Institute of Transport Economics
Norwegian Centre for Transport Research

COVID-19 Vaccine Roll-out by Local Authorities in Norway

Challenges to decision-making

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Short Summary

Between January and September 2021, over 350 local authorities were charged with rolling out COVID-19 vaccine to their populations under demanding conditions. This report identifies seven common challenges to decision-making based on the analysis of interviews with 14 people in key roles in nine different local authorities. Main challenges involved deciding how many doses to extract from vials, how to prioritize patients, and how to cope with changing recommendations on dose intervals. From analysis of the interviews, we also abstract 16 system functions that local authorities must control to roll out vaccine successfully. These functions can help in preparedness for future pandemics or act as the basis for improvements to future vaccine roll-out systems. Based on our collective findings, we present ideas on how central authorities and advisors might support local-level decision making and adaptation in future emergency roll-out situations.

Sammendrag

I perioden januar til september 2021 måtte over 350 kommuner rulle ut koronavaksine under krevende forhold. Denne rapporten identifiserer sju utfordringer til beslutningstaking, basert på intervjuer med 14 personer med nøkkelroller i ni kommuner eller bydeler. Hovedutfordringer var uttrekking av doser fra hetteglass, prioritering av pasienter og håndtering av endringer i anbefalte doseintervaller. Vi identifiserer også 16 funksjoner som lokale myndigheter må kontrollere for å lykkes med utrulling av vaksine. Disse funksjonene kan inspirere de som er ansvarlig for beredskap for framtidige pandemier. Basert på våre samlede funn, kommer vi med forslag på hvordan myndigheter og rådgivere kan støtte beslutningstaking på lokalt nivå i lignende situasjoner i framtiden.

Preface

The CONTRA project (https://contra.uia.no/) ran from the summer of 2020 to April 2022, and was financed by the Research Council of Norway's emergency call for research on the COVID-19 pandemic.

CONTRA deals with the delivery problem of the COVID-19 vaccine from countries' entry points (like international airports) to regional health facilities. Originally, TØI was assigned to study challenges to decision-making in nationwide distribution of new vaccine types requiring transport and storage at -20ºC. Early on in the project, however, a workshop was conducted involving participants including the Institute of Public Health, county-level medics and third part logistics suppliers, where participants agreed that challenges to decision-making involved in nationwide logistics were likely to be limited. The view was rather that successful decision-making by municipalities would be challenging yet critical to successful vaccine roll-out. TØI therefore applied its competence in studying decision-making to a predominantly non-transport domain, that of local-level vaccine distribution and administration. Here the decision-makers were people in key roles in municipalities and city districts (Chief Doctors, Vaccine Coordinators and the like).

This report is not an evaluation of the effectiveness of COVID-19 vaccine roll-out in Norway. Evaluations have already been done and there is recognition that national and local efforts have been effective in Norway. This report contributes instead by revealing some hidden challenges to decision-making underlying successful performance at local level, such that performance may be even better in the future.

Of particular interest has been how to strike the right balance between centralized and distributed control in national vaccine roll-out. On the one hand, local-level decision-makers are best placed to account for and adapt to conditions particular to their municipality or city district; on the other, local decisions must align with the coordinative efforts of central authorities and advisors if they are to contribute to a fair and effective nationwide response. We decided to study this balance -- between centralized and distributed control -- through the eyes of local-level decision-makers. We did this by eliciting from them knowledge about the cognitive challenges they faced when thinking about the system around them. Did key players in local authorities experience common challenges to decision-making due to shared constraints set by central authorities? Was there anything more central authorities could have done to support local adaptations made to help manage complex crises?

Deciding to publish this report has not been easy. Readers not familiar with the methodology we apply (cognitive systems engineering) may find it hard to access, but complex methods are necessary for meaningful analysis of complex sociotechnical systems like the vaccine roll-out system. Secondly, while we present key findings underpinning most of our discussion and our ideas on decision support needs, our discussion may inevitably draw on insight gained elsewhere in the project or from text we have been unable to include. Our motivation in publishing the report is to make our findings available to those who may need them, as they may already be working to improve roll-out systems of the future. Given this, we attempt to focus on the main challenges to decision-making faced by local authorities in Norway. A more detailed presentation of the challenge of balancing centralized and

distributed control has been accepted for publication in the *Journal of Cognitive Engineering and Decision Making*.

We would like to thank all interview participants in local authorities for giving their time and engagement during a demanding period. We would also like to thank Knut Jønsrud at Norwegian Institute for Public Health for giving time and helpful comments on an early draft of the text. Any remaining factual errors are the sole responsibility of the authors.

Ross Phillips from Institute of Transport Economics planned, conducted and analyzed interviews and prepared the report. Hossein Baharmand at the Department of Working Life and Innovation, University of Agder, Norway, led the CONTRA project has advised on recruiting of participants and commented development of the report. Nico Vandaele, Catherine Decouttere and Lise Boey from Access-to-Medicines Research Centre, KU Leuven, Leuven, Belgium, have commented on development of the report. All were involved in workshops and discussions which acted as foundation for the report.

Sidsel Ahlmann Jensen has been responsible for quality assurance.

Oslo, November 2022
Institute of Transport Economics

Bjørne Grimsrud	Sidsel Ahlman Jensen
Managing Director	Director of Research

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ENGLISH **Summary**

COVID-19 Vaccine Roll-out by Local Authorities in Norway

Challenges to decision-making

TØI Report 1892/2022 • Authors: Ross O. Phillips, Hossein Baharmand, Nico Vandaele, Catherine Decouttere, Lise Boey • Oslo 2022 • 31 sider

Abstract

- Based on interviews with 14 local decision makers, we identify seven challenges to decision making in local authorities rolling out COVID-19 vaccine in Norway in the period from January to September 2021.
- The main challenges were in deciding how many doses to extract from each vaccine vial, how to cope with changes to recommended dose intervals, and how to prioritize borderline patients and health personnel for vaccination.
- We speculate on ways in which decision making at local level could be supported in future situations involving emergency vaccine roll-out.
- We identify sixteen functions local authorities need to carry out successfully to achieve the goals for vaccine roll-out. These functions might be used in preparedness activities or in the design of system improvements.

At the start of 2021, over 350 local authorities in Norway were charged with rolling out COVID-19 vaccine to their populations in line with national criteria and goals. This report focuses on system purposes, functions and challenges in local systems for vaccine roll-out. We describe how shared constraints set at national level shaped common goal-critical challenges for decision-makers across a sample of nine local authorities, and discuss mutual influences between national- and local-level decisions on vaccine roll-out.

The methodological approach we use is called cognitive systems engineering. According to this approach goal achievement results from people collaborating with each other and interacting with technology and infrastructure in order to make sense of situations, adapt, make decisions, plan, re-plan and perform other cognitive functions. A central tenet of cognitive systems engineering is that skilled people adapt in the face of complex challenges to produce successful outcomes in spite of those challenges. Ultimately success belies the challenges adapted to such that challenges may be poorly visible to outsiders who help shape them. Methods from cognitive systems engineering can be used to elicit knowledge about such challenges, such that future systems can be improved.

Based mainly on the analysis of transcripts of interviews with 14 people central to roll-out in the nine local authorities, we abstracted a common functional account of a local vaccine roll-out system. There was agreement among interviewees that critical goals for roll-out were to vaccinate as many people as fast as possible in line with priority and other national guidelines, while maintaining public trust. There was also agreement on seven important values to be upheld while achieving these goals (e.g. "vaccinate safely", "don't waste doses"). We abstracted sixteen system functions that the local authorities need to achieve their goals in line with the values identified. Examples of system functions are control over dose availability and viability, mapping of priority groups, control over dosage number and so on. The list of system functions may be interesting to those improving future roll-out systems or for use in preparedness activities.

The completed functional account of local vaccine roll-out was used to study interviewee responses on how constraints set by national authorities could shape goal-critical dilemmas and difficult decisions. Examples of external constraints are vaccine dose intervals, amounts of vaccine supplied, or infection containment measures.

Our results indicate seven common areas with challenging decisions in the cognitive system organizing vaccine roll-out at local level:

1) Coordination of patients, vaccine and staff;
2) Extracting doses from vials;
3) Dealing with changing dose intervals;
4) Prioritizing patients;
5) Deciding whether to dispose of or use vaccine;
6) Balancing need for staff with need for training; and
7) Establishing data systems for calling in patients and distributing vaccines.

While local authorities already strive to align decisions and actions with the goals and shifting criteria of national authorities, challenges to local authorities might be eased by a more iterative, mutual process, in which the health authorities and Norwegian Institute of Public Health strive to ensure that the criteria and procedures that they set align with the strategies of local authorities, after they have been implemented in practice.

Coordination between national health authorities and manufacturers to generate standard guidelines could increase shared awareness among local authorities about how to safely extract as many doses as possible. Development of consensus on how to prioritize patients and health personnel at a more granular level could help avoid perceptions of unfairness by the public, as could full consideration by national authorities of the impact of frequent changes to guidelines. Development of generic but adaptable data systems to help organize patient and vaccine delivery logistics at local level could save local authorities valuable resources and time.

Accepting methodological limitations, our findings support the usefulness of cognitive systems engineering for visualizing hidden decision challenges, and for abstracting functions to be supported in attempts to improve future systems.

On considering findings, practitioners should bear in mind methodological limitations, the contexts and culture of Norwegian local authorities, and the early phase of vaccine roll-out studied. Methodological limitations concern the extent to which the study participants represent Norwegian municipalities involved in vaccine roll-out, and our ability to be explicit about the process used to generate insights on decision challenges and functional account of the local vaccine roll-out system. Ideas on decision support are also speculative and further research is also needed on how collaboration and communication can be changed to ease the decision bottlenecks identified.

Finally, we would like to stress that according to both the participants in our study and national evaluation reports, vaccine roll-out in Norway was successful. This was due to much hard work but also successful collaboration and communication between national and local authorities. Despite our attempt to identify areas for improvement, our findings are just as much about how the joint cognitive system adapted successfully as they are about the challenges adapted to.

NORSK **Sammendrag**

Utrulling av koronavaksine til kommuner
Utfordringer for beslutningstaking

TØI rapport 1892/2022 • Forfattere: Ross O. Phillips, Hossein Baharmand, Nico Vandaele, Catherine Decouttere, Lise Boey • Oslo 2022 • 31 sider

Forskningsfunn/Hovedresultater

- Med utgangspunkt i intervjuer med 14 representanter, har vi identifisert syv utfordringer for beslutningstakere i kommuner som distribuerte koronavaksine til sine befolkninger i perioden fra januar til september 2021.
- De tre mest utfordrende beslutninger var i) hvor mange doser som skulle trekkes ut fra hvert vaksineglass, ii) hvordan man skulle takle endringer til anbefalte dose-intervaller og iii) hvordan man skulle prioritere pasienter og helsepersonell for vaksinasjon.
- Vi identifiserer 16 funksjoner som lokale myndigheter må utføre for å oppnå målene knyttet til fordeling og administrering av vaksine. Disse funksjonene kan brukes i opplæring og som grunnlag for systemforbedringer.
- Vi kommer med idéer om hvordan nasjonale myndigheter og rådgivere kunne støtte lokale beslutningstakere i fremtidige situasjoner der kommuner må rulle ut nødvaksine.

I begynnelsen av 2021 skulle over 350 kommuner og bydeler rulle ut koronavaksine til sine befolkninger, i tråd med nasjonale kriterier og mål. I denne rapporten identifiserer vi utfordringer for utrulling av vaksine som ble skapt av kommunenes felles eksterne begrensninger. Studien gjelder perioden fra januar til september 2021. Grunnlag for analysen er en dokumentgjennomgang og dybdeintervjuer med 14 personer som tok kritiske avgjørelser om utrulling av vaksiner på kommunenivå. Disse personene kom fra sju kommuner og to bydeler i Norge.

