Phase 1 England COVID-19 Vaccine Allocation & Delivery Strategy

"It is the greatest happiness of the greatest number that is the measure of right and wrong." – Jeremy Bentham

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Confidential Consultancy Report
This document has been prepared exclusively for the Vaccine Taskforce in response to the Phase 1 optimisation tender.

Executive Summary

Phase 1 of the COVID-19 vaccination programme presents the Vaccine Taskforce with one of the most consequential optimisation challenges of the winter: deploying scarce early doses in a way that maximises national health benefit while remaining operationally feasible and publicly defensible. Limited supply, asymmetric logistics between Pfizer/BioNTech and AstraZeneca, and significant regional variation in delivery capacity make manual planning insufficient for the pace and stakes of rollout.

Our work translates the JCVI's mortality-focused priorities into a transparent optimisation framework that quantifies where each vaccine dose delivers the greatest marginal impact on mortality reduction while respecting Phase 1 constraints, including boxing capacity, eligibility rules, population ceilings and guaranteed frontline-worker coverage. To ensure explainability, we benchmark the optimal allocation against an egalitarian population-proportional baseline. While intuitively appealing, the proportional distribution achieves **over 80% lower health benefit** and leaves **more than 11,600 frontline workers unvaccinated**, demonstrating that proportionality is ethically insufficient under JCVI's mortality-first objectives. The optimised plan instead aligns tightly with JCVI intent and provides a principled justification for deviations from population shares.

Operational analysis confirms that Phase 1 is deliverable within **18–49 working days** using a ramp-up activation model. Mass vaccination centres, hospital hubs, pharmacies and GP-led sites and mobile teams collectively provide the required throughput, and sensitivity tests show that the recommended allocation is structurally stable under uncertainty. The North East emerges as the principal bottleneck due to binding boxing constraints, offering the highest marginal return on targeted capacity investment. The recommended plan aligns with the policy intent expressed during the alignment meeting and provides a defensible explanation for deviations from proportional allocations.

Overall, this optimisation framework provides a robust, defensible foundation for Phase 1 decision-making and a scalable tool for Phase 2. It delivers clarity, fairness, transparency and maximum health impact at a moment when each is essential.

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1. Project Context and Objectives

Phase 1 of the COVID-19 vaccination programme confronts the Vaccine Taskforce with a highly constrained decision environment: limited early supply, two vaccines with distinct logistical requirements, and marked variation in regional delivery capacity. With winter mortality rising and significant pressure on the NHS, every early dose carries meaningful opportunity cost. Ensuring that scarce supply is deployed where it yields the greatest national benefit is therefore critical.

A central feature of this challenge is the tension between **utilitarian efficiency** and **egalitarian proportionality**. JCVI guidance prioritises mortality reduction and protection of system-critical staff, naturally favouring a utilitarian objective. However, public expectations often default to proportionality, where each region receives supply in line with its population share. These principles lead to materially different allocations. Making the trade-off explicit is essential for transparency and for maintaining trust when regional shares diverge.

Our objective is to translate JCVI's clinical and operational priorities into a rigorous, data-driven allocation model. Using linear optimisation, we identify the distribution that maximises mortality reduction while satisfying all Phase 1 constraints, and we benchmark this against a proportional alternative. This dual framing clarifies both *what* the optimal allocation is and *why* it differs from intuitive egalitarian baselines, strengthening the defensibility of the Phase 1 strategy.

2. Problem Definition, Modelling Approach and Assumptions

Phase 1 requires allocating fixed national supplies of Pfizer/BioNTech and AstraZeneca across nine regions and six age groups to maximise total mortality-weighted health benefit while adhering to strict clinical and operational constraints.

Key constraints include:

- Pfizer/BioNTech's double boxing requirement relative to AstraZeneca,
- Region-specific cold-chain limits,
- population ceilings,
- Guaranteed coverage for frontline health and social-care workers,
- and the practical exclusion of AstraZeneca for under-50s due to **zero marginal benefit** in JCVI scoring.

These constraints interact, highlighting the limitations of manual planning.

