Can we track these?

   d. How do you want to see the impact of decisions?

e. Resilience as a response to uncertainties

   a. Does the supply system meet demand: nurses? Elderly, comorbidities, local risk? Priority 'X'?

All these answers have been recorded in the Miro system, first by two independent observers of Agens, then complemented by two researchers from ATM.

4. Findings

4.1 Actor map

Based on notes from interviews and review of documents, a map of actors and actor relations was drawn based on principles for mapping control structure in complex socio-technical systems (Leveson, 2012). The map was sent out to workshop participants for review and comment prior to the workshop. Figure 2 was reviewed in the workshop and subsequently modified. The version presented here is subject to further development as the project progresses.

The Actor Map describes the control structure in the *system* under study. The system is defined as the collection of people, organizations, technology, and procedures aiming to distribute vaccine in Norway in line with government goals. The Actor Map was prepared to 1) Analyze ways in which the system might fail to achieve its goals, to be reported later; 2) Inform the System Dynamics Map (see below).

In Figure 2, a downward arrow signifies purposeful action taken to influence the object (person, organization, plans, technology) described underneath the arrow. The action may be policy, procedures, communications, or a physical act, such as the delivery of the vaccine, storage equipment, and so on. Information to the left of a downward arrow describes the purposeful action. For example, a municipality may give its population (or subgroups of its population) an offer of vaccination with information about when and where they can be vaccinated.

An upward arrow in Figure 2 describes data, knowledge, awareness, etc., informing purposeful action. Information to the right of an upward arrow describes the nature of the information provided. For example, a municipality informs FHI about the number of people in priority groups in that municipality. A sideways arrow describes information flows that do not directly inform purposeful action.

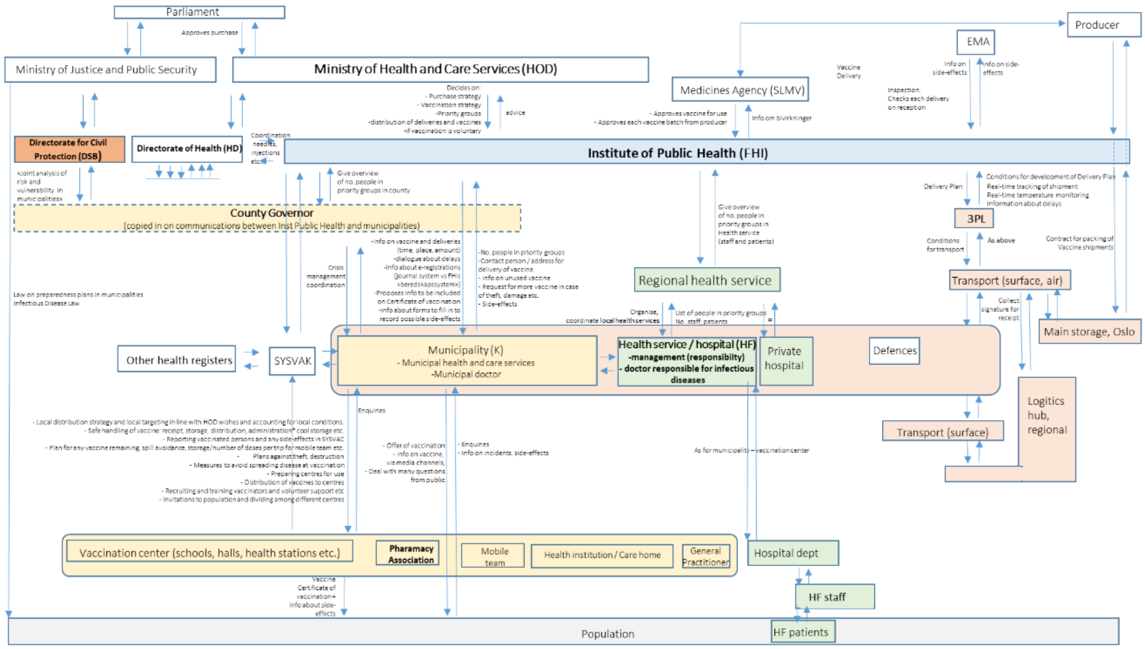


Figure 2[5]. Illustration of actors and actor relationships involved in the distribution of vaccine in Norway. Draft version subject to change. 3PL = third-party logistics company, EMA = European Medicines Agency, SYSVAK = database for registering of vaccination data. Acronyms in brackets following actor names are the Norwegian acronyms in common use in Norway. Otherwise, see the text for an explanation.

Here we give a short description of the Actor Map, to be elaborated on in later reports.

Actions and information flows in the Actor Map are underpinned by the following four guiding principles for emergency preparedness in Norway (Nasjonal helseberedskapsplan, 2018):

- Responsibility – the organization with responsibility for a professional domain or service in a normal situation is also responsible for the necessary preparations for dealing with extraordinary incidents.
- Proximity – the incident should be handled by the people or organizations closest to the incident.
- Likeness – Organizations established in crises should resemble those used to organize normal operations.

[5] Full-size photo in Appendix C

- Cooperation – All organizations have an independent responsibility to ensure the best possible effect is achieved by collaborating with other key actors.