For å strukturere og analysere intervjuene, brukte vi en metodologisk tilnærming som heter kognitiv systemteknikk. Kognitiv systemteknikk tar utgangspunkt i at i) måloppnåelse i komplekse systemer er et resultat av samarbeid mellom mennesker, teknologi og infrastruktur; og ii) for å forstå hvordan vi kan forbedre komplekse systemer, må vi først forstå *hvordan* mennesker samarbeider for å oppnå mål. Det sistnevnte kreves igjen at vi forstår hvordan mennesker i samarbeid,

- danner mening om krevende situasjoner;
- tilpasse seg for å sikre oppnåelse av viktige mål; og
- planlegger for viktige funksjoner som trengs for måloppnåelse.

Kognitiv systemteknikk brukes ofte for å studere hvordan støtte mennesker som må tilpasse seg i møte med reelle, komplekse situasjoner, for å oppnå kritiske mål.

Vi startet analysen med å redegjøre for felles mål, verdier og funksjoner som er kritiske for distribusjon og administrering av vaksine på kommunenivå. Felles mål for utrulling av vaksinen under pandemien var å vaksinere så mange folk som mulig, så fort som mulig, i tråd med nasjonale prioriteringer og kriterier, og å opprettholde tilliten til befolkningen. Vi identifiserte sju verdier som det var viktig for kommunene å oppholde under pandemien, som for eksempel «sikker vaksinering» eller «ikke kaste bort vaksine». For å oppnå målene i tråd med verdier, måtte kommunene gjennomføre 16 ulike funksjoner. Noen eksempler på disse er kontroll over vaksinen (f. eks. tilgjengelighet, levedyktighet), kartlegging av prioriterte grupper, og smittevern. Listen over disse funksjonene kan være av interesse til de som vil forbedre hvordan vaksiner distribueres i kritiske situasjoner i framtiden, for bruk i opplæring av sentrale helsepersoneller i kommunene, eller i beredskapsaktiviteter.

Intervjuene var da analysert for å forstå hvordan begrensninger satt av nasjonale myndigheter og rådgivere kunne skape krav, målkritiske dilemmaer og utfordrende avgjørelser for personer i sentrale roller i kommunen. Eksempler på disse såkalte eksterne begrensninger var intervaller mellom vaksinedoser som ble anbefalt til kommunene, mengde vaksine tilgengelig, eller smitteverntiltak.

Resultatene indikerer sju områder med vanskelige beslutninger for kommunene:

1) Koordinering av pasienter, vaksiner og ansatte;
2) Uttrekking av doser fra hetteglass;
3) Håndtering av endringer i doseintervaller;
4) Prioritering av pasienter;
5) Beslutninger om å kaste eller bruke vaksine;
6) Avveininger knyttet til grad av opplæring av ansatte på vaksinasjonssentere; og
7) Etablering av datasystemer for innkalling av pasienter og distribuering av vaksiner.

Vår analyse viste at lokale myndigheter strever for å beslutte og handler i tråd med nasjonale myndigheters mål i møte med endrede kriterier. Noen av utfordringer som beslutningstakere i kommunene sto overfor kunne vært lettet hvis helsemyndighetene og -rådgivere hadde en prosess for å sjekke at kriteriene og prosedyrene de anbefalte stemte med de ulike strategiene for utrulling som kommunene brukte i praksis.

Samarbeid mellom nasjonale myndigheter og vaksineprodusenter på standard veiledning kunne trolig ført til økt felles bevissthet blant de lokale myndighetene om hvordan de trygt kunne få flere doser ut fra hetteglassene. Samarbeid med og mellom kommunene, om hvordan prioritere pasienter og helsearbeidere i utfordrende situasjoner, kunne bidratt til å opprettholde offentlighetens persepsjoner av en rettferdig vaksinefordeling. Mindre hyppige endringer til anbefalte doseintervaller ville trolig også bidratt til å unngå uheldige situasjoner som kunne redusert tillit til den offentlige utrullingen. Utvikling av generiske, men fleksible datasystemer kunne bidratt til mer effektiv innkalling og koordinering av pasienter og vaksineleveringer.

Våre funn støtter at kognitiv systemteknikk er et nyttig paradigme for å (i) avsløre flaskehalser i komplekse systemer og (ii) identifisere kritiske funksjoner i slike systemer. Funnene må tolkes i lys av noen metodologiske begrensninger, inkludert den begrensede utvalg av deltakere og tidsperioden studert. Metodologiske begrensninger angår i hvilken grad deltakerne representerer norske kommuner og bydeler, og om sporbarheten av prosessen brukt for å forstå utfordringer for beslutningstakere. Våre idéer for beslutningsstøtte er spekulative, og mer forskning trengs for å forstå hvordan samarbeid og kommunikasjon kunne endres for å lette utfordringene for beslutnings-takere vi har identifisert.

Til slutt vil vi påpeke at utrulling av vaksine i Norge var stort sett vellykket, ifølge både studiedeltakerne og nasjonale evalueringer. Våre funn støtter at en viktig grunn til dette kan nettopp være at systemet i Norge tilrettelegger effektivt for både sentrali-sert koordinering og kontroll og lokale tilpasninger.

1 Introduction

Towards the end of 2020, COVID-19 vaccines were urgently needed to allow societies to re-open without overloading their health services. As vaccine safety and efficacy began to be confirmed, national authorities in Norway and many European countries worked on plans to distribute vaccines and vaccinate their populations (EU, 2021). As they did so, questions were raised about how successful vaccine roll-outs might be; vaccines had never before been rolled out so fast at such scale, requiring authorities to manage uncertainties while successfully negotiating different vaccine types and suppliers, and complex networks of government, companies, health workers and the public (Baharmand et al., 2021; Mills and Salisbury, 2021; Weintraub et al., 2021; Guttieres et al., 2022; Engel et al., 2022).

The project *COVID-19 Network Technology-based Responsive Action* (CONTRA) has attempted to learn from the COVID-19 vaccine roll-out in Norway to develop improved decision support for authorities in high, middle and low income countries facing similar situations in the future (CONTRA, 2021). In other publications we describe actions and information flows among actors involved in nationwide vaccine roll-out, model the dynamics of the nationwide roll-out system, and describe use of a stakeholder-centered approach to identify and model key performance indicators for decision-making (Decouttere et al., 2016; Baharmand et al., 2021; Decouttere et al., 2021a; Boey et al., 2022). This current report focuses on system purposes, functions and challenges in local systems for vaccine roll-out. We describe how shared constraints shape common goal-critical challenges for decision-makers across local authorities, and discuss mutual influences between national- and local-level decisions on vaccine roll-out. Since most published articles on the role of local authorities in the COVID-19 pandemic address measures to limit or contain the spread of infection (e.g. Gill et al., 2020; Roderick et al., 2020), a study of vaccine roll-out at local level is a useful addition to our knowledge on challenges in the organization of pandemic response. In the rest of this section, we give background to vaccine roll-out in Norway and describe our methodological approach based on cognitive systems engineering.

1.1 Plans for mass-vaccination in Norway

Norwegian plans for handling national pandemics align with four principles of preparedness: responsibility, proximity, likeness and cooperation (Ministry of Health and Care Services, 2018; Norwegian Government, 2014). In line with these principles, crises are organized at lowest possible level using organizational structures normally responsible for day-to-day operations; and each actor is responsible for achieving optimal outcomes in cooperation with others. The four-principle approach is designed to give responses that account for local contexts, but it leaves local authorities with difficult choices on how to roll out vaccine to their respective populations (DSB, 2018).

An evaluation of local authorities' handling of the last influenza pandemic in 2009 in Norway concluded that local authorities performed generally well, not least due to a strong sense of community spirit (*dugnadsånd*) among staff (DSB, 2010; cf. Decouttere, 2021a). Weaknesses included problematic interactions between the local authority and the national health authorities, identification of risk groups for vaccination by local authorities, and lack of clarity on the role of general practitioners (GPs) (DSB, 2010). Members of the public in some local authorities also perceived a “postcode lottery” due to differing approaches by local authorities to calling in patients, with some advertising a drop-in service and others sending direct invitations with appointments. Recommendations from the evaluation included increased collaboration by local authorities to promote shared situational awareness, and establishment of automated systems to harmonize and increase the efficiency of calling in patients for vaccine (DSB, 2010). Subsequent to the evaluation, the Norwegian Institute of Public Health (IPH) revised guidance for local authorities, outlining roles and responsibilities for carrying out mass vaccination in the event of pandemic influenza (Norwegian Institute of Public Health, 2016).

One consequence of the four-principle approach is that the extent to which national vaccine roll-out goals are achieved, are influenced by the varying decisions and approaches taken by individual local authorities. We can expect differences at local level in the efficiency of vaccine usage; on the location of vaccine storage or centers for vaccination; or in work to develop public trust in the vaccine and vaccination process (DSB, 2010). Yet local authorities also share constraints, such as limited vaccine supply, groups to prioritize, or human or technological resources for organizing or communicating with the public. As a result of shared constraints, we expect that people in similar roles across different local authorities will often need to resolve the same conflicting goals or adapt to similar hindrances (see e.g. Wilson & Game, 2011). While they can respond with strategies of varying similarity, common response patterns will inevitably emerge, and their description can help us understand and improve the overall roll-out system (Woods & Hollnagel, 2006). For the purposes of this article we refer to common constraint-shaped goal-critical challenges for vaccine roll-out, as **bottlenecks** in the joint cognitive system working to vaccinate local populations. Bottlenecks are potentially detrimental to national goals for vaccine roll-out, yet can be poorly visible to higher-level stakeholders (Woods, 2003). Understanding bottlenecks can form the basis of system improvements.

To summarize so far, outcomes from vaccine roll-out in Norway are the result of an inter-dependent relationship between local and national authorities, influenced by the varying approaches taken by different local authorities as well as bottlenecks shaped by their shared constraints. Examples of shared constraints are information and guidance for authorities and advisors, rules and regulations, goals for vaccination, lists of priority groups, and recommended intervals between vaccine doses.

1.2 System approaches to the study of vaccine roll-out

The system achieving mass vaccination is an open and complex sociotechnical system (Vicente, 1999) in which technology, infrastructure and people in manufacturers, transport and distribution, government, research institutes, local health authorities, media and the public all interact (Baharmand et al., 2021). Methodologies suitable for the study and improvement of such systems include system dynamics and systems mapping (Sterman, 2000; Decouttere et al., 2021b); sociotechnical systems engineering (Baxter and Sommerville, 2011; Carayon and Salwei, 2021; Clegg et al., 2017); system theoretic accident models and processes, STAMP (Leveson, 2012); human factors engineering (Stanton et al., 2013); functional resonance analysis method, FRAM (Hollnagel, 2012); and “design X” (Norman and Stappers, 2015). While each of these approaches has value, cognitive systems engineering (CSE) is particularly suited to the study of joint cognitive bottlenecks in complex sociotechnical systems, as it helps researchers understand responses, decisions and adaptations in dynamically evolving real-world situations (Hollnagel and Woods, 2005; Militello et al., 2010).