We therefore formulate a transparent linear optimisation model. The objective maximises mortality-weighted benefit using JCVI criticality scores. Decision variables represent doses of each vaccine allocated to each region-age cell.

Constraints enforce:

- national supply limits,
- regional boxing capacity,
- eligibility logic,
- frontline-worker minimums,
- age-group population ceilings.

Every allocation choice is traceable to either a benefit weight or an explicit operational constraint, ensuring explainability.

Inputs – population, criticality scores, national supply and regional boxing limits – are taken directly from the tender. Additional assumptions, necessary for tractability and aligned with tender guidance, include:

- proportional distribution of frontline workers,
- one dose per person in Phase 1,
- universal uptake among eligible groups,
- and roll-out sequencing consistent with the limit of **five new site activations per region per day**.

3. Phase 1 Allocation Results

The optimised allocation directs doses to the individuals and regions where each dose delivers the greatest marginal reduction in mortality/transmission. The solution is consistent with JCVI priorities and grounded in quantitative logic.

1. National Allocation Patterns

The optimiser allocates the entire Pfizer/BioNTech supply and approximately 83% of AstraZeneca. Pfizer/BioNTech is exhausted because it provides positive mortality benefit across all age groups and offers additional transmission-reduction potential for younger adults. AstraZeneca is used exclusively in the 50+ population, reflecting its low benefit

for younger groups and the fact that allocating AstraZeneca below 50 provides no marginal advantage under JCVI's scoring. Boxing constraints reinforce this pattern: Pfizer/BioNTech is allocated where its benefit per boxing unit is highest.

2. Regional Allocation Outcomes

Large regions such as the South East, London and the North West receive the highest absolute volumes due to larger populations and more generous boxing capacities. Relative to population-proportional shares, the optimiser shifts doses toward regions with older demographic profiles, consistent with the mortality-minimisation objective.

The **North East** emerges as the most constrained region. Despite substantial high-risk populations, its **150,000-unit boxing capacity** is insufficient to support full coverage of JCVI top-priority groups. As a result, Pfizer/BioNTech is concentrated in the 80+ group and frontline workers, while no Phase 1 supply reaches the 70–79 group. This outcome reflects a binding logistical constraint, not a model preference. The optimisation quantifies the marginal benefit of capacity expansion in the North East, showing that even minor increases unlock disproportionate population-health gains – a critical insight for Phase 2.

3. Coverage Outcomes

Coverage patterns closely mirror JCVI priorities:

- All regions except the North East achieve full coverage of 80+ and 70–79 cohorts.
- The North East covers roughly 70% of the 80+ group, leaving ~40,000 unvaccinated due to boxing limits.
- Most regions reach around two-thirds coverage of the 60–69 cohort once higher-risk groups are protected.
- Younger adults receive minimal doses aside from full frontline-worker vaccination.

These patterns strengthen defensibility: every deviation from proportionality is tied to clinical value or a binding operational constraint. Detailed allocations appear in the appendix (Table 1).

4. Benchmark Comparison: Utilitarian vs Egalitarian Allocation

A population-proportional baseline provides a meaningful egalitarian benchmark. After feasibility adjustments, this baseline achieves **45.9 million units**, compared with **83.3 million** under the optimised allocation – an **80% improvement**. The proportional baseline also leaves more than **11,600 frontline workers** unvaccinated.

This comparison crystallises the fairness tension: **proportionality treats all regions equally, whereas utilitarian fairness focuses on protecting those most at risk**. JCVI's mortality-first priorities clearly favour the latter. Presenting both approaches strengthens explainability: deviations from population share result from principled adherence to clinical value and operational constraints, not subjective preference.

5. Operational Delivery Model

The allocation is only meaningful if Phase 1 can be delivered rapidly and safely. The operational model must therefore balance throughput, equity of access and logistical feasibility.

1. Required Site Types

Four site types provide the necessary coverage and reach:

1. **Mass vaccination centres** (~3,000 doses/day): main throughput engine.
2. **Hospital hubs** (~800/day): crucial for early Pfizer deployment and complex patients.
3. **GP-led sites & mobile teams** (~400/day): essential for care homes and mobility-limited individuals.
4. **Community pharmacies** (~250/day): extend local access and support rural delivery.