In line with these principles, municipalities and local health authorities are given considerable autonomy and responsibility for organizing vaccination and regional vaccine distribution.

Starting at the top of Figure 2, the Norwegian Parliament approves (decisions on) vaccine purchase and prioritization formulated by the Ministry of Health and Care Services (HOD). In the case of COVID-19, a working group has been set up, which includes FHI and the Directorate of Health (HD). HD arrange syringes, needles, and other equipment needed as part of vaccine response and coordinate with FHI on this. FHI is the central high-level actor for the vaccine distribution system. They also give scientific advice to health authorities (HD, HOD) on which groups should be prioritized and advise vaccine distribution strategies. FHI is responsible for vaccine receipt and distribution, following approval of the vaccine by the Medicines Agency (SLMV). FHI arranges for vaccine storage, packing, and distributing the vaccine to each of Norway's 356 municipalities using a third-party logistics company. FHI communicates with each municipality or local health authority directly, informing about the delivery of vaccine and providing information about the vaccine characteristics, dosage, etc., and receiving back information on local populations (e.g., how many in risk group in each municipality) data on vaccine efficacy and side-effects.

Each municipality is responsible for recruiting and training vaccinators, organizing administration infrastructure, and many other tasks. Other tasks may include informing the vaccine and vaccination process, issuing vaccination certificates, and recording data in the national vaccination database SYSVAK. Municipalities also receive and deal with information and inquiries from its population. Hospitals perform parallel tasks in arranging for the vaccination of their staff and patients. Although we have included Pharmacy Associations as part of the civil infrastructure for vaccine distribution, these are the particular case in that they may purchase vaccines independently of distribution through the municipality.

The county governor is responsible for coordinating and overseeing vaccination distribution and administration across the municipalities in its area, communicating with FHI on issues and strategies. Regional health authorities perform parallel tasks for their local health administrations.

4.2 System map

As explained in Section 3.3 on the workshop outline, the System Actors map was the basis for organizing the workshop both from a content and a practical point of view. The information from all the brainstorming sessions and subsequent discussions was captured in the Miro map, shown in Figure 3. This Miro sticky notes map is vertically arranged per stakeholder and horizontally per brainstorm session. Based on these insights, the ATM constructed a first system map in the format of a Stock-Flow Diagram (SFD). Subsequently, this Stock-Flow Diagram has been validated by the entire project team.

The system map is visualized in Figure 4. This map is the basis for further discussion both within the project team and with stakeholders. It should be noted that this map will change over the course of the project, not only due to the additional insights from further validation opportunities but also because the COVID-19 context is dynamic and is changing permanently. However, this system map serves as a basis for the problem definition in the next section.

4.3 Problem definition

Based on our findings from the stakeholder meetings and system mapping, the project team has decided to focus on defining and studying the *central vaccine allocation problem* (CVAP). This problem concerns the role of FHI in the vaccine distribution network. While we are still in the process of framing the CVAP, here, we provide an initial description.

The Covid-19 vaccine supplies are expected to arrive in the country in multiple waves (i.e., shipments spread over time). One or multiple types of vaccines, each with different characteristics (e.g., in terms of volume, cold storage and transportation requirements, doses, etc.), may arrive in each wave, which is uncertain at the time being. Upon arrival, the vaccines, which will be stored in the national storage point, must be allocated among the municipalities and distributed within the country. The FHI needs to determine the number of vaccines (and what type) to ship to each municipality.