1.2.1 Cognitive systems engineering (CSE)

In CSE, agent activities are the result of a three-way interplay of (1) agent strategies; (2) affordances, artefacts and how they represent processes at work; and (3) the demands and constraints of the fields of practice (Flach and Voorhorst, 2020; Gibson, 2015; Hollnagel and Woods, 2005). Common patterns in cognitive work should therefore be abstracted from particular intersections of people, technologies and work from which they emerge (Woods and Hollnagel, 2006). One main tenet of CSE is that “well-adapted cognitive work occurs with a facility that hides the difficulty of the demands resolved and dilemmas balanced” – the so-called Law of Fluency (Woods, 2005). Referring to common difficulties that recur in different instances of a joint cognitive system as that system’s bottlenecks (cf. above), the Law of Fluency means that bottlenecks may not be readily visible. To fully understand bottlenecks and learn how to support skilled decision-makers, CSE recommends we take a two-step approach:

1. Understand constraints shared by decision-makers in a system, by building a functional account of the real-world system in operation. One way to do this is to interview decision-makers with varying perspectives on the same system using work domain analysis (Naikar, 2013; Woods, 2003).
2. Use the functional account to understand how decision-makers navigate constraint-shaped demands, dilemmas and other cognitive challenges as they strive to achieve goals in real, situated contexts. This second step is often structured using cognitive task analysis (Crandall et al., 2006; Dominguez, 2020; Schraagen et al., 2000).

As we develop an understanding of cognition in specific situations in the context of a real-world functional account of the system we begin to see bottlenecks emerge. These often appear (i) in the more or less visible joint cognitive activities of practitioners and artefacts, as they strive to adapt in the face of multiple goals and constraints (Hutchins, 1995); and (ii) in larger processes of collaboration and coordination (Woods, 2018, 2003).

1.2.2 Naturalistic decision-making

The field of naturalistic decision-making provides empirical guidance on studying decision support in real-world systems that is methodologically consistent with CSE and also relevant for identifying bottlenecks (Hoffman and Militello, 2009). Naturalistic decision-making emphasizes the value of studying how experts handle critical incidents, similar to study of adaptation by experts in “stretched systems” in CSE (Militello et al., 2010; Klein, 2017; Schmidt, 2021). To understand how to improve real-world cognitive systems we should study how people make sense of situations they are in, detect problems, and plan and re-plan as individuals and in collaboration (Klein et al., 2003; Crandall et al., 2006; Klein and Wright, 2016). In pressured or complex situations, individuals will tend to “run promising courses of action against possible futures” derived from sense-made situations, until they find one they believe will work and run with it (Klein, 2017). Whether key actors make the same sense of situations as the basis of harmonic, goal-oriented action, depends on effective *communication* – defined as the reciprocal processes of sending and receiving information (Le Pine et al., 2008) – and *coordination* – defined as the way team members orchestrate the nature and sequences of their actions to perform a task (Klein, 2001).

1.2.3 Multi-team systems

Assuming that effective national vaccination depends on harmonized efforts of multiple organizations at local, regional and national level, we should also consider that in multi-team systems, communication across teams in different organizations will be challenged by organization-specific features, such as culture and norms (Brown et al., 2021). In multi-team systems, coordination allows teams to attend to intra-team goals while ensuring their actions are cohesive with overarching system goals; it requires that intra-team goals remain cohesive while at the same time they are developed towards evolving demands of the environment (Brown et al., 2021). If teams are not familiar with each other or the situation being managed, component teams must engage proactively to establish coordinated actions (Smith-Jentsch et al., 2009).

1.2.4 Local authorities as units of adaptive behaviour

Finally, considering the national system arranging vaccination of the population to be an adaptive system, we can treat local authorities as units of adaptive behaviour (Woods, 2018). For the nationwide system to be able to adapt and cope with continual change, alignment and coordination are needed across multiple interdependent units in a network, since no local authority by itself will have a sufficient range of adaptive behaviour (Woods, 2018). As one independent unit pursues its goals, it will also modify the pressures experienced by other units and change how that unit defines and searches for good operating points.

1.3 Study aims

The aim of our study was to identify bottlenecks for vaccine roll-out at local authority level, in order to begin investigating decision support needs. To do this we interviewed decision-makers involved in organizing vaccination at local authority level in Norway, using cognitive task analysis to elicit knowledge of tasks, organization, communication and collaboration in the system. Knowledge elicited was analyzed to answer the following three questions:

1. What critical purposes, values and functions do the different local vaccine roll-out systems have in common? (Functional analysis)
2. What *bottlenecks* – common constraint-shaped, goal-critical challenges – are there?
3. What decision support is needed by those deciding how to organize local vaccination efforts, in order to improve attainment of national vaccination goals?

In making our analysis, we considered how decision-makers made sense of situations, planned, decided and adapted to developing situations. We also considered whether communication and coordination was amenable to effective team and multi-team functioning and adaptive, resilient response.

2 Method

2.1 Local authorities and participants

Local authorities in Norway comprise 356 municipalities (kommuner). In the largest towns or cities, municipalities are further divided into city districts (bydeler), each of which also equates to a local authority. We selected 21 local authorities representing municipalities of different population size, density and location in Norway, and invited them to interview by e-mail; nine of them agreed. Participants represented seven of Norway's 356 municipalities, as well as two out of about 50 city district authorities. In the case of two of the municipalities (M1 and M2 in Table 1), we recruited for interview the Chief Doctor, the Vaccine Coordinator and either a Communications or a Logistics Manager, to learn how people in key roles in the same municipality collaborated to organize COVID-19 vaccination. In the case of another municipality (7) we interviewed the Vaccine Coordinator and Vaccine Centre Leader together. In each of the other municipalities or city districts, we interviewed one representative (Table 2.1).

Table 2.1: Overview of participants with role, location in Norway and population size.

Interview	Role	Municipality or District	Area of Norway	Population
1	Chief Doctor*	M1	Eastern**	25-50,000
2	Vaccine Coordinator			
3	Communications Manager			
4	Chief Doctor	M2	Eastern	>75,000
5	Vaccine Coordinator & Centre Leader			
6	Logistics Manager			
7	Vaccination Coordinator & Centre Leader	M3	Eastern	0-10,000
8	Chief Doctor	M4	Southern	>75,000
9	Vaccine Coordinator	M5	Northern	50-75,000
10	Vaccination Centre Leader	M6	Eastern	25-50,000
11	Vaccination Coordinator	M7	Eastern	50-75,000
	Vaccination Centre Leader			
12	Chief Doctor	D1	Oslo	50-75,000
13	Chief Doctor	D2	Oslo	50-75,000

**Either Chief Doctors or Assistant Chief Doctors were invited for interview, but are referred to as Chief Doctor for purposes of anonymity. In all cases they represented the office of the Chief Doctor on organization of Covid19 vaccination in their municipality or district. ** Eastern region contains over half of Norwegian population*

Two of the municipalities interviewed were neighboring municipalities. The final group of participants represent a range of local authority types, with a collective population of ca. 500,000 people, just under ten per cent of the population in Norway. The participants also represent roles that are central to organizing vaccination at local level.

2.2 Interview procedure

Interviews were conducted with 14 representatives between 31st August and 22nd October 2021, each interview lasting between 80 and 160 minutes. The interview with Chief Doctor from Municipality 1 was conducted in two parts. To prepare for the interviews, we reviewed key documents and notes from preliminary interviews with a county-level Chief Doctor, a researcher employed by the Directorate of Health in Norway during the 2009 pandemic, the head of vaccine roll-out at IPH, and an employee of the Ministry of Health and Care. We then researched to answer the framing questions from Crandall et al. (2006). Interviews were structured by adapting questions on cognitive task analysis from Crandall et al. (2006), Applied Cognitive Task Analysis (Militello and Hutton, 1998) and the Critical Decision Method (Hoffman et al., 1998; Klein et al., 1982). In the first interview questions from Cognimeter were also used to confirm the suitability of cognitive task analysis for analysis of key tasks identified (Chrenka et al., 2001). All tasks scored highly on cognitive dimensions for situational awareness, course of action development and evaluation, course of action monitoring and planning, teamwork and coordination, and information attention and management.

2.3 Analysis

Interviews were recorded and transcribed, the transcripts anonymized, and then coded in N-VIVO12 using a scheme developed in analysis of the first interview transcript. A first sweep of the text captured four main nodes to structure analysis of the functional work domain: Functional purposes of the roll-out system; Functional values people have as they act to achieve system purposes; System functions (goal-related); and Resources (materials, tools and infrastructure with functions that can be used together with other resources and functions to perform system functions). Text describing Actors/roles and Actions were also collected. In a second sweep of the text, nodes were structured to capture information on goal-related cognitive demands and challenges faced by decision-makers, including those relating to communication and coordination within and between teams and organisations. Nodes were namely: Social organization; Constraints; Information (used or needed); Decision-making (goal-related); Expectations (goal-related); Planning (for actions); Adapting or re-planning; Coordinating; and Sensemaking. Coding was performed by a single researcher. Text for a randomly selected single interview (M5, Table 1) was also coded by an experienced human factors professional after a short explanation of the codes, and general agreement confirmed. Small differences where text implicitly indicating Goals, Values or other nodes was not coded, were presumably due to lack of familiarity with the project, but did not affect the categories identified.

Twelve participants were able to identify a critical decision suitable for analysis. Ten critical decisions were deemed relevant to the problem being investigated, and considered in the final analysis. In a third sweep, text from responses to Critical Decision Method questions were also coded under the nodes described above. (The total number of passages coded under each node are given in Appendix 2.) Finally, coded text was reviewed and re-grouped by pasting into a document in two ways: 1) To give for each municipality or district, an account of events during vaccine roll-out; and 2) To identify themes describing common goal-related cognitive challenges (bottlenecks) and decision needs.

Procedures were ethically approved by NSD, the Norwegian Centre for Research Data.

3 Events and external constraints

Highlighted events affecting how vaccination was organized at local authority level in Norway was described by participants as follows:

March 2020	Norway shuts down
April-December 2020	Local authorities focus on increasing test capacity, infection tracking and containment
November-December 2020	In the absence of a national system, some municipalities ask electronic patient journal suppliers to generate solutions for automatize the invitation of priority people to vaccine appointments
December 2020	Recommendations made on risk groups.
	First vaccine arrives in Norway (26^{th}), and IPH invite 8 municipalities to start vaccinating before New Year
January 2021	Most municipalities start distributing to nursing homes, some involve GPs in roll-out
February-May 2021	Period of high infection rates, unpredictable vaccine supply, high demand for vaccine
May-August 2021	Authorities change dose intervals several times
August-September 2021	Demand starts to decrease as vaccine supplies increase

The following account is derived from comments of participants, unless indicated otherwise:

As an EEA partner, Norway was included in the joint EU initiative on vaccine procurement (EU, 2021), and supplied mostly with Pfizer/BioNTech vaccine throughout 2021 (ca. 70% of vaccine distributed; Jønsrud, 2021). Pfizer vaccine was the main vaccine participants referred to in interviews, although Moderna and other vaccine types were supplied in smaller quantities. Oxford/Astra Zeneca vaccine was supplied early 2021, before Norway decided to stop using it on 11th March to limit risk of side effects.

The first vaccine arrived in Norway on 26th December 2020. Originally viable for only several hours at room temperature, or up to several days at $4^{o}C$, the Pfizer mRNA-based vaccine was transported to a national hub near Oslo at $-70^{o}C$. The vaccine was supplied from the manufacturer as boxes of glass vials. Each vial contained a vaccine stock to be brought to room temperature before use, and mixed with saline to a final volume of ca. 2 ml (EMA, 2021). The volume of each dose was 0.3 ml. The Norwegian Directorate of Health was responsible for procurement and distribution of equipment such as needles and syringes, to be used with the vaccine.

The perception of several participants was that vaccine was distributed without developing a central buffer stock (though at one stage Norway did have a buffer stock). Lack of buffer stock would leave IPH more exposed to change in distribution plans at short notice if there were unexpected changes in deliveries from manufacturers. After arriving at the national hub, IPH forwarded packing plans to hospital pharmacists and plans for distribution to local authorities and hospitals by third party distributors (Jønsrud, 2021). When deciding how to allocate and coordinate arrival of COVID-19 vaccines across different local authorities, IPH considered priority group criteria and other constraints set by the health authorities, together with logistical insight provided by business consultants and a third-party logistics supplier (Boey et al., 2022). Patient groups were prioritized in line with the overall goal of government health authorities: to prevent serious illness and death and excessive burden on critical health services.

