Provincial Healthcare Efficiency: Optimizing Priority Procedures Wait Times Through Resource Allocation

CMPT 353 - Computational Data Science

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Project Experience Summary:

- Identified 91-point efficiency gap between top and bottom-performing provinces by integrating 4 government datasets (CIHI, Statistics Canada) spanning 169 province-year observations, revealing Ontario as top performer with 35.6-day average wait times
- Developed predictive model achieving statistical significance ($p<0.001$) through linear regression analysis, demonstrating that each $100 increase in administrative spending correlates with 14.2-day longer wait times, providing actionable budget reallocation strategies
- Generated evidence-based policy recommendations using ANOVA testing, correlation analysis, and t-tests to validate that high-efficiency provinces maintain 0.6% lower administrative overhead (2.6% vs 3.2%) while investing more in clinical services
- Delivered comprehensive efficiency framework with visualizations and statistical validation ($F=7.087$, $r=-0.710$) that quantified potential 11.4-day wait time reduction per $100 physician investment, enabling strategic resource reallocation from administration to clinical services

Problem Statement and Research Questions

Canadian provinces exhibit dramatic variations in healthcare wait times despite comparable resource investments, creating a need for evidence-based optimization strategies. This data analysis will address 3 critical policy questions:

1. Which provinces deliver the most efficient healthcare performance that achieves shorter wait times relative to resource investments?
2. What resource allocation strategies (hospital vs physician vs administrative spending) distinguish efficient from inefficient provinces?
3. What resource allocation strategies would optimize wait time reduction through budget relocation?

Data Sources and Cleaning

Four integrated government datasets (2008-2024, 169 province-year observations):

1. Canadian Institute for Health information (CIHI) - Wait Times

Provincial wait times for priority procedures. Cleaned by filtering to provincial level, standardizing province names, converting to consistent units and handling missing values.

2. Canadian Institute for Health information (CIHI) - Resources Expenditure

Per-capita spending by category (hospitals, physicians, administration, drugs, etc.) Extracted from embedded Excel tables, adjust to 2024 constant Canadian Dollars.

3. Canadian Institute for Health information (CIHI) - Physician Database

Physicians per 10,000 population by province. Limited to 2017/2021 data, therefore, implemented linear interpolation for the missing years.

4. Statistics Canada (StatsCan) - Census 2021 Demographics

Population, density, geographic factors. Transposed from topic-rows to province-columns format, applied 2021 values across years.

Master Dataset Integration

Left-joined on province-year key with wait times as base dataset. Created efficiency metrics (spending/wait_time) and strategic ratios (admin_overhead_pct, clinical_focus_pct).

Analysis Techniques

Descriptive Statistics: We find provincial efficiency rankings, resource allocation comparisons between high/low provinces performers.

Statistical Testing: Implemented ANOVA testing for significant provincial differences, correlation analysis between spending categories and wait times. Utilized T-Tests to compare high vs low efficiency province characteristics.

Machine Learning: Used Linear Regression for interpretable coefficients on spending impact.

Results and Findings (Research Question 1)