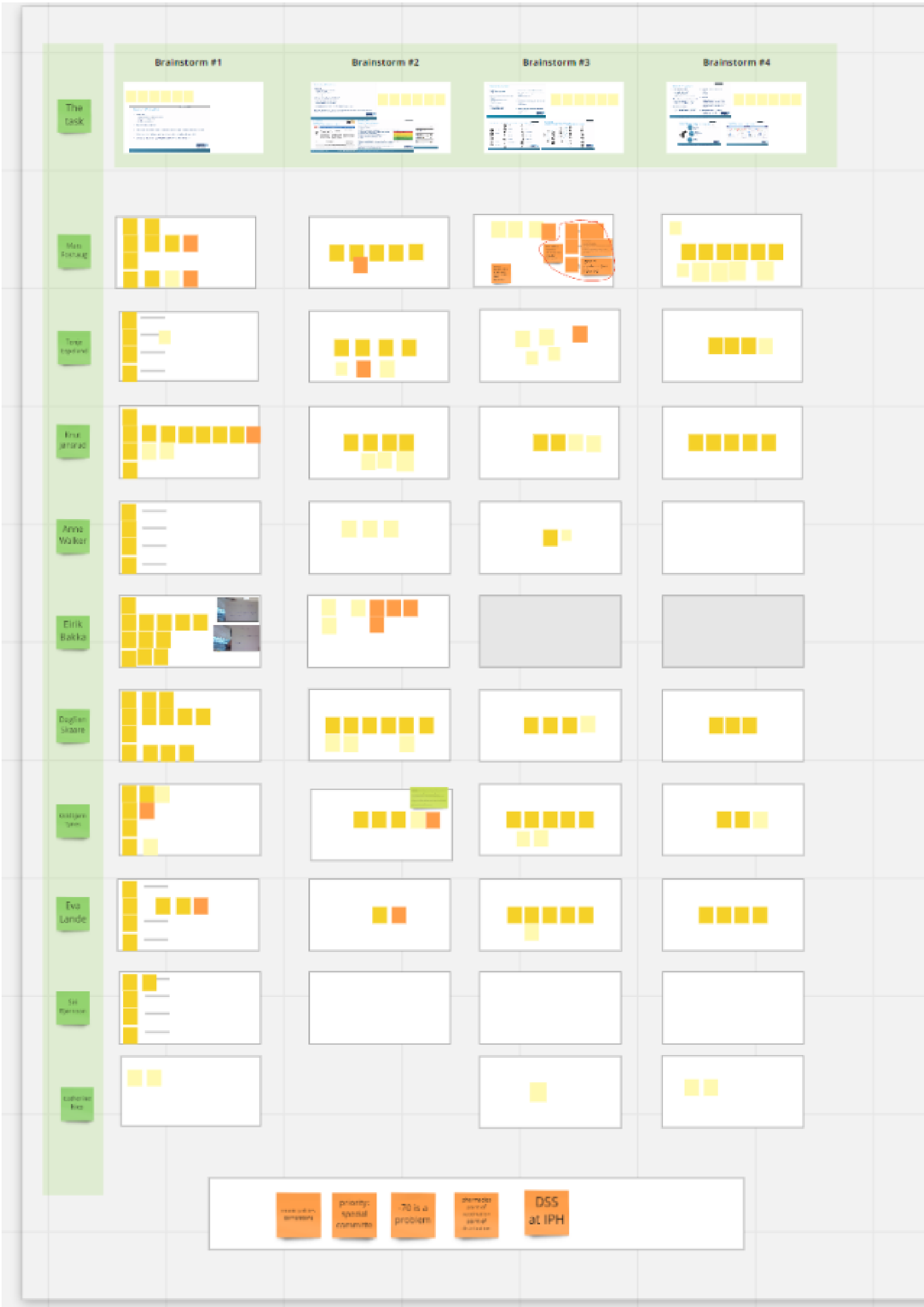


Figure 3. Screenshot from the Miro workshop output data

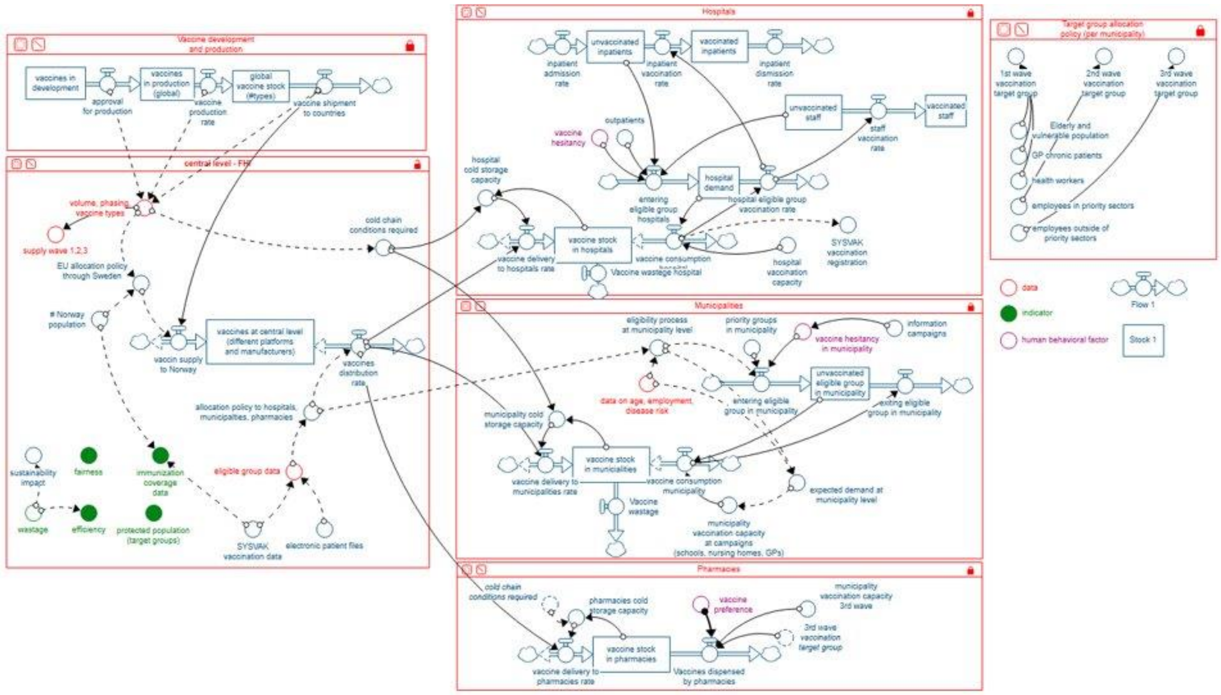


Figure 4[6]: Stock-flow Diagram serving as a system map

Our stakeholder meeting revealed that the 3PL company, which will be responsible for transporting the vaccines within the country, has enough capacity (or will be able to increase its logistics capacity to desired levels) to handle the distribution. Therefore, in CVAP, we initially focus on the allocation decision at the FHI. Moreover, since the characteristics of local distribution of vaccines within a municipality may show significant differences across municipalities, it is challenging to design a standardized decision support tool that can be applied by every municipality (generalizability problem). Therefore, the CVAP does not address how the vaccines will be delivered in the last mile (within each municipality).