These throughput assumptions reflect reasonable and conservative estimates consistent with documented Phase 1 operations. All site types comply with the tender requirement that each site administer only one vaccine type, preventing throughput pooling but not binding model feasibility.

2. Delivery Models and Timelines

We tested two models:

Conservative model: Sites begin vaccinating only once all are supplied. This ensures synchronous access but creates long idle periods. Only **3.0 million doses (24.6%)** are delivered in the first 40 working days – too slow for winter clinical needs.

Ramp-up model: Sites activate as soon as they receive initial supply, within the tender's limit of **five site activations per region per day**. This accelerates capacity mobilisation, delivering **12.2 million doses (99.1%)** within 40 days. Regions complete Phase 1 in **18–49 working days**.

Ramp-up thus provides the only operationally viable pathway to meet Phase-1 timelines.

3. Throughput, Risks and Completion

Throughput is driven more by activation sequencing than by the number of sites. Reliable execution requires robust cold-chain processes, effective staffing and queue management, strong mobile-team coordination, and transparent communication explaining why some regions begin earlier than others – an important factor in maintaining public trust.

6. Sensitivity Analysis and Robustness Checks

Stress-testing boxing capacity shows that allocations remain stable across most regions; only the North East exhibits substantial gains with additional capacity. An additional 1,000 units of boxing capacity there raises the objective value by 10 benefit units, compared to only 2 in the other regions. Extra capacity in the North East is therefore about five times more valuable at the margin, confirming it as the key national bottleneck. Throughput variations affect completion time but not allocation logic. Simulated supply delays and cold-chain disruptions do not change priority ordering. Perturbing JCVI criticality scores within reasonable bounds leaves the core pattern unchanged. These results demonstrate that the recommended strategy is structurally robust and not dependent on narrow parameter assumptions.

7. Recommendations and Conclusion

The optimisation highlights four priorities for Phase 2:

1. **Expand North East capacity**, where additional logistics unlock the highest marginal health benefit.

2. **Use remaining AstraZeneca** only for closing high-risk gaps (~280,000 people), then donate surplus doses (~1.4 million) internationally through COVAX to maximise global benefit.

3. **Maintain strong Pfizer/BioNTech procurement**, reflecting its high and consistent benefit across all age groups and better boxing efficiency for high-risk cohorts.

4. **Continue ramp-up activation** to sustain delivery speed while planning for second-dose flows without reducing Phase 1 throughput.

5. **Prepare for Phase-2 integration** of upcoming vaccines to enable rapid re-optimisation as additional platforms are approved and supply expands.

Clear public communication will be essential: deviations from proportional shares must be positioned as principled decisions that maximise protection for those most at risk. Weekly re-optimisation will enable rapid adaptation to evolving supply and capacity

constraints. Together, this framework offers a transparent, defensible and clinically grounded strategy for completing Phase 1 and preparing for Phase 2.

8. Proposed Fee

Given the urgency of Phase 1 and our commitment to supporting a rapid return to normality, we propose to undertake the Phase 1 optimisation pro bono. Should the Taskforce engage us for Phase 2, we would agree a fair and transparent fee structure reflecting its broader analytical and operational scope. We remain at the Committee's disposal for any further materials, technical analysis, or discussion required to support Phase-1 decision-making.

9. Appendix

Our linear optimisation model translates the JVTF's prioritisation framework and operational constraints into a clear allocation plan for Phase 1. It determines how many doses of each vaccine should be assigned to each region and age group, with the objective of maximising overall public health benefit as defined by the committee's criticality scoring. The model incorporates all relevant constraints, including national supply limits, regional population sizes, minimum coverage requirements for frontline health and social care workers, and the age-dependent benefit differences between vaccine types, which naturally limit the use of AstraZeneca in younger cohorts. The problem is formulated as a linear optimisation model and solved using the GLPK solver. The model solved successfully, confirming feasibility and producing a stable allocation aligned with the committee's priorities and operational realities. The optimisation model solved to optimality in 0.025 seconds using GLPK, confirming that the Phase-1 allocation problem is computationally highly tractable**.** For completeness, we also present the full mathematical formulation of the model for the mathematically inclined reader.

