Vaccine Demand Simulation and Optimization Report

1. Introduction

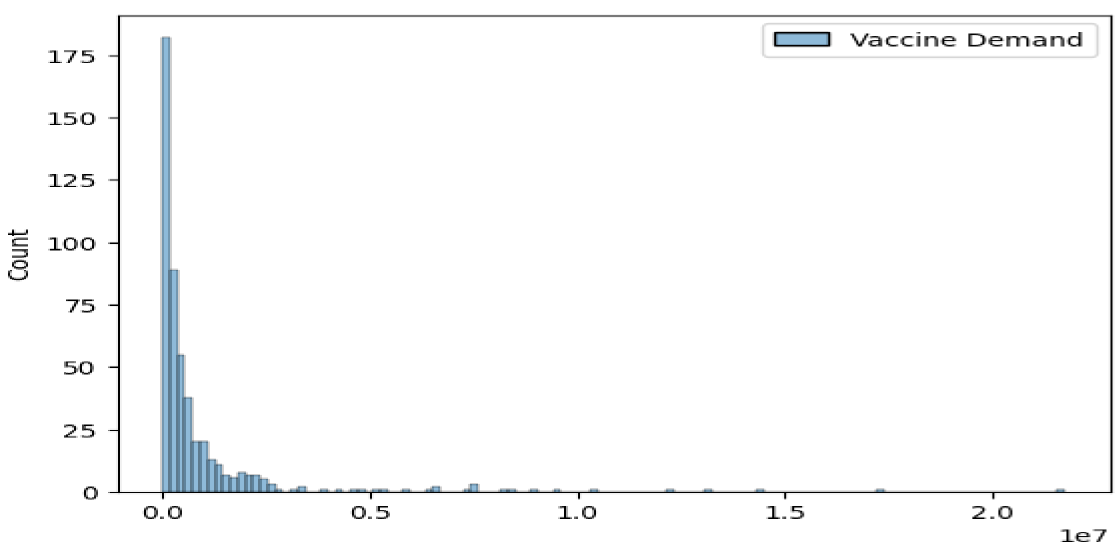
In the face of uncertain demand, ordering the optimal quantity of vaccines is a complex yet essential decision for healthcare providers. This report evaluates possible order quantities for vaccines, with the aim of maximizing profitability while minimizing the risk of stockouts. The demand data for vaccines is analyzed to determine an appropriate statistical distribution, followed by a Monte Carlo simulation to model various order scenarios. The insights derived from this report can guide decision-makers in optimizing their inventory strategy.

OuRx, a retail pharmacy chain, needs to determine the optimal number of flu vaccine doses to order for the upcoming flu season. Given the uncertainty in demand and the lengthy production lead time, OuRx faces the challenge of balancing profitability with the risk of either excess inventory or insufficient supply.

2. Demand Data Distribution Analysis

To accurately model vaccine demand, it's crucial to understand its distribution. A histogram of historical demand data, presented in **graph**, highlights the frequency of different demand levels. The distribution appears positively skewed, suggesting it may follow a log-normal or another asymmetric distribution.

Let x represent the seasonal demand for flu vaccines. Epidemiologists provided data to estimate this demand, with an extreme outlier (demand ≥ 30,000,000 doses) removed from the analysis. The histogram of the demand estimates, suggesting that the distribution may follow either a normal or triangular pattern. To evaluate the fit of both distributions, a $\chi 2$ (chi-square) goodness-of-fit test was conducted.



The histogram shows a highly right-skewed distribution of vaccine demand, with most values concentrated near zero and a few extreme high-demand outliers. This indicates that low demand is common, while high-demand spikes are rare but possible. This pattern supports the choice of a log-normal distribution for modeling and suggests a balanced ordering strategy to avoid excessive inventory costs while preparing for occasional high demand.

Goodness-of-Fit Testing $\chi 2$: By conducting a goodness-of-fit test on several candidate distributions (normal, gamma, uniform,and log-normal) to identify the most suitable model. The log-normal distribution was selected based on the highest p-value and best visual fit. Chi-Square Goodness-of-Fit Test Results:

- **For a uniform distribution**, the min estimate is 3157.000000 and the max estimate is 21738695.000000. The test statistic for a uniform distribution is 8694.279483 and the p-value is 0.000000. Uniform Distribution: (3157.0, 21738695.0)
- **For a normal distribution**, the mean estimate is 924033.462926 and the standard deviation estimate is 2069466.437573. The test statistic for a normal distribution is 2299.479433 and the p-value is 0.000000. Normal Distribution: (924033.4629258517, 2069466.4375729202)
- **For a gamma distribution**, the alpha estimate is 0.560517 and the scale = 1/beta estimate is 1648536.845273. The test statistic for a gamma distribution is 88.282388 and the p-value is 0.984214. Gamma Distribution: (0.5605173251512638, 1648536.8452732263)
- **For a lognormal distribution**, the log mean estimate is 12.622927 and the log stdev estimate is 1.486323. The test statistic for a lognormal distribution is 29.309394 and the p-value is 1.000000. Lognormal Distribution: (12.622926731401646, 1.4863231192380928)

Given its fit, the log-normal distribution was used in the subsequent simulation to model demand variability.

- Log mean (μ) = 12.622927
- Log standard deviation (σ) = 1.486323
- χ^2 test statistic = 29.309394
- p-value = 1.000000

3. Simulation Parameters

To simulate real-world scenarios and account for variability in demand, we set the following parameters:

- **Vaccine Price**: $20 per dose, representing the sale price of each vaccine dose.
- **Unit Production Cost**: $12 per dose, covering manufacturing and distribution costs.
- **Order Quantities Tested**: 400,000,450,000, 500,000, 550,000, and 600,000 doses

- **Number of Simulations**: 1,000 per order quantity, ensuring a robust set of results to analyze profit and stockout probability.

4. Monte Carlo Simulation Methodology

A Monte Carlo simulation was employed to evaluate different ordering policies under uncertain demand. This technique generates numerous possible demand outcomes based on the log-normal distribution and estimates the resulting profits and stockout probabilities for each order quantity.

5. Simulation Results and Analysis

The simulation is available here:
https://colab.research.google.com/drive/1G78nmq7YxwfXusZLP2-yx5XEK5phOSq2?usp=sharing

The simulation yielded insights into how varying order quantities impact expected profit and stockout risk.

Order Size	Expected Profit	95% CI for Net Profit	Probability of Stockout
400,000	$424,309.12	(-4,513,101, 3,200,000)	44.0%
450,000	$297,391.08	(-5,085,801, 3,600,000)	40.0%
500,000	-$56,014.07	(-5,650,710, 4,000,000)	36.0%
550,000	-$440,801.61	(-6,275,516, 4,400,000)	33.9%
600,000	-$648,744.54	(-6,919,820, 4,800,000)	31.3%