There are 356 municipalities in Norway, which differ in size, population, priority groups, and distance to the national storage point. The allocation-transportation of available vaccines to municipalities is challenging due to uncertainties in demand and supply, different characteristics and requirements of vaccines, and multiple goals, which may conflict with each other. Given that

[6] Full-size photo in Appendix D

the volume of vaccine available will be scarce compared to total needs, effective prioritization among different population groups (such as health care personnel, chronic patients, elderly and vulnerable groups, employees in priority sectors, etc.) will be necessary. Which population group to target in each supply arrival must be decided by FHI.

Given the scarce amount of vaccines, the current immunization level, population, and priority groups in each municipality, CVAP (which allocates vaccines to the municipalities) will be formulated as a multi-objective resource allocation problem. Specifically, we will define and formulate objectives related to the following performance dimensions:

- efficacy (e.g., total coverage, coverage per priority group, etc.),
- efficiency and sustainability (e.g., logistics costs, waste), and
- fairness (e.g., distribution of efficacy among municipalities).

The different objectives interact, and it is valuable to study tradeoffs among them.

5. Conclusions and next step

This report summarizes the activities carried out under work package one (WP1) of the project "COVID-19 Network Technology-based Responsive Action" (CONTRA). The objective of the CONTRA project is to support the decision-makers at public health authorities to design an effective, efficient, sustainable, and fair COVID-19 vaccine distribution network. To achieve this goal, WP1 aims to identify the main stakeholders involved in the vaccine distribution network in Norway, map their relationship, and explore critical decisions in the system.

As a first step, the five key stakeholders such as the Directorate for Civil Protection (DSB), Ministry of Health and Care Services (HOD), Institute of Public Health (FHI), the County Governor for Vestfold and Telemark, and the Directorate for Civil Protection (DSB) were selected for the unstructured interviews. The interviews' outcome was three-fold: first, it helped us find the relevant material on vaccine distribution and emergency response in Norway. Second, other prominent actors in vaccine distribution in Norway were identified based on the insights derived from the interviews. Moreover, an Actors Map was developed, and stakeholder representatives were invited to the system mapping workshop.

The Actors Map confirms that the system for vaccine distribution in Norway is a complex socio-technical system (Vicente, 1999) because: (1) it is a system with a large problem space, (2) it involves several actors working together with a strong need for effective communication and coordination, (3) the actors have different perspectives on the system, different goals, and values, (4) actors are in distributed locations, (5) there are coupled subsystems influencing each other (e.g., transportation and vaccine administration), (6) the system is highly dynamic, and there are several changing parameters from day to day, (7) the system includes mediated interaction (e.g., from FHI to population via the municipalities), and (8) the system is highly subject to disturbances. Further working on the Actor Map is one of the next steps in the project.

A virtual workshop was organized, and representatives from eight different organizations participated in the workshop. Before the workshop, the Actors Map was sent to workshop participants for review Based on the feedback, the map was revised. During the workshop, the stakeholders participated in four consecutive brainstorm sessions. These four sessions covered the following aspects of the COVID-19 system: supply side, demand side, supply meets demand, and decision making related to supply and demand. The system map that was the basis for organizing the workshop pointed towards decision support needs and problem definition. The findings of the workshop revealed vital opportunities and challenges for the Norwegian in-country COVID-19 supply system. Preparing a full report from the workshop findings is another next step in the project.

One key finding from the workshop was that there are multiple decision-making points when designing a vaccine distribution network. However, CONTRA project's limited time, we found that we cannot model the whole system, but only a part of it. Yet, the selected decision will inevitably influence the entire distribution network as both maps clearly depict.

That said, the project team has decided to focus on defining and studying the central vaccine allocation problem (CVAP). This problem concerns the role of FHI in the vaccine distribution network. Upon vaccine(s) arrival, they must be allocated to the municipalities and distributed within the country. The FHI needs to determine the number of vaccines (and what type) to ship to each municipality. The project's future steps include defining the relevant performance metrics and finalizing the problem definition of CVAP. We will then develop a mathematical model for the CVAP, which will be incorporated within a decision support system in WP3.

Compared with the previous literature, the main contribution of CONTRA will be to develop a decision support system that accounts for tradeoffs in distributing the COVID-19 vaccine. For practice, a working group at FHI is working on the priority list for the COVID-19 vaccine distribution in Norway. However, an extensive set of scenarios that can hamper delivery to target points is missing. The workshop findings supported some of the literature-derived scenarios (see Appendix B), such as excess demand, excess supply, vaccine batch size, challenges associated with transport and cold storage, and recruiting of service providers. More investigation of potential scenarios is another next step in the project.