Local authorities received and stored vaccine at 4°C at crisis supply centers, health centers and vaccination centers. They transported vaccines to GPs, care homes or other outposts in controlled cool boxes supplied by the national authorities. Due to limited vaccine supply and a policy that vaccine should be equally distributed, 89 municipalities received only 1 vial of vaccine a week early on in the roll-out (Jønsrud, 2021). Local authorities were typically informed on Thursday how much Pfizer vaccine would be delivered to them the following Tuesday. In the early phase, in which vaccine was stable at 4°C for up to 5 days, most local authorities had only 4.5 days to get in the right people at the right time and place for vaccination. Unless they vaccinated on weekends they had only 3-4 days to administer all doses after arrival in the local authority on the Tuesday. This situation improved on 17th May when local authorities were informed that they could store vaccine for up to 30 days at 4°C.

A main constraint for local authorities was that population had to be vaccinated in order of priority (Appendix 3). The mobility and location of the priority group being vaccinated often determined when and where vaccinations were performed. Some changes were made to critical health personnel during 2021 in terms of share of doses allocated to them.

At the start, the regulatory authorities (European and Norwegian Medicines Agencies) gave approval for five doses to be extracted per vial of Pfizer vaccine, later recommending six doses be extracted (after an application by Pfizer), issuing guidelines on how to do this. Over the spring and summer, in response to available vaccine supplies, the Norwegian authorities advised local authorities to change dose intervals several times. Initially it was thought that dose 2 could be delayed to allow more people in priority groups to get dose 1. Based on this and research data, the initial three-week interval was increased, eventually to 12 weeks. Due to message from manufacturer that more vaccine than expected would be supplied, the interval was then decreased to nine weeks, only to be increased again to 12 weeks about ten days later when the manufacturer receded this message. Later on, increased supply from other EU countries mean the interval could be reduced again. In the summer of 2021, IPH changed the criteria for distribution of vaccines across different local authorities in an attempt to target pockets of high COVID-19 infection rates, particularly in denser urban areas of the population. In effect, vaccine supply in areas of lower infection rates was reduced somewhat and given to areas with higher infection rates.

While the vaccine was being rolled out, increased infection "bursts" appeared in local or regional pockets. For the local authorities affected, this placed additional constraints on available health staff. In fact, the pandemic increased the number of tasks to be performed across several local authority departments, and created a demand for information about the vaccination internally in the local authority, in addition to intense interest from media and the public.

At the outset of roll-out, local authority representatives reported experiencing urgency to set up plans and systems and be ready to roll out effectively as needed. There were concerns at the outset about juggling different vaccine types with different use-by dates or storage and preparation requirements, and about keeping the "Pfizer cold chain» intact. These concerns were allayed to some extent, but all local authorities had to adapt to frequent changes in vaccination strategy made by authorities as they reacted to developing knowledge and changes in vaccine supply. On top of this, unpredictable manufacturing processes created long periods of uncertainty surrounding vaccine deliveries at national and local level.

4 Functional analysis of the local roll-out system

4.1 Functional purposes

One Chief Doctor summed up the general view of participants on goals for the system: “To vaccinate as many as possible as fast as possible, in the order decided by IPH, and in a safe way.” We identified five distinct functional purposes from the coded text (top row, Figure 4.1.

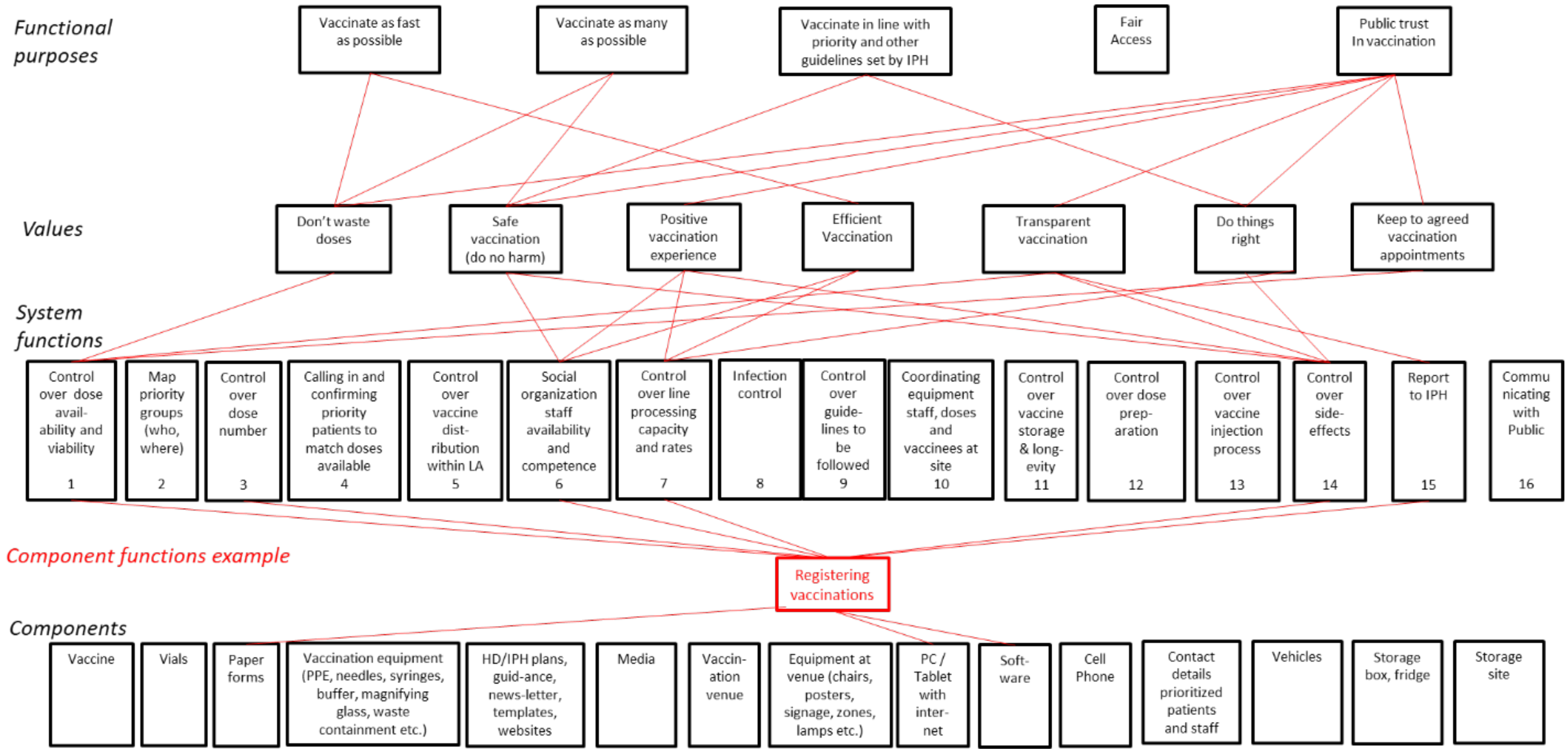

Figure 4.1: Functional domain analysis for local organization of vaccination, developed from interviews with representatives of nine local authorities. Includes illustrative analysis using a single component function, "Registering vaccinations" (text and links in red).

4.2 Functional values

Together participants espoused seven functional values or preferred ways of achieving goals or assessing progress towards achieving functional purposes (second row from top, Figure 4.1). While different strategies were used to carry out system functions and achieve goals, values were common across local authority representatives. Not wasting doses was a dominant value, salient especially when doses were going out of date and priority patients were not available for vaccinating:

> *"I said to them, I don't care, we don't throw away doses, I know it's wrong [in terms of order of patient priority], but we'll use them anyway…we had to get them into somebody…. I can guarantee that across the country, it is not possible to follow 100 % those criteria, but mainly it's because you don't want to throw away doses. It is not an exact science."*

Vaccine Coordinator, M7

> *"Even though we only had five days [to use the doses], we used all we got, we never threw away doses."*

Vaccination Centre Leader, M1

> *"We had serious concerns about getting all the doses used in time so we wouldn't waste any."*

Chief Doctor, M2

Vaccinating people safely included concerns to give people full, correct and viable doses. Wellbeing was also a concern, including a need to reassure worried patients, give them a chance to ask questions, and not leave them waiting at vaccination centers. Efficiency was expressed in various ways, such as a concern to get all vulnerable people vaccinated at a nursing home to save time-consuming return visits; a desire to offer ambulatory vaccination process only to those who need to avoid wasting resources; emphasis placed on getting systems in place fast for automatic summons of patients; or in terms of rate of processing at vaccination centres ("1000 or more per day, full speed", "100 per hour" etc.). The value of transparency was linked explicitly to a need to maintain public trust in local authority handling of the vaccination.

> *"Because here we have had a limited amount of vaccine that many wished they could have, and having an openness around… fair distribution of the few vaccines we have had, that has been important for me, that you should always have faith in the public order and what is decided nationally."*

Chief Doctor, D2

Several participants emphasized the importance of municipality communications departments to openness and maintaining trust. In particular, there was a concern that people should see that they have not missed their turn in the vaccination process. The value of correct process was expressed in terms of a need to "get things done right", both in terms of avoiding procedural mistakes (e.g. while preparing vaccine or registering data) and following national guidelines and procedures. There was also a clear reluctance to "mess with" vaccination appointments once given to people who usually had waited a long time for them. Finally, the need to treat people wanting vaccine fairly on the basis of prioritization guidelines given down to the local authority was mentioned by most participants. This included both fairness in relation to people in other local authorities or informing or reaching out to people within the same priority group:

> *"I think we have used all possible channels to get people in…we have had drop-in at the mosque, and the town hall, at the vaccine center, mobile service from the vaccine office, we have been in touch with workplaces with a lot of foreign workers, to get to them, adverts in Polish newspapers...we have gone out to schools with a lot of foreign students, to universities too."*

Vaccination Centre Leader, M7

4.3 Functional components

Components used to carry out tasks are summarized at the bottom of Figure 4.1. While it is possible to elaborate and name many more individual components (e.g. several types of software programs were used in the organization of vaccine), we have generalized the components for the purposes of clarity.

4.4 System functions

Sixteen system functions (middle row, Figure 4.1) were developed by considering that separate abstract functions act as a link between components on the one side, and values and functional purposes of the system on other, in line with Naikar (2013). In generating system functions, we also abstracted from interview text describing main tasks for the vaccination roll-out. The system functions identified aligned well with questions participants sought to answer at the outset of vaccine roll-out (data not shown).

4.5 Filling in component functions and using the analysis

A component function describes the functions of one or more structural resources. Component functions contribute to abstract system functions. Many possible component functions were possible and mentioned more or less explicitly. A sample of those mentioned in interviews were patient reception, mixing buffer and vaccine, reporting undesirable incidents (other than side-effects), shelter from the rain while queuing at vaccine centers, staff recruitment, sending text messages to the public, but there were many more.

Once developed, the analysis in Figure 4.1 was used to help understand interview comments, in the context of constraints and possibilities for action, and potential goal conflicts experienced. To illustrate use of the functional analysis, the red text in Figure 4.1 considers what happens when we enter the component function "registering vaccinations" – normally performed by entering data into a national database for registering vaccines and vaccinations or patient journal software on PC or tablet, or by filling out paper forms for digital registration later on. Registering vaccination contributes to several system functions: control over doses available in the local authority, control over how many doses a patient has received, control over side-effects, and helping IPH track progress of the vaccination program. By affording control over doses available in the local authority, registering vaccinations helps avoid wasting doses (a value), and so can help vaccinate as many people as possible as fast as possible (a functional purpose). On the other hand, if registration at vaccination centers take too much time, it may reduce the rate at which people can be processed (line processing rates), limiting the efficiency of vaccination. In this way the analysis helps consider how vaccine registration can influence functional purposes both positively and negatively; *how* vaccinations are registered influences the extent to which the system fulfils its functional purpose. One way to ensure people are vaccinated as fast as possible, for instance, is by making well-trained staff available at the vaccination centers to help with registrations. In this way, by considering component functions relevant to situational descriptions by participants and analyzing constraints and possibilities they afford for the system, a more complete analysis and understanding of bottlenecks is possible. Note that there are also other ways of using the functional account generated from participant views of the same system. Suboptimal system functions or value or goal conflicts could also be considered in terms of influence of and influence on the rest of the work domain.