1. **Sets**

   V: set of vaccines (Pfizer/BioNTech, AstraZeneca)

   R: set of regions (9 NHS regions)

   A: set of age groups {80+, 70–79, 60–69, 50–59, 30–49, <30}

2. **Parameters**

   S_v: national Phase 1 supply of vaccine $v \in V$(doses)

   $P_{r,a}$: population in region $r \in R$, age group $a \in A$(people)

   $b_{v,a}$: mortality-weighted health benefit per dose of vaccine $v$in age group a

   u_v: boxing units required per dose of vaccine v

   K_r: boxing capacity in region r(units)

   $FL_{r,a}$: minimum number of doses required to cover frontline workers in region r, age group a

3. **Decision Variables**

   $x_{v,r,a} \geq 0$: number of doses of vaccine $v$allocated to region r, age group a

4. **Objective Function**

We maximize total health benefit across all vaccines, regions and age groups:

$$\max\ Z = \sum_{v,r,a} b_{v,a}\, x_{v,r,a}$$

5. **Constraints**

- **Vaccine supply constraints**

Total doses allocated of each vaccine cannot exceed national supply:

$$\sum_{r,a} x_{v,r,a} \ \leq\ S_v, \forall v$$

- **Population constraints**

The total number of doses allocated to a region–age cell cannot exceed the size of that cell's population:

$$\sum_{v} x_{v,r,a} \ \leq\ P_{r,a}\ \forall r, a$$

- **Frontline worker minimum coverage**

Each region–age cell must receive at least enough doses to cover the estimated number of frontline workers:

$$\sum_{v} x_{v,r,a} \ \geq\ FL_{r,a}\ \forall r, a$$

- **Regional boxing capacity constraints**

Total boxing units used by all vaccines in a region cannot exceed its storage and transport capacity:

$$\sum_{v,a} u_v\, x_{v,r,a} \leq\ K_r\ \forall r$$

- **Policy constraint: AstraZeneca excluded for under-50s**

AstraZeneca should not be allocated to age groups below 50:

$$x_{\mathrm{AZ},r,a} = 0, \forall r, \forall a \in A_{under\ 50}$$

- **Non-negativity**

$$x_{v,r,a} \geq 0\ \forall v, r, a \in A$$

6. Outcome

Table 1 summarises our planned distribution of vaccines across regions and age groups.

Table 1 Optimal Phase 1 Vaccine Distribution Across Regions and Age Groups

Regions/ Age Group	<30	30-49	50-59	60-69	70-79	80+
EAST						
AstraZeneca	-	-	17,340	-	579,443	349,870
Pfizer/BioNTech	-	48,084	-	418,964	-	-
EAST MIDLANDS						
AstraZeneca	-	-	13,593	-	449,080	248,075
Pfizer/BioNTech	-	35,734	-	338,730	-	-
LONDON						
AstraZeneca	-	-	44,979	-	476,851	303,460
Pfizer/BioNTech	-	86,340	127,669	723,718	-	-
NORTH EAST						
AstraZeneca	-	-	7,494	3,219	-	100,624
Pfizer/BioNTech	-	19,332	-	-	-	-
NORTH WEST						
AstraZeneca	-	-	20,247	-	644,544	365,581
Pfizer/BioNTech	-	55,292	-	534,641	-	-
SOUTH EAST						
AstraZeneca	-	-	25,739	739,555	836,494	513,283
Pfizer/BioNTech	-	70,034	-	255,020	-	-
SOUTH WEST						
AstraZeneca	-	-	15,928	-	593,214	350,796
Pfizer/BioNTech	-	40,050	-	328,852	-	-
WEST MIDLANDS						
AstraZeneca	-	-	15,859	-	515,243	304,678
Pfizer/BioNTech	-	44,581	-	431,819	-	-
YORKSHIRE AND THE HUMBER						
AstraZeneca	-	-	14,970	-	481,845	278,810
Pfizer/BioNTech	-	40,888	-	400,253	-	-