Appendix A

Table A1. Focus group members

Organization	Representative role
Norwegian Institute of Public Health	Head Vaccine Supply Unit
Ministry of Health and Care Services	Senior Advisor, Infectious Diseases
Norwegian Directorate for Civil Protection	Senior Advisors
Norwegian Directorate of Health	Former decision-maker involved in vaccine distribution in 2009 pandemic
Country Governor, Vestfold & Telemark	Assistant County Doctor
Vestfold Hospital	Chief Physician, Infectious Disease Section and Head of Civil Defense
Pharmacy Association	Director of Business Policy
World Couriers (3rd party logistics service provider)	Project Coordinator

Appendix B

Table B1: Different scenarios based on the literature review

Scenario			References
1.		*Different priority group:*	
	i.	Health-care workers, essential services, people in high risk, children, elderly, key decision makers, influenza cases, hospitalized cases and unvaccinated	Uscher-Pines et al. (2006[7])
	ii.	Homeless individuals.	Buccieri and Gaetz, 2013
	iii.	Children (6 months to 17 years) and high-risk adults (25-64 years).	Davila-Payan et al. (2014)
	iv.	17 age groups (ages 0, 1 to 4; 5 to 9; 10 to 14; ...,70 to 74; and 75 and older).	Medlock and Galvani (2009)
	v.	6 age groups (1 = 0–5 yr, 2 = 6–12 yr, 3 = 13–19 yr, 4 = 20–39 yr, 5 = 40–59 yr, 6 = >60 yr).	Lee et al. (2012)
	vi.	Preschool age children (0–4 years), school age children (5–19 years), adults (20–64 years) and older adults (65+ years).	Araz et al. (2012)
	vii.	Prioritized people who came to receive their second doses over persons who were receiving their first doses.	Biggersta et al. (2015)
	viii.	Pregnant women, infants (0-3 years old); people between age 4-24; and	Huang et al. (2017)

[7] This grouping is based on review of pandemic influenza prioritization plan of different countries. The results show that countries gave top prioritization to high risk individuals, followed by health care workers and service workers.

	adults at high risk and infant caregivers.	
	ix. Four categories based on the risk level of their immune system (very sensitive, sensitive, slightly sensitive, and normal).	Govindan et al. (2020)
	x. Seven compartments (susceptible, exposed, presymptomatic infectious, unascertained infectious, ascertained infectious, isolated, and removed) and five age group (0-17, 18-44, 45-64, 65-74 and 75+).	Chen et al. (2020)
2	Excess demand (limited resources to meet the demand)	Majority literature addressed the situation of excess demand except Arora et al. (2010) who considered excess supply in the form of transshipment between the counties.
3	Excess supply When vaccine is available perhaps people would not be willing to get vaccinated.	See https://qz.com/1928206/the-countries-most-willing-to-take-a-covid-19-vaccine/
4	Transshipment between the counties/regions (excess supply in one county/municipality can be transferred to the region with shortage of vaccine.	Arora et al. (2010)
5	Vaccine pack size	Abrahams and Ragsdale (2012)
6	*Structure of the pandemic vaccine supply chain and possibility to restructure it (hypothetical scenarios):* A typical pandemic vaccine supply chain consists of a four-level delivery system that are i). the national depot, ii). department stores and one regional store,	Brown et al. (2014)