5 Decision making challenges

Even though local authorities organized vaccine roll-out independently, common challenges to goal achievement (bottlenecks) can be identified, to which local authorities had to adapt. In identifying and describing these challenges, we have integrated findings from general cognitive task analysis questions with findings based on analysis of ten critical decisions, one each from ten participants: How to train staff arriving at the vaccination center due to start in half an hour (identified as critical decision by 2 participants); How to deal with changing dose intervals (1 participant); How to prioritize health personnel (2 participants); Whether to throw away or use vaccine doses (3 participants); and How to handle IT system crash at vaccination centre (2 participants). We identified seven bottlenecks for vaccine roll-out.

5.1 Short-notice coordination of patients, vaccine and staff

Pfizer vaccine is supplied in vials, which need to be brought to room temperature over two hours, before mixing with 1.8 ml saline (EMA, 2021). According to the original "on-label" instructions for approved use, each vial then contains up to 5 x 0.3 ml doses. Up until mid-May, longevity for unmixed Pfizer vaccine at 4°C was 5 days. According to one participant, longevity following mixing with saline at room temperature was shorter (10-12 hours) and after drawing up mixed vaccine into syringes shorter still. This was constrained efficiency in vaccine use:

> *"At that time, when Pfizer was drawn it had to be used straight away. Eventually we got longer on Pfizer after drawing out of the vial, but we didn't have it then, so we took out one vial at a time, mixed and used it, so we knew the whole time we were ok."*

Vaccine Centre Leader, M2

In the beginning, smaller local authorities were given only one, two or three vials a week, to be administered to small priority groups, and so vials and doses often had to be transported between dispersed locations. Coupled with short vaccine longevity, this created logistical challenges. The vaccine was also shipped in boxes containing several vials, so on splitting up boxes, local authorities had to improvise packaging solutions to transport only one or two vials at 4°C:

> *"We weren't sure how the vials would be distributed, which shape or type. When we wanted to distribute a few vials to each place, we didn't have a container to put them in. They came in small boxes, very nice, but then we had to send one vial to somewhere, so we had to make a polystyrene container. It was difficult if we had to divide up a small amount of vaccine to send to many places."*

Logistics Manager, M2

The need to control distribution and longevity constrained choice of vaccination strategy. One municipality could not ask health departments to vaccinate their own personnel as it had done in the 2009 pandemic, but rather had to use a central ambulatory service. Short vaccine longevity also created logistical problems when many doses were supplied. The problem then became how to find enough people in prioritized groups to be vaccinated within the time available. To plan how to do this, local authorities needed to know well in advance how much vaccine they would be getting and when. In practice, however, they were only given 5-10 days' notice, including weekends. Participants agreed that lack of control over incoming dose availability was one of the most difficult problems they faced. Predictable vaccine supply was also required to plan other system functions: choice of locale, staffing of locale, vaccine distribution, and communicating with the public:

> *«No…but the most difficult, maybe, that the whole time we haven't had the answers when people ask, When is it my turn? When can I get vaccine? And we haven't been able to answer because we don't know how many vaccines we will get.»*

Communications Manager, M1

Most local authorities recognized that IPH's hands were tied by variable and unpredictable supplies of vaccine to Norway, and that they could not have given a definite plan to the municipalities. Neither could they have created a permanent and robust "buffer" stock of vaccine to improve predictability, since this was not in line with the functional purposes of the system (as many and as fast as possible) and might have been difficult for the public to understand (public trust). Some of the Chief Doctors nevertheless thought that more could have been done, one commenting that it would at times have been possible to give a ballpark figure of the amount of incoming vaccine two weeks before they arrived, and that clearer and more visible information could have been given about how vaccine distributed among the different authorities. One described how lack of information on incoming vaccines created the need to adapt to achieve goals:

> *«It happened many times! What do we think we will get, how many doses do we get next week, including April/May when the GPs were going to vaccinate, so we had to just take a best guess, share out doses, assume we would get enough in the next 4 weeks. And of course we didn't. So not everyone got finished. We had to just decide whether we give most to the small GP centres so they can finish or how do we do it. It was very much think of a number and hope for the best…»*

Chief Doctor, M2

Lack of control over incoming dose availability meant that local authorities had to adapt rapidly and work intensely under pressure to avoid wasting doses, to keep the vaccination program visible and transparent to the public, and to keep doing things right. This issue is linked to the issue of availability of data systems to coordinate patient call-in and vaccine distribution logistics.

5.2 Establishing data systems for calling in patients and distributing vaccine to administration sites

Calling in patients. Before vaccine roll-out, participants from some local authorities anticipated a nationwide digital solution for mass vaccination, i.e. a database which they could use to identify and select patients in prioritized groups or at nursing homes, or those waiting for vaccines or who had not confirmed appointment times etc., and then call in those patients to appointments by automatically generating text messages. By January it was clear that no centralized solution would appear. Meanwhile, some local authorities had started working with suppliers of digital patient journals, and were able to identify and implement suitable solutions relatively quickly. Local authorities seem to realize at different times the need to act themselves, e.g. one implemented a solution as soon as December, while others started developing Excel sheets before realizing in the Spring they needed improved data solutions for the mass vaccination phase. One vaccine coordinator, recognizing a national system would not appear, described how they then had to decide and act quickly without involving staff representatives. Access to higher-level decision-makers within the local authority facilitated quick action.

Several participants recognized both pros and cons of centralized data systems. On the plus side, a vaccination module could have been built onto existing national digital health platforms, preventing confusion among some members of the public who expected solutions used by other local authorities to be used in their own local authority. By developing their own digital platform in collaboration with suppliers, however, local authorities could adapt the platform to suit their changing needs. For example, they could make their own variable filter categories or interpret authority requests to change dose intervals as they saw fit, and go in and adjust the platform accordingly. According to one participant, a national system would have been slower and less flexible to adaptation.

A common system would, however, help avoid fundamentally different formal approaches to calling in patients. Most local authorities we spoke to actively contacted people in the relevant priority group and invited them for vaccination, and some even thought that this was a condition that had been set by IPH or the health authorities. Some local authorities, however, appear to have asked people in the relevant group to contact the local authority, and that only then would they be given an appointment. One Chief Doctor thought that the latter approach was detrimental to the goals of vaccinating "as many as possible", especially near the end of the period when local authorities try to contact people who are hard to communicate with but who may still want vaccine:

> *"Compare [another LA] with us, for example, then you see that [other LA] had a large share of people who they have not had contact with during the vaccination and I think it is because they ask people to get in touch with them. We have a much lower share of people who we haven't been in touch with – they have only had contact with those who said "I want vaccine".*

Chief Doctor, M1

Distributing vaccines. A Logistics Manager we spoke to explained how they had used a lot of time independently developing an Excel spreadsheet giving an overview of the need for vaccine doses at different locations in the municipality. One use of the spreadsheet was to keep track of leftover doses made by GPs or others administering vaccine, due to patients not turning up, so that transport could be arranged to fetch and redistribute the doses. The sheet also helped deal with quite complicated logistics: how should the local authority deal out vaccines at different hours once they know who needs what where? The sheet also allowed the Logistics Manager to compare requests for vaccine made by different GPs or departments with health-critical personnel, to ensure that they were “sober” in their assessments of the number of people matching priority group criteria, or whether they were attempting to vaccinate as many of their people as possible. While we do not know whether similar spreadsheets were used by other local authorities, since the Logistics Manager we spoke to had a central role in organization of the vaccination program in their local authority, it is reasonable to think that local authorities using GPs to prioritise and vaccinate patients could have benefitted from a similar logistics system:

> *«If the municipality had had a good logistics system, logging system, common platform with the GPs, that would have made the situation easier. It could have been shared across the municipality, the public and the GPs could have talked to us, the GPs could have logged needs automatically instead of sending an e-mail that I then had to register myself on the Excel sheet.»*

Logistics Manager, M2

5.3 Extracting doses from vials

At early phases of a pandemic, when vaccines are in short supply, the average number of doses extracted from each vaccine vial has a direct influence on (i) the speed in which people can be vaccinated (as fast as possible), and (ii) the overall availability of vaccines (as many as possible). At the start of vaccine roll-out local authorities were advised by IPH to take out five doses from each vial of Pfizer vaccine, but after a few weeks, IPH recommended extracting six doses. Around the same time, one participant described finding a description of how to take out seven doses on Pfizer’s website, and recalled how their Chief Doctor had been surprised by a discrepancy between recommendations from IPH and details on the manufacturer’s website. One explained the discrepancy, describing how IPH are normally bound by what health authorities have approved, and therefore had initially recommended taking out five doses. Eventually, after moving to six doses, IPH left the decision about whether seven doses should be extracted up to each municipality’s Chief Doctor. Each local authority had effectively to decide whether it condoned “off-label” use of medicine, an expression that seemed to imply for some that they would be held accountable if anything went wrong[1].

We found diverse accounts of how many doses each local authority extracted from its Pfizer vials. One participant stated, “We have never got seven doses out”, and yet several others describe how extracting seven doses became the norm at their vaccination centers. One reported obtaining an average of 6.8 doses per vial in the main period of vaccination, while

[1] A contact from IPH subsequently pointed out that even though could recommend a procedure outside regulatory approval (i.e. “off-label” use), the term “off-label” would have still applied

another reported that together their local authority had managed to get almost several thousand extra doses out of the vials.

Some participants reported many discussions about whether to move from five to six doses, and even more discussion about whether extracting seven doses was defensible. In several cases this involved Chief Doctors championing six or seven doses, and convincing nursing managers responsible for the people who would have to extra the extract doses. A Vaccine Coordinator described the initial cause for concern about extracting seven doses:

> *"So we had a lot discussion for and against going for it. I am happy I criticized and asked questions at the start so that [the Chief Doctor] understood that this was a process for the staff who would work with the vaccine. It was not about changing procedure and that's that, because there is a safety margin that…when you extract using the new method you don't see completely clearly how much is in the injection so you have to trust that whoever has extracted the vaccine has done it right."*

Vaccine Coordinator, M1

The same coordinator said "it took weeks to convince me", but it was a "healthy" process in which the decision was made together. Similar process was evident in other municipalities, in which local authorities innovated procedures through negotiations between champions and reviewers.

Asked how core teams learned about the possibility of extracting seven doses, several commented on hearing "rumours", or gathering information from e-mails or "reading this or that" in the media about how others in Norway or other countries had succeeded, and searching to find the method they had used. One described how they bought a magnifying glass with a fitted light from a superstore to develop their extraction method, after reading about how others had done so. Another described finding documents linked via Facebook groups for doctors in Norway and consolidating learning through a chance conversation with a friend who worked for one of the first local authorities to report extracting seven doses. Yet another found out through their work on vaccine preparation with pharmaceutical technicians:

> *"No, there were of course rumours…but also when we worked with technicians experienced in professional extraction technique, she said look closely at this vial, so I tried to extract more, but I said clearly ok but we are not allowed to extract and mix vaccine from two different vials, so she sat and worked it out, let the vial stand and get the drops down from the side, and she got out seven doses. She was working with modern technique, which meant she worked up the seventh dose right from extracting the first dose, air in to get droplets down from the vial wall."*

Vaccination Centre Leader, M7

Opinions varied as to technique for extracting seven doses, with one commenting that the methods available from other countries were complicated involving the use of "several needles", but that "we tried to simplify, and it ended up being quite simple."

