Memorandum

To: The Gates Foundations Date: February 21, 2025
From: DLAC LLC
Subject: Funding Proposal for ML-Based Pneumonia Detection in Bangladesh

1. Executive Summary

Investing $2 million in a Convolutional Neural Network (CNN)-based pneumonia detection system will significantly enhance diagnostic accuracy, reduce costs, and save lives in Bangladesh. Our model, trained on 2,872 child X-ray images, outperforms traditional methods, increasing accuracy by 2%, improving AUC by 1%, and reducing annual healthcare costs by $17 million. Further tuning optimized the CNN, achieving 99.83% AUC on an external test set. This investment will allow automation for the most confidently predicted cases, enabling doctors to focus on complex cases while augmenting remaining images to enhance accuracy. These improvements will reduce misdiagnoses, lower costs, and ultimately save more lives.

2. Background and Descriptive Analysis

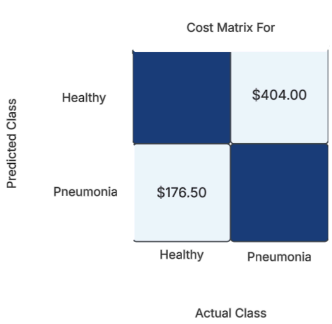
In 2018, it claimed the lives of over 12,000 children in this age group, accounting for 13% of all child deaths that year. According to an article published in the *BMJ Public Health Journal*, there are approximately 15.8 million children under the age of five, with an acute respiratory infection rate of 2.03% and a guardian non-treatment rate of 16.63%. Based on these numbers, we estimate that there are around 320,000 cases of acute respiratory infection in Bangladesh, with approximately 267,400 doctor visits for the condition. The World Health Organization's Integrated Management of Childhood Illness (IMCI) guidelines serve as Bangladesh's primary method for pneumonia diagnosis. However, research has shown that relying solely on clinical signs such as cough, rapid breathing, and chest indrawing can result in misdiagnosis. Based on information from an article published in the *National Library of Medicine*, we estimate that the current sensitivity and specificity rates for doctors correctly diagnosing pneumonia are 85% and 64%, respectively. The inaccuracy in diagnosis not only poses serious health risks to children but also places a significant financial burden on the healthcare system.

3. Model Comparison

For the machine learning models, we used 2,872 child patients' X-ray images, evenly divided into healthy and pneumonia samples. These were split 80-20 for training and validation, respectively.
To compare their approximate dollar value, we made the following assumptions:

- The annual number of suspected pneumonia cases is equal to the number of children with acute respiratory infections who seek treatment and undergo testing for pneumonia.
- The cost of falsely predicting a healthy child as having pneumonia (False Positive) is equivalent to the cost of treatment, as stated in an article published in the *BMJ Public Health Journal*, along with the cost of a four-day hospital stay.
- The cost of falsely predicting a child with pneumonia as healthy (False Negative) is equivalent to the cost of treatment in an urban area, as cited in the same article, plus the cost of an ICU bed (calculated the average price from the prices of several hospitals in Bangladesh) for four days. We assumed urban costs because ICUs are predominantly located in urban areas
- For simplicity, all the values from the articles referenced in this memo are assumed to be currently applicable.

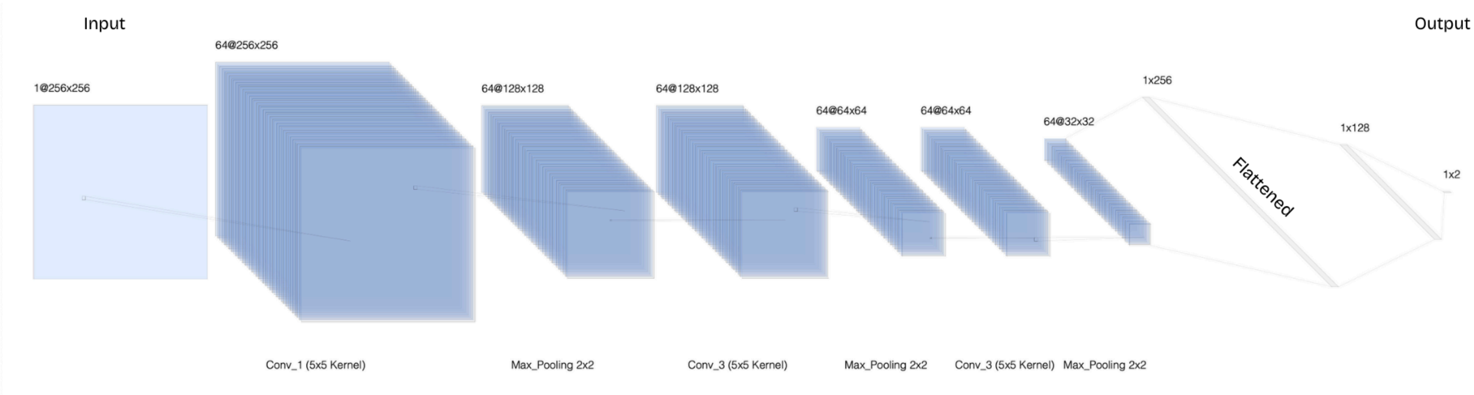
We then built and evaluated several models, comparing their performance against both the current pneumonia detection rates in Bangladesh and each other, as shown in the table below.