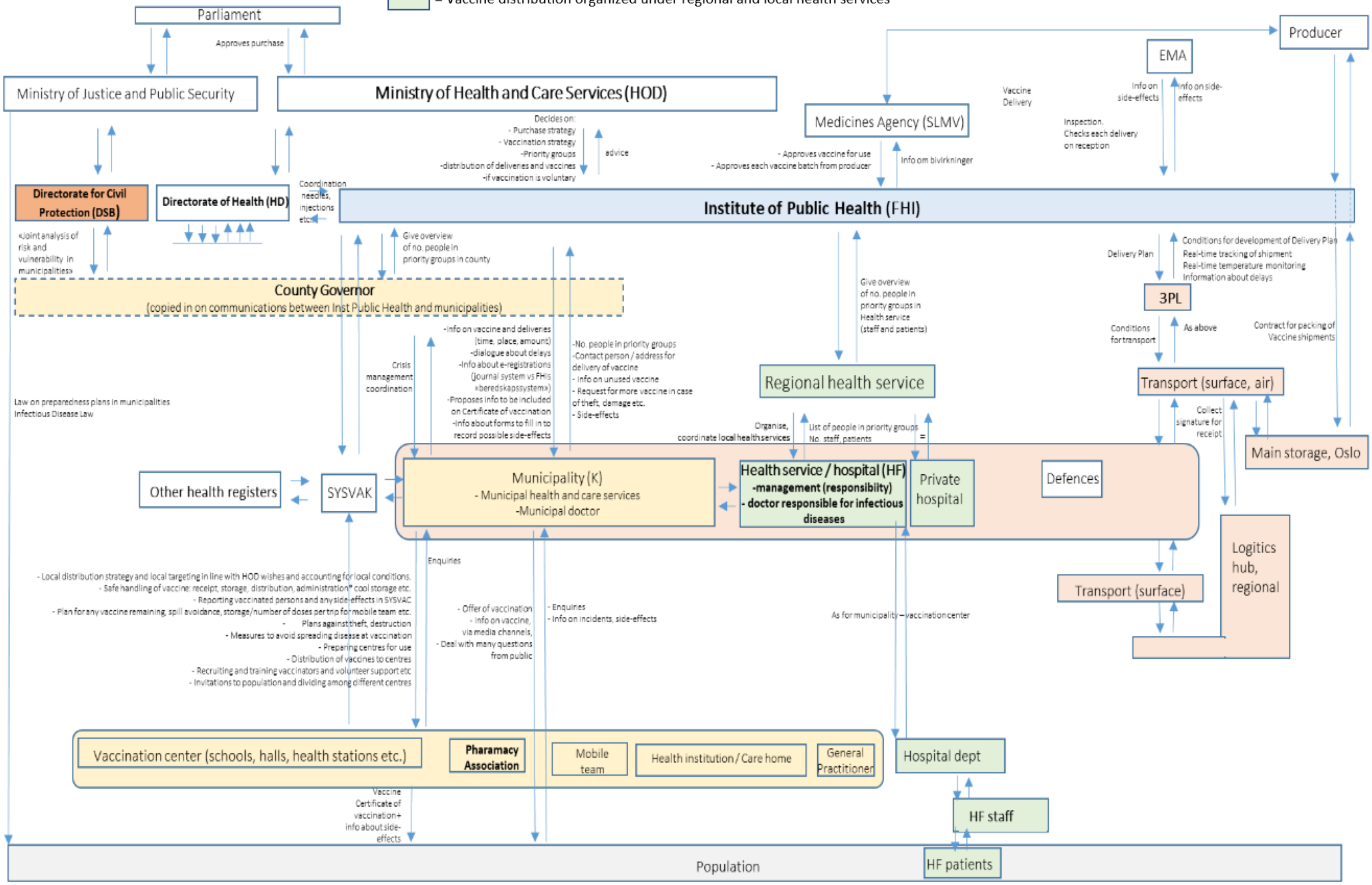
	iii). commune stores, and iv). hundreds of health centres (Brown et al. 2014). *Brown et al (2014) considered the following hypothetical restructuring:* (a) the commune is consolidated to a health zone, (b) the commune level is completely removed (reducing the four level delivery system to three levels), and (c) the removal of commune level but increasing the department store by 12 (this also reduces the four-level delivery system to three levels)).	
7	Close collaboration between the health care service providers, the government agency and other players (Pharmacies)	HHS (2005) Marcello et al. (2014) Fitzgerald et al. (2016)
8	Transport and cold storage capacity	Lee et al. (2012) Shittu et al. (2016)
9	Rapid spoilage upon opening	Abrahams and Ragsdale (2012)
10	Waiting times for vaccines	Araz et al. (2012)
11	Location of vaccination venue	Davila-Payan et al. (2014)
12	Pull based strategy vs Push based strategy	Huang et al. (2017)
13	Recruiting and preparedness training programs for vaccine service providers	Seib et al. (2012)
14	Vaccine inventory status	Li et al. (2018)

Appendix C

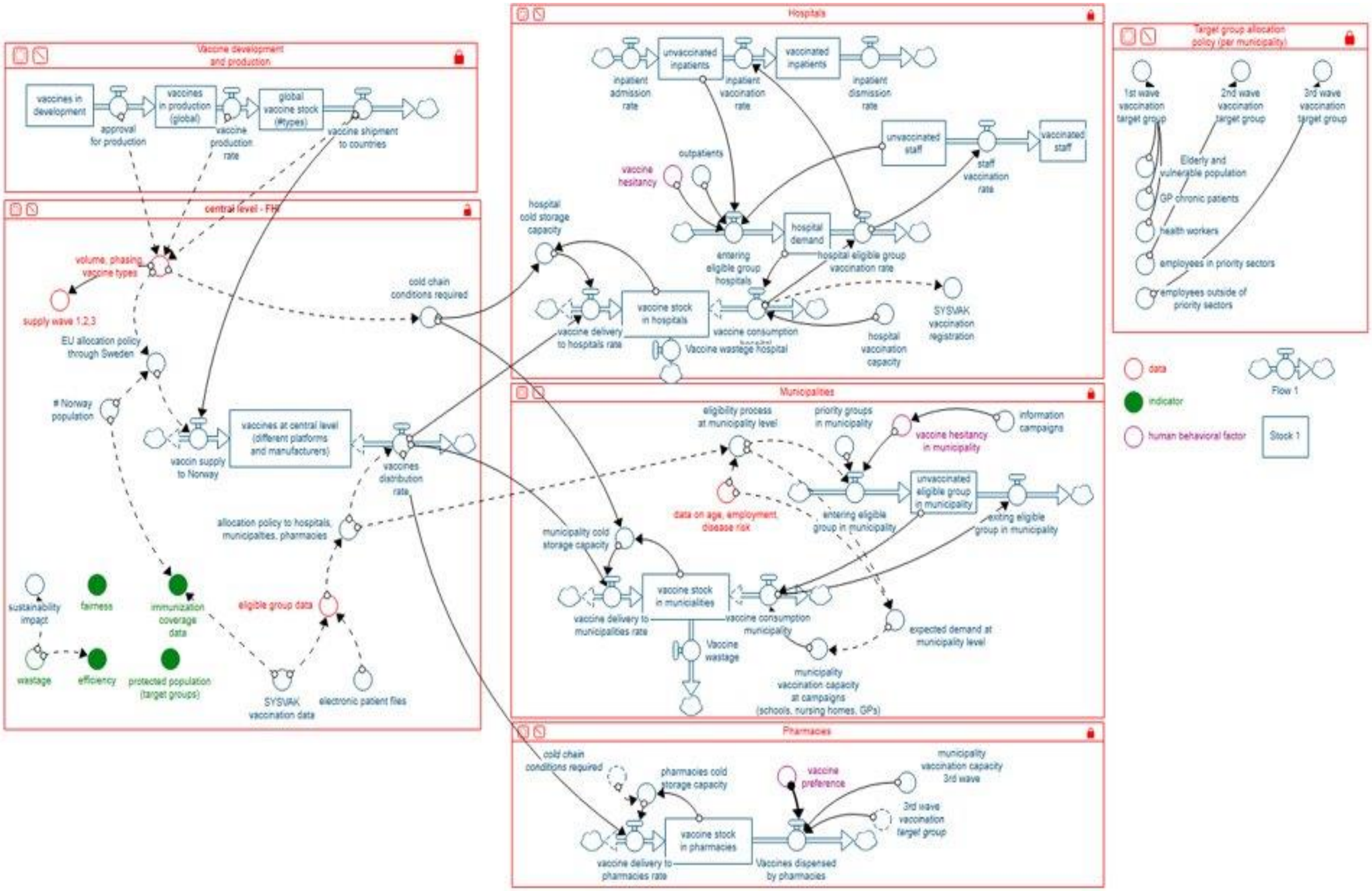
= Transport of vaccine from central to regional and municipal areas