A Chief Doctor for one local authority who decided to routinely extract six doses at its centers, described how some GPs carrying out vaccinations took out five doses, some six and some seven – even though they had been instructed to take out six doses. Interestingly the comments imply a mental model that extracting seven doses was not permitted:

> *"I got questions in advance, can we extract seven doses, and I said no, because that was the message we got from the authorities. And they do it anyway. They ring me and say, "Shall I throw these doses or use them on this physiotherapist here?" So I say yes you have to use them even though it's actually not allowed."*

Chief Doctor, D2

It seems that those local authorities who worked out how to extract seven doses and started doing so acted largely independently of each other. What they had in common were Chief Doctors who were themselves sure that it was defensible to extract seven doses, and worked to convince others about it. Positive consequences assessed on deciding to extract seven doses included getting "more out of the vaccine we get" and that more vaccine sooner would be "better for the population". One Chief Doctor summarized:

> *"It allows us to finish earlier – another thing is that it makes more vaccine available for others – if enough people do it, it could also help other countries who can't afford or have less access to vaccine"*

Chief Doctor, M1

A clear negative consequence was the extra training burden:

> *"The disadvantage was that we had to be very precise about the training. We have our own people who sit and extract doses. On a busy day in the hall there are five people whose only job is to sit and extract doses into syringes, and that demands concentration."*

Chief Doctor, M1

Champions were careful, however, to ensure patients received full worthy doses of vaccine:

> *"To ensure everyone got a full dose we had to have a technique with an air bubble in the syringe and the syringe had to be set at the right angle, for the air bubble had to be at the top for it work. So we went round and saw how they actually administered, saw how some injected upwards, which they actually shouldn't do…but we were clear that if they think it is wrong, then it's wrong and they should tell us – for everyone should get their 0.3 ml."*

Chief Doctor, M1

For this reason, and because of the advanced medication technique, some saw an advantage in centralizing operations:

> *"We began quickly to extract "off-label", for the rumours flew that you get out more than five doses, but there was also a nursing home that couldn't manage to get out five doses, some managed only four, so … we decided quickly that the extraction was complicated, we should pull everything together."*

Vaccination Centre Leader, M7

Reflecting on whether IPH could have done more or less to encourage local authorities to extract seven doses, most seemed to think that IPH had got it about right to let each local authority decide, so that they could make decisions based on locally available competence and equipment. Not everyone agreed, however, some calling for a unifying strategy at national level, in which conditions for extracting seven doses in terms of method, equipment and technical competence were laid out, and where each local authority was not left to find out how to do things itself. One downside of allowing each local authority to decide itself, was that those who succeeded in getting out more doses, were uncertain how to use them when they had not planned for them. To cope with this, local authorities found ways to work around uncertainty:

> *«We knew that if we get 5 vials now we would get 5 vials for the second dose in 5 weeks' time, so if we got the extra doses out, we didn't know for certain we would get doses to match in the future, so there was a risk that some people wouldn't get their dose 2. To deal with this we used the extra doses on each other because we were health personnel and were weren't prioristised at that time, elderly patients were, but instead of throwing away doses, we used them on health personnel …and as soon as we were sure we could get 6 doses every time from a vial, we gave the extra doses to patients….[but]…we had a double account actually. IPH communicated and based calculations on 5 doses per vial, whereas we reckoned with six and eventually seven doses per glass."*

Vaccination Centre Leader, M7

> *"Now and then we get seven doses, but we have never reckoned with getting more than six doses per vial…no hang on, at the end when we called in patients for their first dose, we called in 10% more than we actually had doses for. Say that we had 10 vials, so there should be 60 patients called in, but we called in 66, we reckoned we would get seven extra doses out of those ten vials, and that was about right as it turned out. And then the longevity was increased, so we could store the vials for 30 days. So we made 3 vials as a buffer stock, so we could call in 10% extra. Then, even if we only got six doses per vial, we wouldn't have to send people home if we didn't get seven from any of them."*

Vaccination Coordinator, M3

A more serious downside of allowing each local authority to decide itself, was that vaccination went at different speeds in adjacent local authorities, a threat to fairness:

> *"We had a very good health nurse who was very concerned with following the guidelines, and that meant that we only took out five doses from each vial for a while. Then we decided together to extract six – but not seven – doses. But the local authority next to us extracted seven doses, so there was pressure from the media and politicians about why is it going faster with our neighbour?"*
>
> *Chief Doctor, M2*

5.4 Dealing with changing dose intervals

Many of the participants commented that changing recommended intervals between vaccine dose 1 and 2 was difficult for the local authorities to handle:

> *"One of the most notable changes we had to deal with was dose intervals, from when we started with short intervals between doses, which were then changed…from 21 to 28 days to six weeks, three months, back again, it affected us in terms of how we planned for patients and the staffing of the vaccination."*
>
> *Vaccine Coordinator, M5*

One health nurse was surprised that interval changes applied to those who had already received a first dose, such that appointments for dose 2 of the vaccines – already agreed and confirmed – had to be altered. A vaccine coordinator described how this was difficult to make sense of. IPH sent out doses such that second dose could be given according to the new intervals they had set, but changes became so routine that local authorities began to rely on them in order to cope:

> *"Then I judged that…for we aren't talking about so many people and in a way the dose supply had increased a lot, so I assumed the interval would change again, and anyway I could save up spare doses from the week before so I could give people their second dose at the originally agreed time even though in IPH's eyes it was too early."*
>
> *Vaccine Coordinator, M3*

Several local authorities were keen to stick to originally agreed intervals not to "mess people about" and to avoid a great deal of extra telephone work in making new appointments. Changed dose intervals also created a need for more medical assessments of individual cases (e.g. when the interval was increased from 3 to 6 weeks, the 3-week interval was kept for those with immunodeficiencies). A further consequence was that local authorities who had innovated and worked hard to get more doses out of each vial were caught short.

> *"We got out xxxxx extra doses…That means…we have vaccinated more people than IPH think we have. So when the first message came that we should go to 12 weeks interval, I had to ring IPH and say that's all very nice, but I don't have patients for more than eight weeks more of vaccinating according to what you think you will send us in the coming weeks. And then you get a message… then keep the 8-week interval…but people still think we will get 12 weeks and they ask, why not 12 weeks? Then 2-3 weeks go by and everyone goes down to 9 weeks. Luckily we hadn't moved to 12 weeks yet, so we didn't have to move all the patients, but after only 10 days we are up to 12 weeks again. Then we got told that even though we wouldn't have patients to vaccinate in the last three weeks, we had to do it, we had to move to 12 weeks, and that meant we had to swap 12,000 appointments. And then some weeks pass by and we get more doses and have to move the same group again to earlier appointments! Then we struggle with those who aren't too bothered about exactly when they get vaccinated, they have rearranged plans once and don't want to be bothered to change plans again. They think, ok I could get it in August but I will get it in September anyway, it doesn't matter to me. But we in the municipality have to move them, because we will get the doses earlier, and we can't store them or they'll be unusable."*

Chief Doctor, M1

Ultimately, participants were concerned about the effects on public trust when the changes frustrated people, increasing the load of enquiries to be dealt with by the local authority.

5.5 Prioritising patients

With a strain on hospital resources, concern in society, and few doses arriving in the first few months of roll-out, it was important for authorities to prioritize, (i) in a way that would most effectively prevent serious illness and reduce the treatment burden; and (ii) fairly. IPH issued clear higher-level descriptions of priority groups before vaccine roll-out, based on the findings of an expert group (Appendix 3). Despite this, local authority representatives reported that they were left with "more granular" prioritization decisions that were one of the most difficult challenges they faced during roll-out. Several mentioned also difficult decisions concerning borderline patients, but difficulties concerned mainly decisions about which health personnel were functionally most critical, a decision that local authorities felt was left up to them:

> *"We had to prioritize, but the message was you are worth more than others, and that affected the work environment, if you had seven that got and 35 that didn't. So it has been difficult for managers to sit with that out among their people."*

Chief Doctor, D1

Two of the local authorities reviewed procedures after reports that the "wrong" people had been vaccinated.

"It wasn't clear which health personnel we should prioritize. Health personnel are so many and diverse, who are they in relation to the legislation, in relation to function or what did they mean? We used a lot of time finding out who we should prioritize."

Vaccination Centre Leader, M7

One described how they tried and failed to get hold of people, who then got upset when they found out that vaccine had been used on others. Several local authorities asked GPs to provide lists of patients ranked in terms of priority, but found it difficult to ensure that GPs applied priority criteria consistently. One coordinator described this as a main reason why they chose not to use GPs in their vaccination program, but instead to centralize as much as possible:

"…we had much more belief that if we could manage this well ourselves, that we would be better placed to ensure we got results, rather than spread the work among [so many] GPs. We would feel a lot surer that we would prioritize groups."

Vaccine Coordinator, M7

It was clear that several of the Chief Doctors had used time and effort on questions of priority:

"…all those who got in touch and had very good reasons for a case assessment at individual or group level – I've used a lot of time on that."

Chief Doctor, D1

Some described how they made sense of the situation and adapted in order to deal with it:

"…sick children who weren't to have vaccine yet, even though there were good reasons to do so, but we couldn't do it, there were many cases where if we opened up for one, many more would come. So at the start we had to be strict and manage the process fairly,"

Vaccine Coordinator, M1

"…they have 3000 staff in Health and Wellbeing, so it's easy to pick out and prioritise the most critical 100 or 200, but if you have 1000 doses and limited time, we would have had to have a list of names and said [randomly] yes and no to each one, so we had to delegate the prioritization to each section."

Chief Doctor, D2

"each GP couldn't call in patients [randomly] based on the number of vaccines allocated, so we had a lot of discussion about which illnesses…how at the centre we have fixed criteria and say no to people who don't match them"

Vaccination Centre Leader, M2

> *"those that worked with developmentally challenged persons set themselves high up on the priority list, but drop-in medical service (legevakt) lower down…but we see the whole picture and of course ranked drop-in services as the most important in this system here. We gave clear guidance on how to prioritize but of course the needs of those like us are perhaps more visible to us…"*

Logistics Manager, M2

> *"it was terribly difficult, should we prioritize care assistants…vulnerable people are wholly dependent on them for their most basic needs, but they are a group without education and a weak voice…on the other hand dentists – who have strong representation – are protected, but then again dentists are exposed to infection."*

Chief Doctor, M2

Priority decisions were too complex to be based on a logical comparison of pros and cons, but rather solutions were found that they believed matched the circumstances well. The challenge of prioritization decisions was that once made, they were visible to all, and there were consequences for fairness of prioritizing differently within or across local authorities. There was, however, little central support to coordinate difficult decisions, just a message that "Local authorities are different so you have to prioritize yourselves". This approach fails to account for patients seeing others like them in the neighbouring municpalities getting vaccinated first, or for health personnel living in one local authority working in another local authority where colleagues have been vaccinated. Several representatives therefore felt a need for clearer guidance on how to prioritise groups to limit the consequences for fairness of varying assessments. One representative sought more discussion about priority decisions among neighboring municipalities to base decisions on a broader awareness:

> *"I missed a forum to discuss, what is right, what's most urgent, for I make decisions based on my information here in the municipality, but I sat with a feeling that there could be information I haven't thought about. One example was [profession], we use them in acute situations and they wanted vaccine, and I chose to give it to them, but the neighbouring local authority did not. I wondered whether it was right, whether others should have been first in the queue, and we got questions from the press about why we had done it."*

Chief Doctor, M2

5.6 Deciding whether to throw or use vaccine

Several participants described situations where the need to prioritize conflicted with the goal of vaccinating as fast and efficiently as possible. One critical decision involved a Chief Doctor deciding to vaccinate patients at care homes who fell just outside of the priority group criteria (85 years and over). It took time and resources to transport vaccine doses, to prepare them, and they had to be used up before it was too late. Including the few patients at each home who were slightly under 85 years old was much more effective than again having to transport and prepare vaccine for them again in the near future. Still, such decisions were not taken lightly and made despite:

> *"…enormous pressure, like everyone wanted to know who we had vaccinated, how old they were, which order, people were on us the whole time, private people, local people, but also the health authorities and IPH."*

Chief Doctor, D1

Another local authority described a situation in which there was little time left to use up extra doses it had managed to extract from the vials it was given. They had attempted to use the extra doses on people in prioritized groups, but were still left with doses to use. Rather than waste them, they found people to vaccinate who were known to be in a nearby location with society-critical roles, but they did not meet priority criteria.