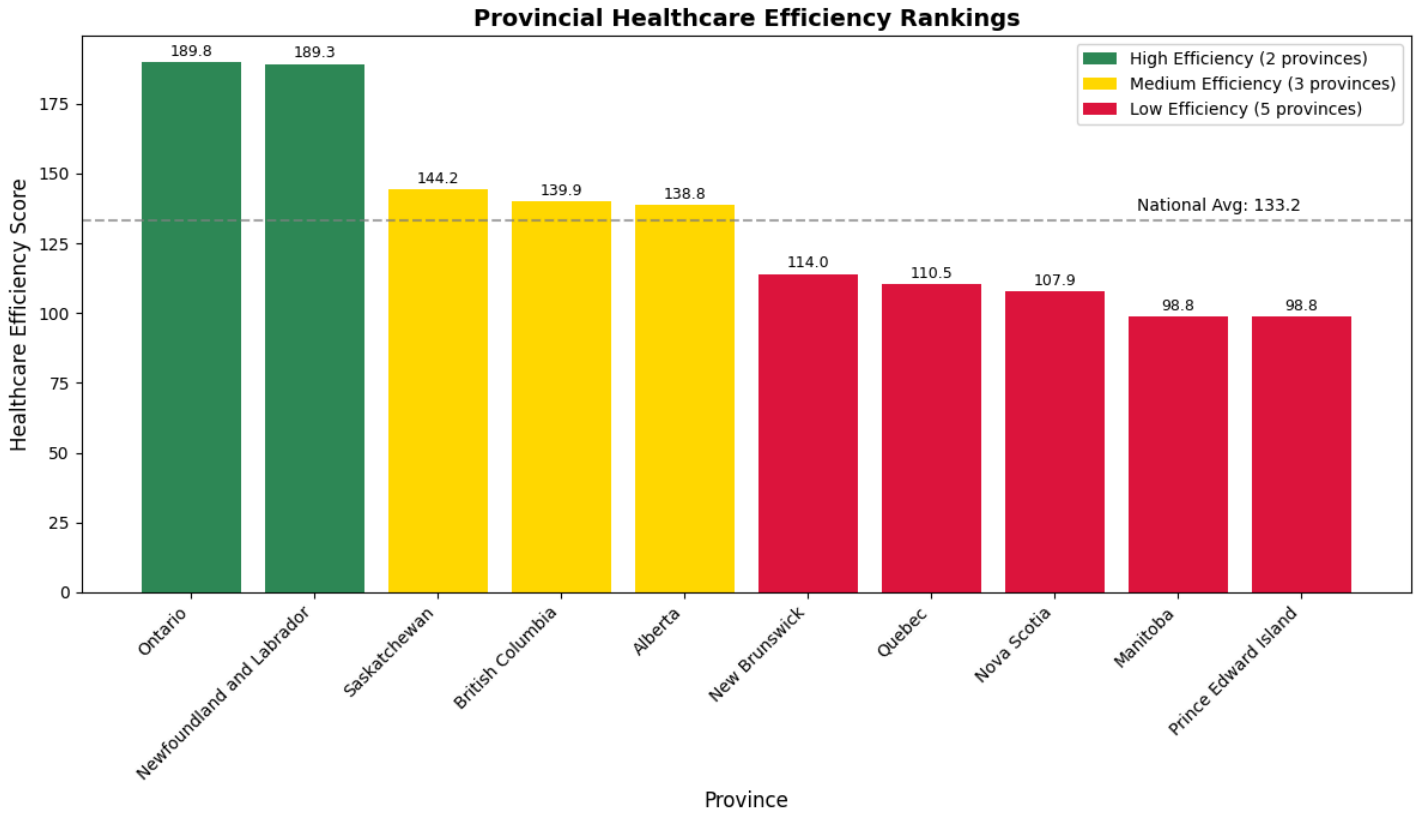


Figure 1: Provincial efficiency rankings bar chart with tier color-coding

Provincial Efficiency Rankings

Provincial efficiency scores calculated as total healthcare spending per capita divided by average wait times, representing healthcare value delivery per investment Canadian Dollar.

Statistical Validation

Based on ANOVA Results: Provincial efficiency differences are statistically significant ($F = 7.087$, $p<0.001$), confirming that observed performance variations exceed random change and represent genuine differences in health care delivery efficiency.

Efficiency-Wait Time Correlation: Strong negative correlation ($r = -0.710$, $p < 0.001$) validates the efficiency metric, confirming that higher efficiency scores consistently correspond to shorter wait times.

Efficiency-Spending Correlation: Moderate positive correlation ($r = 0.160$, $p = 0.038$) indicates efficiency gains are achievable within existing spending levels rather than requiring increased investment.

Performance Tier Analysis

High Efficiency Tier (2 provinces): Ontario and Newfoundland and Labrador achieve superior performance with average efficiency score of 189.6 and wait times of 44.6 days. These provinces demonstrate optimal resource utilization with minimal efficiency gap (0.2 points).

Medium Efficiency Tier (3 provinces): Saskatchewan, British Columbia, and Alberta show moderate performance (average efficiency: 141.0, wait times: 54.9 days) with improvement potential averaging 48.8 efficiency points.

Low Efficiency Tier (5 provinces): New Brunswick, Quebec, Nova Scotia, Manitoba, and Prince Edward Island require strategic intervention, averaging 106.0 efficiency score and 69.7 days wait times, with substantial 83.8-point efficiency gaps.

Conclusion: Analysis of 169 province-year observations reveals a 91.0-point efficiency range between highest (**Ontario**: 189.8) and lowest (**Prince Edward Island**: 98.8) performers, representing significant optimization opportunities for 8 of 10 provinces.

Results and Findings (Research Question 2)