= Vaccine distribution organized under regional and local government

= Vaccine distribution organized under regional and local health services



Appendix D



Vaccine development and production
vaccines in development
approval for production
vaccines in production (global)
vaccine production rate
global vaccine stock (#types)
vaccine shipment to countries
central level - FHI
volume, phasing vaccine types
supply wave 1,2,3
cold chain conditions required
EU allocation policy through Sweden
Norway population
vaccin supply to Norway
vaccines at central level (different platforms and manufacturers)
vaccines distribution rate
allocation policy to hospitals, municipalities, pharmacies
sustainability impact
fairness
immunization coverage data
eligible group data
wastage
efficiency
protected population (target groups)
SYSVAK vaccination data
electronic patient files
Hospitals
unvaccinated inpatients
vaccinated inpatients
inpatient admission rate
inpatient vaccination rate
inpatient dismission rate
unvaccinated staff
vaccinated staff
staff vaccination rate
outpatients
vaccine hesitancy
hospital cold storage capacity
hospital demand
entering eligible group hospitals
hospital eligible group vaccination rate
vaccine stock in hospitals
vaccine delivery to hospitals rate
vaccine consumption
Vaccine wastege hospital
hospital vaccination capacity
SYSVAK vaccination registration
Target group allocation policy (per municipality)
1st wave vaccination target group
2nd wave vaccination target group
3rd wave vaccination target group
Elderly and vulnerable population
GP chronic patients
health workers
employees in priority sectors
employees outside of priority sectors
data
indicator
human behavioral factor
Flow 1
Stock 1
Municipalities
eligibility process at municipality level
priority groups in municipality
vaccine hesitancy in municipality
information campaigns
data on age, employment, disease risk
entering eligible group in municipality
unvaccinated eligible group in municipality
exiting eligible group in municipality
municipality cold storage capacity
vaccine stock in municialities
vaccine delivery to municipalities rate
vaccine consumption municipality
Vaccine wastage
expected demand at municipality level
municipality vaccination capacity at campaigns (schools, nursing homes, GPs)
Pharmacies
cold chain conditions required
pharmacies cold storage capacity
vaccine preference
municipality vaccination capacity 3rd wave
3rd wave vaccination target group
vaccine stock in pharmacies
vaccine delivery to pharmacies rate
Vaccines dispensed by pharmacies

References

Araz, O.M., Galvani, A., Meyers, L.A., (2012). Geographic prioritization of distributing pandemic influenza vaccines. Health Care Management Science 15, 175-187.

Arora, H., Raghu, T., Vinze, A., (2010). Resource allocation for demand surge mitigation during disaster response. Decision Support Systems 50, 304-315.

Baharmand, H., Maghsoudi, A., & Moshtari, M. (Working paper). Integration of volunteer communities into a multi-criteria logistics model for pandemics response: insights from COVID19 pandemic in Iran. Submitted for publication.

Brown, S.T., Schreiber, B., Cakouros, B.E., Wateska, A.R., Dicko, H.M., Connor, D.L., Jaillard, P., Mvundura, M., Norman, B.A., Levin, C., et al., (2014). The benefits of re-designing benin's vaccine supply chain. Vaccine 32, 4097-4103.

Buccieri, K., Gaetz, S., (2013). Ethical vaccine distribution planning for pandemic influenza: Prioritizing homeless and hard-to-reach populations. Public Health Ethics 6, 185-196.

Chen, X. Li, M. Simchi-Levi, D. Zhao, T. (2020). Allocation of covid-19 vaccines under limited supply, Available at SSRN 3678986.

Davila-Payan, C., Swann, J., Wortley, P.M., (2014). System factors to explain 2009 pandemic h1n1 state vaccination rates for children and high-risk adults in us emergency response to pandemic. Vaccine 32, 246-251.