	Averge Doctor (Naïve)	All Positive (Naïve)	Decision Tree	Random Forest	XGBoost	NN	CNN
Accuracy	72.55%	50.35%	83.57%	93.53%	93.53%	93.18%	92.66%
AUC	NA	NA	83.61%	97.59%	98.37%	98.77%	97.67%
Precision	NA	NA	81.82%	92.53%	92.23%	95.06%	88.78%
Recall	NA	NA	84.78%	94.20%	94.57%	90.58%	97.54%
False Negative	43	0	42	16	15	26	7
False Positive	104	288	52	21	22	13	35
Total Annalualized Cost	$ 20,811,324	$ 27,220,599	$ 12,222,844	$ 4,754,549	$ 4,648,196	$ 5,983,097	$ 4,209,930

4. Insights/Findings

Since the CNN model performed the best, we decided to further tune it to achieve the results shown in the table below. This tuning resulted in the following architecture:



Through testing different parameters and incorporating data augmentation, we identified the optimal combination to achieve the highest AUC for accurately predicting test X-ray images. Due to little variation between images—aside from slight movement from the children—the model performs best when data augmentation settings are low. Additionally, we observed that increasing the number of epochs improves the model's learning rate. To further enhance model capacity and handle more complex data, we also increased the number of layers.

	Tuned CNN
Accuracy	95.28%
AUC	98.94%
Precision	96.06%
Recall	94.37%
False Negative	16
False Positive	11
Total Annalualized Cost	$ 3,929,429

After optimizing the CNN, we increased accuracy by approximately 2%, improved the AUC by around 1%, and reduced the annual cost by approximately $300,000. More importantly, compared to the current method, this approach resulted in an estimated cost reduction of $17,000,000.

Additionally, we tested this model on an external dataset of 200 images, where it achieved an AUC of 99.83%. However, it is important to note that this dataset is not highly representative of how the model would perform on external data due to the limited number of images.

5. Recommendations

Upon analyzing our model's performance on the validation set, we observed that for the top 10% of both healthy and pneumonia samples, our model predicted them with 100% accuracy and confidence. Based on this finding, an investment of $2,000,000 would allow us to implement the following approach:

- Automate the diagnosis for the top 10% of healthy and pneumonia images, thereby increasing doctors' availability for other cases.
- Augment the remaining images to further enhance accuracy and speed in pneumonia detection.

By implementing these strategies, we can improve pneumonia detection, reduce long-term costs, and potentially save more lives.

Works Cited

Ashraf, H., Alam, N. H., Sultana, S., Starr, M., Haider, R., Salam, M. A., & Black, R. E. “Identifying Sick Children Requiring Referral to Hospitals in Bangladesh.” *PubMed Central (PMC)*, U.S. National Library of Medicine, Sept. 2008, https://pmc.ncbi.nlm.nih.gov/articles/PMC2486991/

World Health Organization (WHO). “Integrated Management of Childhood Illness (IMCI) to Clinically Diagnose Pneumonia.” *WHO*, https://www.who.int/teams/maternal-newborn-child-adolescent-health-and-ageing/child-health/integrated-management-of-childhood-illness.

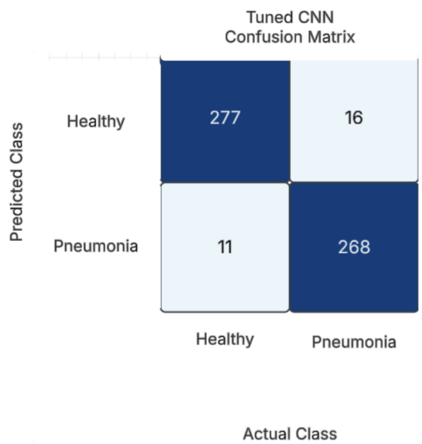
UNICEF. “One Child Dies of Pneumonia Every 39 Seconds, Agencies Warn.” *UNICEF Bangladesh*, 12 Nov. 2019, https://www.unicef.org/bangladesh/en/press-releases/one-child-dies-pneumonia-every-39-seconds-agencies-warn.

Mahomed, N., Fancourt, N., de Campo, J., Graham, S. M., & Goussard, P. “Accuracy of the Interpretation of Chest Radiographs for the Diagnosis of Paediatric Pneumonia.” *PLOS ONE*, Public Library of Science, 27 Aug. 2014, https://journals.plos.org/plosone/article?id=10.1371%Journal.pone.0106051.