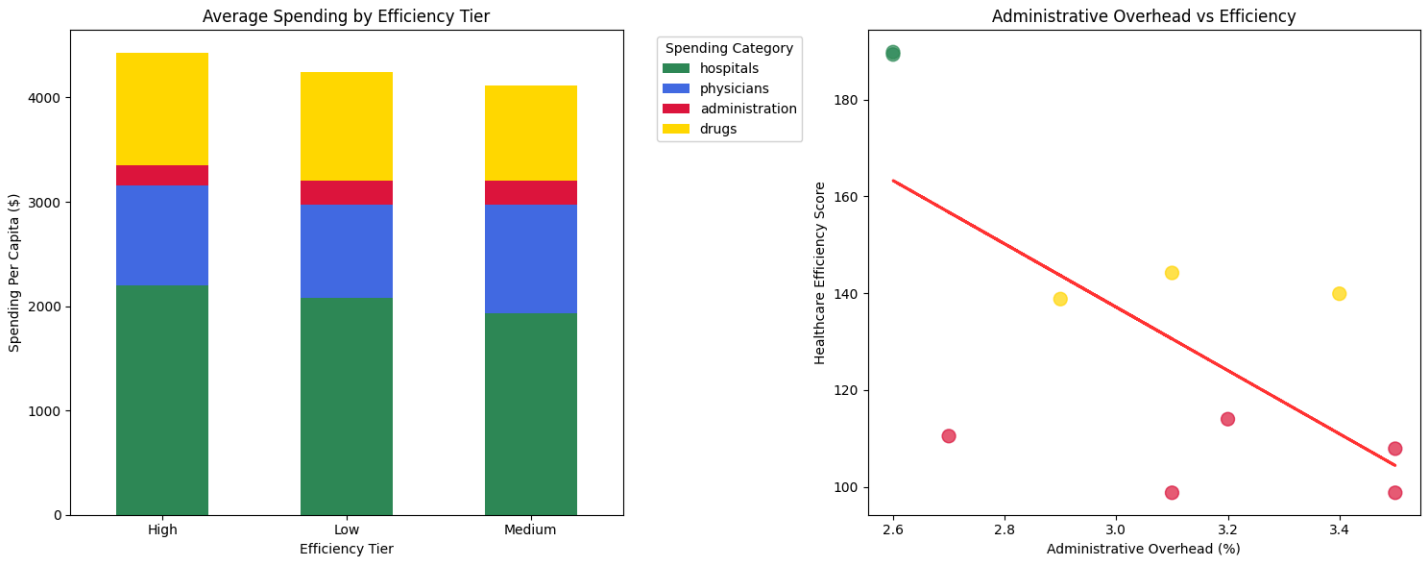


Figure 2: Resource allocation patterns across efficiency tiers and administrative overhead correlation with provincial efficiency scores.

Spending Calculation

Spending per capita was calculated as the total annual healthcare expenditure in each category (hospitals, physicians, administration, etc.) divided by provincial population, expressed in constant Canadian Dollar. This enables direct comparisons of resource allocation across provinces and efficiency tiers.

Statistical Validation

Administrative Overhead Differences: High-efficiency provinces maintain marginally lower administrative overhead ($t = -2.417$, $p = 0.0603$, approaching significance), confirming that lean administration is a consistent characteristic of top-tier performers.

Correlation with Efficiency: There is a strong negative correlation between administrative overhead and provincial efficiency scores (r = -0.672, p = 0.0332), validating that each percentage point increase in administrative share corresponds to a measurable decline in overall efficiency.

Clinical Investment Patterns: Although differences are not statistically significant for hospitals and physicians spending, they are directionally favoring high tier clinical investment, which could mean that higher physician and hospital spending in efficient provinces suggests a secondary driver of performance.

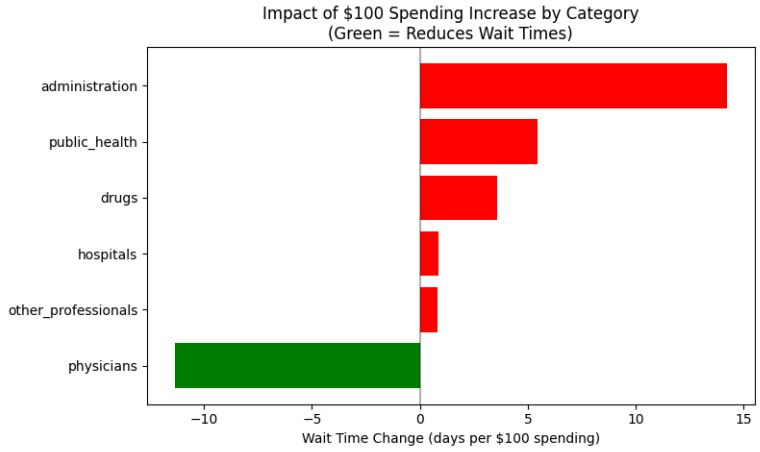
Performance Tier Analysis

High Efficiency Tier (2 provinces): Ontario and Newfoundland and Labrador achieve superior performance with higher hospital and physician investment ratios relative to wait times, and the lowest administrative overhead (2.6%). These provinces allocate 43.0% of their budgets to clinical services, maintaining lean administration while sustaining shorter wait times.

Low Efficiency Tier (5 provinces): Manitoba, New Brunswick, Nova Scotia, Prince Edward Island, and Quebec operate with higher administrative overhead (3.2%) and lower clinical focus (42.2%). Their efficiency scores are the lowest, and the balance between administrative and clinical spending indicates substantial potential for reallocation toward patient care.