DSB (2010). RAPPORT: Ny influensa A (H1N1) 2009. Gjennomgang av erfaringene i Norge. 2. utgave, november 2010. https://www.dsb.no/rapporter-og-evalueringer/ny-influensa-a-h1n1-2009---gjennomgang-av-erfaringene-i-norge/ ISBN-978-82-7768-239-6.

FHI (2014). Nasjonal beredskapsplan pandemisk influensa. 23. Oktober 2014. https://www.regjeringen.no/no/aktuelt/ny-nasjonal-beredskapsplan-mot-pandemisk-influensa/id2354619/

FHI (2016). Planveileder for massvaksinasjon mot pandemisk influensa i kommuner og helseforetak. Utaarbeidet av Folkehelseinstituttet, i samarbeid med Helsedirektoratet og Statens legemiddelverk. https://www.regjeringen.no/no/dokumenter/nasjonal-beredskapsplan-pandemisk-influensa/id2354614/ ISBN 978-82-8082-733-3

Fitzgerald, T.J., Kang, Y., Bridges, C.B., Talbert, T., Vagi, S.J., Lamont, B., Graitcer, S.B., (2016). Integrating pharmacies into public health program planning for pandemic influenza vaccine response. Vaccine 34, 5643-5648.

Govindan, K., Mina, H., Alavi, B., (2020). A decision support system for demand management in healthcare supply chains considering the epidemic outbreaks: A case study of coronavirus disease 2019 (covid-19). Transportation Research Part E: Logistics and Transportation Review 138, 101967.

Helse Sør-Øst (2020). Regional beredskapsplan for Helse Sør-Øst: Styrebehandlet i Helse Sør-Øst RHF, 5. februar 2020. Retrieved from www.helse-sorost.no 2/9/20.

HHS. (2005). U.S. Department of Health and Human Services, HHS Pandemic Influenza Plan, 2005. URL: https://www.cdc.gov/flu/pdf/professionals/hhspandemicinfluenzaplan.pdf?fbclid=IwAR0KGbTVDQj2SovXHddSNa3k8kRj5_3IJD988kqDfQF5Rvxu1sFDTITtmPE.

Huang, H.C., Singh, B., Morton, D.P., Johnson, G.P., Clements, B., Meyers, L.A., (2017). Equalizing access to pandemic in vaccines through optimal allocation to public health distribution points. PloS one 12, e0182720.

Lee, B.Y., Assi, T.M., Rookkapan, K., Wateska, A.R., Rajgopal, J., Sornsrivichai, V., Chen, S.I., Brown, S.T., Welling, J., Norman, B.A., et al., (2011). Maintaining vaccine delivery following the introduction of the rotavirus and pneumococcal vaccines in Thailand. PloS one 6, e24673.

Lee, S., Golinski, M., Chowell, G., (2012). Modeling optimal age-specific vaccination strategies against pandemic in Bulletin of mathematical biology 74, 958-980.

Lee, B.Y., Haidari, L.A., Prosser, W., Connor, D.L., Bechtel, R., Dipuve, A., Kassim, H., Khanlawia, B., Brown, S.T., (2016). Re-designing the Mozambique vaccine supply chain to improve access to vaccines. Vaccine 34, 4998-5004.

Lemmens, S., Decouttere, C., Vandaele, N., & Bernuzzi, M. (2016). A review of integrated supply chain network design models: Key issues for vaccine supply chains. Chemical Engineering Research and Design, 109, 366-384.

Leveson, N. (2011). Engineering a safer world. Systems engineering applied to safety. MIT Press, Cambridge, MA.

Li, Z., Swann, J.L., Keskinocak, P., (2018). Value of inventory information in allocating a limited supply of influenza vaccine during a pandemic. PloS one 13, e0206293.

Medlock, J., Galvani, A.P., (2009). Optimizing influenza vaccine distribution. Science 325, 1705-1708.

Nasjonal helseberedskapsplan (2018). Nasjonal helseberedskapsplan Fastsatt 1. januar 2018. https://www.regjeringen.no/no/dokumenter/a-verne-om-liv-og-helse/id2583172/

Portnoy, A., Ozawa, S., Grewal, S., Norman, B. A., Rajgopal, J., Gorham, K. M., ... & Lee, B. Y. (2015). Costs of vaccine programs across 94 low-and middle-income countries. Vaccine, 33, A99-A108.

Shittu, E., Harnly, M., Whitaker, S., Miller, R., (2016). Reorganizing Nigeria's vaccine supply chain reduces need for additional storage facilities, but more storage is required. Health Affairs 35, 293-300.

Stanton, N.A., Salmon, P.M., Rafferty, L.A., Walker, G.H., Baber, C. & Jenkins, D.P. (2013). Human Factors Methods. 2nd Edition. CRC Press, Boca Raton FL.

Uscher-Pines, L., Omer, S.B., Barnett, D.J., Burke, T.A., Balicer, R.D., (2006). Priority setting for pandemic influenza: an analysis of national preparedness plans. PLOS medicine 3, e436.

Vicente, K. (1999). Cognitive Work Analysis. Toward safe, productive and healthy computer-based work. New Jersey: LEA.