Archives of Disease in Childhood**.** “Pneumonia Diagnosis and Management in Children.” *BMJ*, Aug. 2024, https://adc.bmj.com/content/archdischild/109/8/622.full.pdf

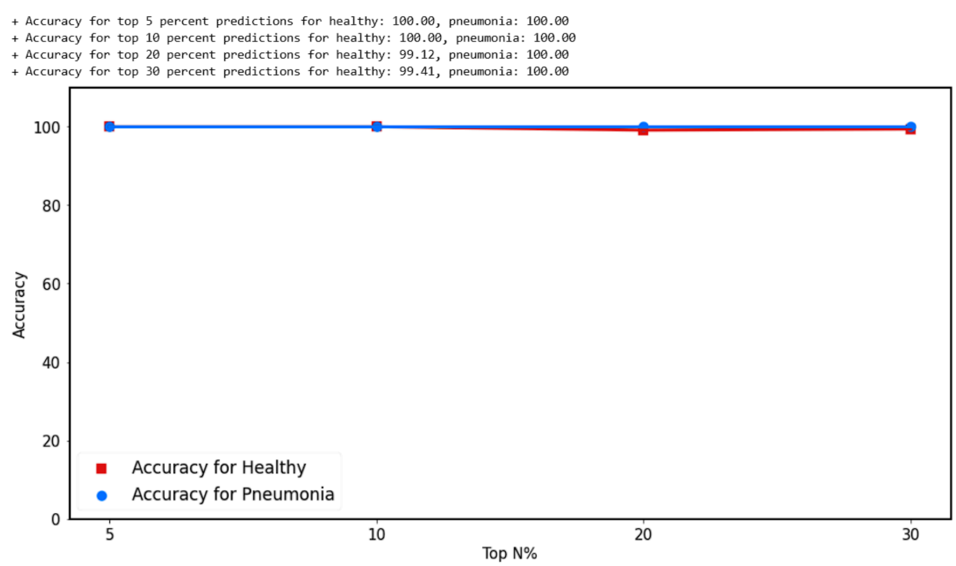
I. Appendix

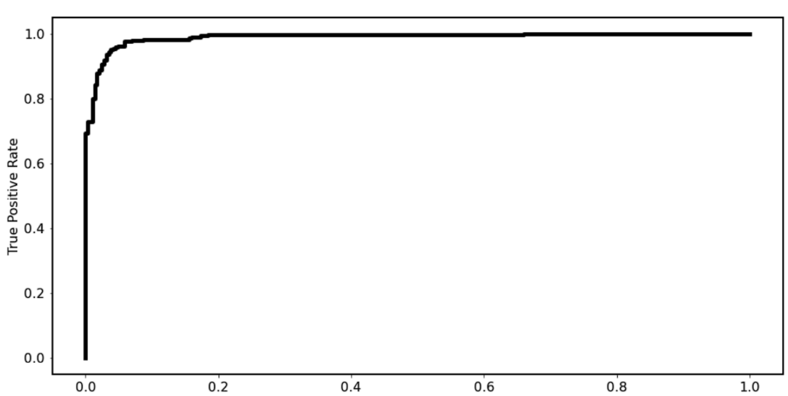
Tuned CNN



The confusion matrix for the validation set for the tuned CNN model. [1]

Accuracy at top N%s





AUC Curve of tuned CNN

[22]: 98.93

Cost Matrix

Models	FP Proportion	FN Proportion	Total Annualized Cost	Delta
Average Doctor (naïve)	0.18	0.075174825	$19,329,783	$0
All positive (naïve)	0.50	0	$27,220,599	$7,890,817
Decision Tree	0.09	0.073426573	$14,194,019	-$5,135,763
Random Forest	0.04	0.027972028	$5,519,764	-$13,810,018
XG Boost	0.04	0.026223776	$5,393,347	-$13,936,435
Neural Network	0.02	0.045454545	$6,972,967	-$12,356,815
Convolutional Neural Network	0.06	0.012237762	$4,854,590	-$14,475,192
Tuned CNN	0.02	0.027972028	$4,574,605	-$14,755,178

Cost FP	Cost FN	Annual number of suspected epsiodes	FP Total	FN Total	CM Total
$202.18	$472.60	267401			572
$9,829,660.76	$9,500,121.75	267401	104	43	572
$27,220,599.03	$0.00	267401	288	0	572
$4,914,830.38	$9,279,188.69	267401	52	42	572
$1,984,835.35	$3,534,929.02	267401	21	16	572
$2,079,351.31	$3,313,995.96	267401	22	15	572
$1,228,707.60	$5,744,259.66	267401	13	26	572
$3,308,058.91	$1,546,531.45	267401	35	7	572
$1,039,675.66	$3,534,929.02	267401	11	16	572

Statistics	
Total Under 5 Population	15800000
Acute Respiratory Infection Rate	0.0203
Rate Not Seeking Treatment	0.1663
Total Pnemounia (Validation)	284
Total Healthy (Validation)	288
Sensitivity (Doctor Naïve)	0.85
Specificity (Doctor Naïve)	0.64
Hospital Costs (Overall)	$ 48.10
Hospital Costs (Urban)	$ 65.80
Hospital Bed	$ 32.10
ICU Bed	$ 84.75
Average Length of Stay (Days)	4.8

Excel Workbook

Individual_Assignment_Memo_Cost_Matrix.xlsx

Vocareum Code

https://labs.vocareum.com/main/main.php?m=clabide&mode=s&asnid=3737931&stepid=3737932&hideNavBar=1