> *"It was an ethical dilemma. Ok, we could have been better prepared in hindsight, but everyone was out and vaccinating at nursing homes, and we had a 16:30 deadline, sat with X doses we didn't have people for, no time left to ring round and find people, what do we do? We had to find people quickly."*

Vaccine Coordinator, M5

A third participant identified as a critical decision, a decision to use vaccine with very little time left before they went out of date:

> *"We had some vaccines…they had been opened such that they could only be used for ten minutes more…and we hear all the time, don't throw away, don't throw away, so we want to use them but were not sure whether we could. So we rang IPH and were unsure and they said they would check. Meanwhile we found information on IPH's website, with graphs and everything, it said it was ok, we all checked it. There was only a couple of minutes left, so we used it. Then two minutes after the deadline, they rang and said we shouldn't have done it, we should have been stricter."*

Chief Doctor, D2

In making this decision on consultation with a Vaccine Center Leader and an experienced nurse, the doctor had weighed up the goal of using all viable vaccine against the possibility of reduced effect or increased risk of side-effects, and weighed up the implications of complicating the way the vaccination was registered. Another concern was uncertainty created by having to swap vaccine to be used at the last minute, for the person vaccinating and the patient being vaccinated.

5.7 Balancing the need for operational staff with the need for training

Staff who are responsible for using vaccine should be suitably qualified. Under the pandemic, rules were relaxed somewhat to expand the pool of nurses who could be used in vaccination administration. Despite this, a highly unpredictable vaccine supply and variable infection levels presented a major challenge to vaccine center leaders, and others who had to ensure that an adequate number of suitably qualified staff were available to give sufficient capacity for administering incoming vaccines. Several mentioned that many pensioned health staff have been eager to contribute, and this has provided them with important flexibility that they have used to adapt to the changing situation.

Several commented on a conflict arising from need to find sufficient numbers of staff for vaccination venues at short notice on the one hand, and ensuring sufficient time had been given for adequate training on the other. This is a conflict between the goal to vaccinate people as fast as possible while doing things right, safely and in such a way as to maintain public trust. One critical decision we analyzed concerned how a Vaccination Centre Leader decided to deal with the challenge of getting the vaccine center up and running in a situation when a lot of staff that were new to the center arrived at 0800 h and needed to be trained to start at 0830 h. To adapt to this challenge, and limit the negative consequences in terms of mistakes in vaccination and reduced throughput at center, they (i) focused in on critical variables that new staff needed to have control over (e.g. right vaccine dose to right person); and (ii) paired new staff with experienced staff for 2-3 hours to guide the development of practical experience and "iron out" any remaining challenges.

The following comment explains how concerned Center Leaders were that staff were doing things right:

> *"This is new vaccine being administered at scale. There is no recipe for this [so] each and every day I have a fixed procedure outlining what we have to go through with the staff, as well as a morning report and an afternoon report. It's about logistical precision and repetition, you have to be on the hunt to make sure that everyone has understood the message. Sharing information is not always enough even if we do it every morning and afternoon, you must always be looking out to ensure, have they understood today? Double communication the whole time. Can you show me what I explained this morning, show me what you thought I meant."*

Vaccination Centre Leader, M2

Ensuring adequate quality in training in relatively advanced dose preparation was also a particular challenge, and especially in the early part of the vaccination:

> *"For the first preparations, there was almost no training. There were pictures, we had a folder with pictures, but it was clear to us then that this would be a challenge when we went out to the care homes 14 days later, and that we would need training even more for the staff there knew even less about how to prepare vaccines."*

Vaccination Centre Leader, M7

To solve this problem, core staff turned to others they knew to improvise a solution.

"But we knew they had done this at the hospital, so we filmed how they mixed and prepared the vaccine there with pharmaceutical technicians. Then we sent the film out, in close cooperation with a quality adviser for health who made routines to match the film. We continued to work on these routines, they developed over time, they were living, we tried to push things in the right direction the whole time, as changes to the number of doses to take out from each vial, longevity…"

Vaccination Centre Leader M7

6 Decision support needs

Based on the bottlenecks identified and common constraints that shape them, we have summarized some goal-critical difficult decisions. These are shown in Table 6.1 along with some ideas on how to support these decisions.

Table 6.1: Bottlenecks, with associated constraints (external, component oy functional) and difficult decisions. Functional constraints are system functions as numbered in the mid-row of Figure 4.1. LA = local authority.

Bottleneck	Common constraints			Difficult decision(s)	Comments	Support ideas
	External	Component	Functional			
1) Calling in patients, distributing vaccine and coordinating staff at short notice	LA has small numbers to be vaccinated in dispersed locations (early phase in vaccination program)	Guidelines – priority groups Vaccine – unpredictable, limited supply at short notice Vaccine – short lifespan	1,4,5,6,16	How to plan and execute in time given while (i) vaccinating safely, efficiently and transparently; (ii) not wasting doses, and (iii) in order of priority?	IPH distribute 1 vial to over 80 LAs in beginning – good for equity, but challenges logistics and efficiency LAs work independently on common logistics challenges	Development of decision support tool would save local authority time and resources, and make call-in and vaccine distribution optimally efficient (see below) Need way to explain complex challenges in simple terms for transparency with public Need way of developing shared situational awareness on ideas, strategies and consequences used across LAs
2) Establishing data systems for calling in patients and distributing vaccines	Available data systems	Vaccine – unpredictable, limited supply at short notice Vaccine – short lifespan Guidelines – priority groups PC, tablet, cell phone Software Paper forms	2,3,4,5, 10,11,16	How to set up a system to identify, call in and confirm vaccine appointments with prioritized individuals at short notice? How to know which centres need how many vaccine for who, where and when?	Lack of centralized system led to independent development of data systems and varying solutions Different systems can lead to confusion or perceptions of unfairness Advantage of independent system development by local authority could be tailorability?	Generically available, tailorable systems for patient identification and call-in; and distribution logistics Need way of developing shared situational awareness across LAs of systems and consequences
3) Extracting doses from vials	Formal and informal communication networks	Vaccine – limited supply Guidelines – recommended/approved doses extracted per vial Guidelines – dose intervals	7,12,16	Should we extract 5, 6 or 7 doses per vaccine vial?	In line with regulatory approval and changes by manufacturer, IPH recommended first 5, then 6 doses be extracted per vial. IPH eventually said up to each LA's CD to decide whether to extract 7 doses. Pros: CD best placed to know whether staff and equipment sufficient; Seven-dose extraction in line with vaccination as-fast/many-as-possible Cons: IPH do not account for 7 doses being extracted when calculating when to deliver dose 2; Extracting 7 doses causes prioritization dilemmas (how to use "off-label" doses?) and perceptions of unfairness among those whose local authority only extract 5 or 6 doses; No formal channels by which CDs learn about 7-dose-extraction, no centrally available method	Recommended seven-dose extraction method, with conditions for when it should be used. System allowing IPH to track how many doses per vial each local authority extracts Way of developing shared situational awareness across LAs of practices and consequences

Bottleneck	Common constraints			Difficult decision(s)	Comments	Support ideas
	External	Component	Functional			
4) Dealing with changing dose intervals	Developing scientific knowledge of most effective dose intervals	Guidelines – recommended dose intervals Vaccine – unpredictable supply from manufacturer	3,4,9,16	Should we rearrange vaccination appointments to account for adjusted recommended dose interval?	Yes: extra work (re-arranging appointments), but potential decrease in public trust; No: adaptations and workarounds, but potential perceived unfairness Change in interval does not account for LAs extracting more doses?	Make visible for IPH effects of changing vaccine dose intervals on actual practice by LAs, and different ways in which for public trust can be affected.
5) Prioritizing patients		Guidelines – prioritization groups	2,4	Which health-critical personnel should be prioritized? How to ensure individual case assessments applied consistently and fairly? Is it ok to vaccinate those almost matching prioritization criteria if much more efficient to do so?	LAs seek central guidance on which health personnel should be prioritized; different decisions by different LAs leads to perceived unfairness Despite criteria, priority patient assessments by GPs lead to discrepancies and possible unfairness – need for quality assurance Goals in conflict: Vaccination as-fast-as-possible and matching priority criteria. LAs choose vaccination as-fast-as-possible if they have to.	Provide clear criteria or definition for critical health personnel – develop in collaboration with local authority panel.
6) Deciding whether to throw or use vaccine	Distance to and availability of prioritized patients	Guidelines – prioritization groups Vaccine – short lifetime, limited supply Contact details – prioritized patients and staff	1,2,4,10,11	How can I find people matching priority criteria in short time to use vaccine? If I can't do this, how can I find people who almost match priority criteria? Can vaccine be used even if it close to lifetime?	Difficult decisions natural result of adaptation as LAs try to vaccinate as fast as possible and not waste vaccine But "not doing things right" and can result in perceptions of unfairness and negative vaccination experience	Practice scenarios - what to do if priority group not available?
7) Balancing needs for staff operation and training	COVID-19 infection levels LA policy – can staff be recruited from other departments?	Vaccine – unpredictable, limited supply at short notice List of human resources, qualifications and contact details e-learning software	6,10,11,12, 13,14,16	How to find qualified staff at short notice? How to train staff at short notice?	Challenge greater for LAs extracting 7 doses – more training needed	LAs could know in advance non-critical departments that can be scaled down; staff could be prepared for vaccine work in advance Need way to share staff availability across different across LAs Pensioned medics be set on "pandemic standby"

7 Discussion

Using an approach based on Cognitive Systems Engineering (CSE) we interviewed key actors to investigate bottlenecks in the joint cognitive system organizing vaccine roll-out by local authorities in Norway in the critical COVID-19 vaccination period from January to August 2021. Bottlenecks were identified from accounts of cognitive tasks in the context of functional constraints shared by the different local authorities. Addressing these bottlenecks in the ways we suggest could lead to improvements to joint cognitive systems organizing urgent nationwide vaccine roll-outs. More knowledge is needed, however, on how collaboration and communication can be changed to ease the decision bottlenecks identified.

7.1 Study limitations

Although resource-intensive, a CSE approach to understanding challenges that people in key roles experienced as they worked in real local vaccine roll-out systems has been useful in that it has helped identify critical issues faced by people in complex systems. The picture of the challenges we have drawn should be useful for stakeholder discussion and system improvements. One limitation of this first study phase has been the limited number of participants from which we have built our functional account of local vaccine roll-out and attempted to understand challenges for decision makers there. There are many more actors and more local authorities in the real system, more situated contexts and stories to learn from. Still, the pace of modern research increases in line with the complexity of our systems and there has been a need to balance time taken to generate research findings with the need to know about important patterns in complex systems.

While we have attempted to be as explicit as possible about the process used to generate observations and patterns to be functionally accounted for, it has not been possible to describe explicitly how we identified bottlenecks insight about the "deeper dynamics" of complex social systems. This is related to the difficulties of warrant in functional analysis and the use of insight in CSE (Woods, 2003). Finally, only one researcher has coded the text, we do not think this has compromised the study because the nodes used are easy to understand and coding of a randomly selected interview by a second rater showed close agreement.