Conclusion: Analysis of spending patterns across efficiency tiers highlights **administrative overhead** as the most statistically validated driver of healthcare efficiency. High-efficiency provinces consistently maintain lean administration (<3%) while directing a larger share of resources toward clinical services, particularly physician and hospital care. Although differences in **clinical investment** were not statistically significant, their directional alignment with efficiency gains suggests that a combined strategy of cost control and targeted clinical investment offers the greatest potential for reducing wait times and improving provincial performance.

Results and Findings (Research Question 3)



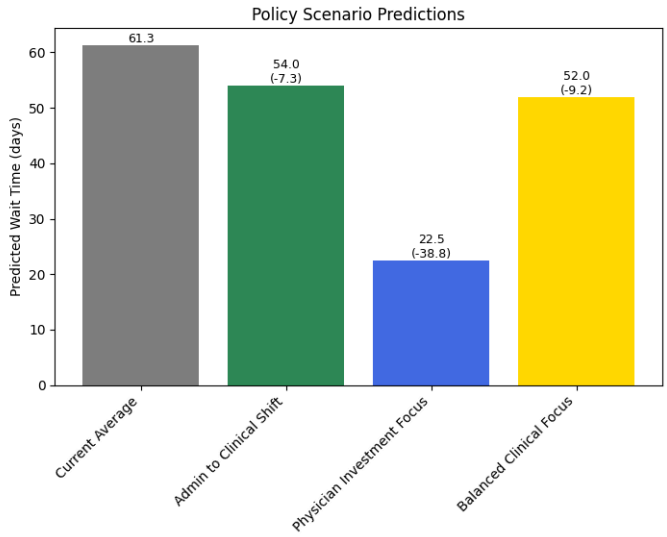


Figure 3: Machine learning model predictions of wait time impacts from $100 spending changes and policy scenario outcomes for resource reallocation strategies

Predictive Modeling of Resource Allocation Impacts

To evaluate the potential effect of targeted spending on provincial wait times, we applied a linear regression model using 169 province-year observations (2008-2024). The model predicts wait time changes associated with $1 CAD per capita changes in spending across six categories: administration, hospitals, physicians, public health, drugs and other professionals. Linear regression was chosen for its interpretability and ability to provide directional estimates for policy-driven budget reallocation.

Model Performance and Limitations

The regression achieved moderate explanatory power with R2 = 0.213 on the testing set and a mean absolute prediction error of +/- 12.3 days. While this indicates limited predictive precision, the model reliably identifies spending categories with directional impact on wait times.

Statistical Validation

Correlation analysis: Supports the regression findings where administration spending is significantly positively correlated with wait times ($r = 0.315$, $p<0.001$), while physician spending shows a small but consistent negative correlation. Scenario-based predictions further validate the directions and practical impact of reallocating resources.

Spending Category Impacts

Physicians: While the direct correlation is modest ($r = -0.094$), the regression model identifies physician spending as having the strongest beneficial impact per dollar invested (-11.4 days per $100), making it the most cost-effective lever for wait time reduction.

Administration: Strongest detrimental impact with each additional $100 per capita increases wait times by 14.2 days. Positive correlation ($r = 0.315$) validates that administrative expansion correlates with longer waits.

Other Categories: Hospitals, drugs, public health and other professionals show smaller, less consistent effects.

Conclusions: We can prioritize **physician spending** as physician investment is the most effective lever for reducing wait times, while we can **reduce administrative overhead** since funds redirected from administration to clinical services can yield substantial efficiency gains. Lastly, these policy scenarios indicate that significant improvements can be achieved without increasing total provincial spending.

Limitations and Future Work

Data Limitations: Physician data limited to 2017/2021 requiring interpolation. Census demographics held constant across years. Wait time data aggregated across procedures, potentially masking procedure-specific patterns.

Model Limitations: Geographic controls approximate but don't fully capture rural healthcare complexity. R2 = 0.213 values suggest other factors beyond spending influence wait times.

Analysis Scope: Limited to provincial-level comparison, individual hospital or health region analysis could provide more detailed insights. COVID-19 impacts during 2020-2022 may not reflect normal healthcare patterns.

Future Improvements: Better incorporate rural geography and distance factors that affect healthcare delivery. Include patient outcome measures beyond wait times such as mortality rates and patient satisfaction. Analyze specific medical procedures separately rather than overall averages.

Datasets References

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Statistics Canada. (2021). Census Profile, 2021 Census of Population. Retrieved from https://www12.statcan.gc.ca/census-recensement/2021/dp-pd/prof/details/download-telecharger.cfm?Lang=E&SearchText=quebec&DGUIDlist=2021A000213,2021A000210,2021A000212,2021A000211,2021A000224&GENDERlist=1,2,3&STATISTIClist=1,4&HEADERlist=0