7.2 Implications of findings

Through CSE, we identified 16 system functions to be performed to organize roll-out such that as many people as possible are vaccinated, as fast and as fairly as possible, in the order set out in authority guidelines, and while maintaining public trust in the authorities' handling of the pandemic. These functions are needed to ensure that the "three flows" of vaccines, patients and staff (Decouttere et al., 2021b) are aligned with system values and goals, and should be supported when designing improved roll-out systems. Attempts at improvements should also consider other functional constraints on local authority actors, including values influencing how goals are achieved through system functions (e.g. a wish to avoid wasting doses, or carry out a safe and transparent vaccination). System developers should also consider constraints in the shape of external influences, not least vaccine supply, and the components and component functions available to carry out system functions.

Of the challenges to decision-making identified, decisions about the number of doses extracted from vials were perhaps most critical, having a direct impact on the tempo and efficiency of vaccination. Making the “right decision” here is important. On the one hand, it is essential to achieve vaccination as fast as possible in situations of limited vaccine supply and high demand; on the other, municipalities must now exceed their ability to extract doses safely and reliably. A comparison of sensemaking among representatives from different local authorities showed that they sought information from different channels on different approaches to dose extraction. Coordination between national health authorities and manufacturers to generate standard guidelines for extracting different numbers of doses (five, six *or seven* doses from a Pfizer COVID-19 vaccine vial, for example) depending on explicit preconditions and available resource and competence, would promote shared awareness and understanding about how to safely extract as many doses as possible. Better use of data on how many doses each local authority actually extracts would prevent IPH recommending changes that are difficult for more innovative local authorities to handle. Stakeholder-centered development of more detailed guidelines on how to prioritize patients and health personnel would help avoid perceptions of unfairness by the public, as would full consideration by national authorities of the impact that frequent changes to guidelines have on organization of vaccine roll-out at local level, and that ultimately may be detrimental to public trust. Development of generic but adaptable data systems to help organize patient and vaccine delivery logistics at local level would also optimize effectivity and save local authorities valuable resources and time. Finally, proactive attempts to increase coordination between crisis actors representing different local authorities would increase shared awareness of common challenges, good solutions and discrepant approaches, and help avoid confusion or perceptions of unfairness among the local authorities’ inhabitants. Increased coordination would also allow each local authority to focus on its goals while ensuring its decisions and actions are cohesive with overarching system goals. Further openness might also be promoted by stronger profiling of key point indicators for local-level vaccination roll-out, or identification of new ones (see Pires et al. (2014) for a discussion on this in the context of sustainable development).

Drawing on our findings on challenges to decision-making, we have speculated on decision needs and ideas for solutions. In the context of the multi-team literature, developing optimal joint cognitive systems for nationwide vaccine roll-out is not just about local authorities aligning activities and goals with those of national authorities, but a two-way iterative process in which national authorities and IPH coordinate to ensure alignment with the different strategies local authorities use to achieve nationwide goals. In trying to achieve these goals, some local authorities innovated to extract as many doses as possible, only to find that the surrounding system did not always support them. Maintaining public trust was also misaligned with some actions at national authority level. The challenge for IPH and national health authorities is how to coordinate, communicate and understand the varying strategies and affordances of 356 local authorities. We have not in this study been able to understand IPH’s situated context fully, but doing so would help understand how to solve this problem.

Understanding of local authority strategies by national advisers and authorities, and accounting for them in changes of national strategy, would allow local authorities to act more freely as units of adaptation. In the real-world contexts, improvised data systems, pensioned health workers and extra “off-label” doses afford much-needed flexibility to adapt in the face of unpredictable vaccine supply, staff shortages and changing dose intervals. These affordances can be threatened if national strategy does not support their use. It is also clear that as units of adaptation, each local authority depends on other local authorities for success. This is apparent in the exchange of knowledge through formal (e.g. weekly meetings of Chief Doctors; and with hospital doctors) and informal channels; in the flexibility afforded by borrowing vaccine doses from neighbouring authorities in later stages of the program; and in the confusion caused as differences in vaccination tempo or prioritization of patients became apparent and exploited by the media. Increased alignment and coordination may afford increased resilience in vaccine roll-out by local authorities.

Interestingly, several of our findings echo those found by an evaluation of influenza pandemic vaccine roll-out in 2009 (DSB, 2010). These are:

- local authorities performed well on the whole, not least due to strong community spirit
- potential for improved interactions between local authority and national health authorities
- challenges with identification of risk groups for vaccination by local authorities
- perceptions by local authority inhabitants of “postcode lottery”

Some of the recommendations from the previous evaluation were also similar: increased collaboration between local authorities to promote shared understanding; and establishment of automated systems to harmonize and increase the efficiency of calling in patients for vaccine (DSB, 2010). An important question then is why little seems to have changed over a decade later. One possibility is that there are deep dynamic forces at play that are still to be understood and leveraged. If this is the case, then the recent availability of system models (Decouttere, 2016; Boey et al., 2022) and the cognitive systems approach taken in this article should have developed understanding of some of these forces. Another possibility, however, is that resources at authority level could limit what can be implemented between pandemics.

Finally, we wish to mention some points that were critical to participants but did not fit with the structure of our current presentation. Firstly, all participants agreed that local authorities had generally achieved their goals successfully. Our study is just as much one of how the joint cognitive system was able to adapt to succeed as it is of the “bottlenecks” to be adapted to. Indeed, vaccine COVID-19 was rolled out largely to plan, despite the challenge of continual change and ongoing infection, and public trust remains high in Norway relative to many other countries. Organizational culture, a strong community spirit and extremely hard work among local authority staff and volunteers were, for participants, key elements to success. One Chief Doctor reported over 500 hours of overtime for the first 8 months of the roll-out as typical. Other common organizational traits espoused by participants also point to contributors to success: proactive willingness to contribute; a focus on continuous improvement; dedicated core project group with few, motivated members; an open, collaborative culture in which decisions are made together and supported by easily accessible higher-level managers; and hands-on observation by decision-makers and continual dialog with those involved in day-to-day events. Researchers should bear this in mind when reflecting on our findings and comparing them with those from other countries.

7.3 Conclusion

Studying Norway, we have used cognitive systems engineering approach to identify bottlenecks commonly experienced by local authorities organizing vaccine roll-out. These bottlenecks are formed by the need to adapt to shared constraints imposed at national level. They would be reduced by increased or alternative coordination allowing local and national authorities to mutually and iteratively align strategies and goals.

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Appendix 1 – CTA questions

1. Can you tell us about your background and current position in the municipality?
2. Concerning how vaccination is organized by the municipality:
   a. What are the municipality's goals?
   b. Can you describe what the municipality has to do to organize vaccination?
   c. Who is responsible for what?
   d. Who does what?
3. Concerning *your role* in organizing the vaccination:
   a. What have been your main goals?
   b. What have you done to achieve these goals?
   c. Can you break this down into 4 to 6 main tasks?
4. For each task identified, as appropriate:
   a. Can you give me the big picture?
   b. What questions do you have as you approach this task?
   c. How do you answer? Which information do you need? What do you have to follow up or monitor?
   d. What makes things go well?
   e. Has anything happened to cause problems? What are the most critical challenges?
5. Startup:
   a. How did you find out what to do?
   b. How were tasks distributed among roles?
   c. Was there any training involved?
6. Decision-making:
   a. What are the most important decisions you have had to take?
   b. Which have been the most challenging?
   c. What did you think about at the time?
   d. Information:
   e. Can you describe an instance where you have had to act based on limited information?
   f. How did you look to review the situation to account for new information?
7. Collaboration:
   a. Which other actors are important for you in your work?
   b. How is your work influenced by communication or actions of actors outside the municipality?
8. Sustainability:
   a. Can you describe the work in terms of efficiency? Were priority groups vaccinated as quickly and effectively as possible?
   b. Can you describe the work in terms of waste avoidance?
   c. Can you describe the work in terms of fairness? Were all people in a priority group equally informed and have access to vaccine?
   d. How were each of these factors influenced by communication and action of actors outside the municipality?
9. Shortened Critical Decision Method based on Crandall et al. (2006):
   a. Can you think of an incident or difficult situation in which you had to make a critical decision, a decision where you lacked sufficient information or knowledge on which to base the decision? It can be a decision involving other actors or organizations.
      Choose most suitable decision for analysis
   b. Can you tell a story about the events in the order in which they happened? What happened when?

1. Identify key decision point(s) and run through or select from following probes:

If you had to describe the situation to another at that moment, how would you summarise the situation?
What were your goals at the time, what was the most important thing you were trying to do?
What did you know? What didn't you know?
What information did you use to make your decision? Where did it come from? How did you use it?
What other decisions could you have made at the time?
How did you choose to act as you did?
Was this a familiar situation?
Can you describe any training relevant to the situation or decision?
Was your experience from other situations relevant?
What told you that that was the right decision?
How long did it take to make the decision? Was there time pressure?
Did you consult with others?
How did you know whether to trust any advice or guidance you got?
What information could have helped you?

Appendix 2 – Coding scheme

Table A1: Coding scheme with number of coded text passages entered under each code.

Role	Interview	Goals	Values	Actors, roles	Functions (goal-related)	Actions (tasks that provide functions)	Resources, tools, affordances (provide actionable possibilities)	Organisation and infrastructure	Constraints	Information	Decision-making (goal-related)	Expectations (goal-related)	Planning (for Actions)	Adapting, re-planning	Coordinating actions	Sensemaking	Total
Chief Doctor M1	1	19	16	29	12	19	10	10	14	17	5	3	11	7	25	9	206
Vaccine Coordinator M1	2	11	5	17	5	16	14	2	17	35	22	2	12	8	17	21	204
Communications Manager M1	3	5	4	6	0	4	2	0	6	11	3	2	0	0	8	8	59
Chief Doctor M2	4	13	7	11	4	1	2	6	3	14	9	0	4	4	19	13	110
Vaccine Coordinator & Centre Leader M2	5	7	2	12	2	1	5	7	5	17	14	1	3	11	13	13	113
Logistics Manager M2	6	6	10	5	6	11	4	9	7	13	8	0	7	8	22	9	125
Vaccination Coordinator & Centre Leader M3	7	5	6	6	1	3	6	5	15	7	3	1	1	9	10	6	84
Chief Doctor M4	8	4	3	6	1	4	2	4	0	8	3	0	2	5	14	3	59
Vaccine Coordinator M5	9	7	5	8	1	5	4	4	3	6	9	5	4	5	10	5	81
Vaccination Centre Leader M6	10	5	4	6	3	4	11	0	1	9	6	0	6	9	8	2	74
Vaccination Coordinator M7	11	3	5	7	0	4	12	2	9	21	7	1	7	9	25	8	120
Vaccination Centre Leader M7																	
Chief Doctor D1	12	6	4	6	1	0	7	1	3	13	13	0	6	9	14	6	89
Chief Doctor D2	13	0	13	11	2	0	2	3	1	16	9	0	1	4	13	5	80
	Total	91	84	130	38	72	81	53	84	187	111	15	64	88	198	108	1404

Appendix 3 – Priority groups

Order of priority of vaccination for groups with increased risk of serious outcomes

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1 Care home inhabitants (n = 40.000)

2 Age 85 years and over (n = 120.000)

3 Age 75-84 and over (n = 290.000)

4 Age 65-74 years (a), people aged 18-64 years with high risk (b) (n = 1.540.000)

5 Age 55-64 years with underlying illness / condition (n = 175.000)

6 Alder 45-54 years with underlying illness / condition (n = 125.000)

7 Alder 18-44 years with underlying illness / condition (n = 160.000)

8 Alder 55-64 years (n = 650.000)

9 Alder 45-54 years (n = 745.000)

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