University of Toronto
Faculty of Applied Science and Engineering
MIE364 - Introduction to Quality Control and Improvement
Project Report

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Executive Summary

The efficacy and efficiency of Emergency Room (ER) services are critical in the ever-changing healthcare sector to guarantee prompt access to expert health assessment and care. Hospitals around the world continue to face difficulties in managing ER waiting times. Patient safety and quality of care are seriously compromised by long wait times, which also contribute to patient dissatisfaction. By analyzing ER waiting time data for major hospitals in the province of Ontario and implementing quality control measures, this investigation aims to optimize patient flow, minimize wait times, and enhance the efficiency and reliability of emergency care delivery.

With average ER waiting time data from approximately 110 hospitals and health centres across Ontario, stratified sampling was conducted to increase precision and reduce bias. The methodologies chosen help in revealing significant insights into ER waiting times. These include the X-bar & R-chart, the X-bar & S-chart, the NP-chart, the C-chart, the CUSUM chart, and the process capability analysis. By implementing control charts and statistical analysis techniques, the project identified areas of improvement and recommended strategies for enhancing the quality and efficiency of ER services.

The implementation of these control charts and quality control techniques highlighted the severity of the case as a majority of the hospitals across Ontario have an average ER wait time for the patient until admitted into the hospital greater than the specification limit of 8 hours. In fact, the average wait time lies at approximately 17.79 hours, which is more than twice as much as that of the target time.

Based on the results, recommendations include optimizing staffing levels based on demand patterns, implementing advanced health protocols to prioritize patients based on the severity of the condition, and enhancing communication and coordination among healthcare team members. Various queuing optimization techniques can also be applied to decrease the time spent in general waiting to be served. As such, with the results of this investigation taken into account and the solutions it presented administered, the hospitals not only in Ontario, but around the world can better provide patients with the care they need and a speedy recovery.

Introduction

In the dynamic industry of healthcare, the effectiveness and efficiency of Emergency Room (ER) services play a crucial role in ensuring timely access to professional health assessment and care. However, the management of ER waiting times remains a continuous challenge for hospitals worldwide. Long wait times not only contribute to patient dissatisfaction but more importantly also pose significant risks to patient safety and quality of care [1]. Addressing this issue requires a comprehensive understanding of the factors influencing wait times and the implementation of effective quality control measures. In Ontario alone, the average wait time until the first assessment by a doctor is 2 hours, going up to 4.1 hours in more severely congested hospitals. The time spent in the emergency department until admitted to the hospital is 20.5 hours on average, with only 26% of patients being admitted to the hospital within the target time of 8 hours [2]. Thus, the goal is to investigate various aspects of ER waiting times, with a focus on improvement and devising strategies to enhance the efficiency and reliability of ER services. With this gap addressed, it would set the foundation for further research and development in optimizing patient flow, minimizing wait times, and ultimately improving the overall quality of emergency care delivery.

Methodology

For this investigation, only the ER waiting times for hospitals in the province of Ontario were considered to limit the scope and align with the sourced dataset (Appendix A). As a brief description of the dataset, it consists of a list of major hospitals and health centres in Ontario along with the average time spent in the emergency department until admitted to the hospital. For analysis, various quality control concepts and techniques were employed, which are described and contextualized for the ER waiting time case below.

Sampling

Stratified sampling was used to sample the data. Stratified sampling involves dividing the population into subgroups that are non-overlapping and independent, after which sampling was done from each group independently. By ensuring that each stratum is presented in a sample, this methodology provides higher precision for observations within each stratum and

reduces the bias produced by other sampling methods such as Simple Random Sampling (SRS). To perform stratified sampling, the data was grouped by column values representing the average time spent in the ER in hours. Then for each group, *n* random samples were taken. For this scenario, *n* was set as *2*, as shown in Figure 1 below.

```
n_samples = 2

sampled_df = df.groupby('Average (hrs)', group_keys=False).apply(lambda x: x.sample(min(len(x), n_samples)))

sampled_df
```

Figure 1. Implementation of stratification sampling.

X-bar & R-chart

To Monitor the central tendency and variability of the average waiting time of patients, X-bar and R-control charts were utilized, where the X-bar chart tracks the average value of the process over time by plotting the sample means of subgroups from a process. It helps identify trends and shifts in the process. Similarly, R-charts are used to monitor the variability within each subgroup by plotting the ranges of the subgroup. It is ideal for monitoring and identifying any shifts to variability in subgroups. Additionally, by using X-bar and R-control charts, any shifts in mean and variability can be detected in a short period, enabling quick identification of out-of-control processes and timely corrective actions. Lastly, this control chart is relatively simple to construct and interpret, making it widely useful in various industries such as healthcare. For the purpose of this investigation, the range represents the variability of patient waiting time across different hospitals in Ontario

X-bar & S-chart

X-bar and S-charts are control charts used in statistical process control to monitor central tendency and variability. They are similar to X-bar and R charts, but X-bar and S-charts utilize standard deviation instead of range for process variability. The S-chart monitors the process variability within each subgroup by plotting the sample standard deviations. It aids in identifying any changes in process variability. Similar to X-bar and R-charts, this type of chart is known for quickly identifying out-of-control conditions, such as shifts in the process mean and shifts in standard deviation within the subgroups. In the context of this analysis, the standard deviation represents the dispersion of waiting times during a specific period, aiding a hospital to better manage patient flow.

NP-chart

Also known as the number of defective items chart, the NP-chart is another control chart used to monitor the number of defective items or nonconformities in a sample. These charts are particularly helpful in situations where the number of units inspected remains constant within each sample. They help in identifying trends or patterns that may indicate a process is out of control, allowing for corrective actions to be taken. NP-charts are commonly employed in various industries and service sectors to track the count of nonconformities over time. In the context of ER waiting times, a nonconformity can be defined as any instance where the wait time exceeds a certain threshold, such as the hospital's target wait time or a benchmark set by regulatory authorities.

C-chart

A C-control chart is a control chart that is used to monitor the number of nonconformities or defects in a process over time. These charts are useful for the early detection of process changes that may indicate shifts in quality or performance. Furthermore, they provide a quantitative. In the context of ER waiting times, nonconformities could refer to instances where patients can no longer wait in line, or exceed their threshold waiting time. Sudden increases in nonconformities might signal higher demand or other factors such as resource constraints or inefficiencies in scheduling.

CUSUM chart

A CUSUM chart is a statistical control chart, used to monitor shifts in process mean from a target value over time. These charts are useful for detecting persistent shifts or changes in process mean. By detecting small deviations, CUSUM charts are capable of signalling the presence of shits earlier than other control charts. Moreover, CUSUM charts provide quantitative measures of process performance by considering the cumulative sum of deviations from the target mean, allowing for a better understanding of the magnitude and direction of the process mean shift. In the context of this investigation, healthcare providers utilize CUSUM charts to assess whether patient wait times are within acceptable limits. Healthcare providers can benefit from analysing trends in data using CUSUM charts, such as an upward trend, which signals deviation from the target mean.

Analysis

The application of the quality control concepts and techniques from the proposed methodology provided results from which valuable insights can be extracted. For quantitative analysis, some descriptive statistical metrics of the dataset *D* are displayed in Table 1 below.

Table 1. Calculated statistics regarding the sourced dataset *D*.

Mean	μ_D	17.79
Standard Deviation	σ_D	8.52
Median	$\tilde{x}_D$	17.05
Minimum	*min(D)*	4.2
Maximum	*max(D)*	45.6

X-bar & R-chart

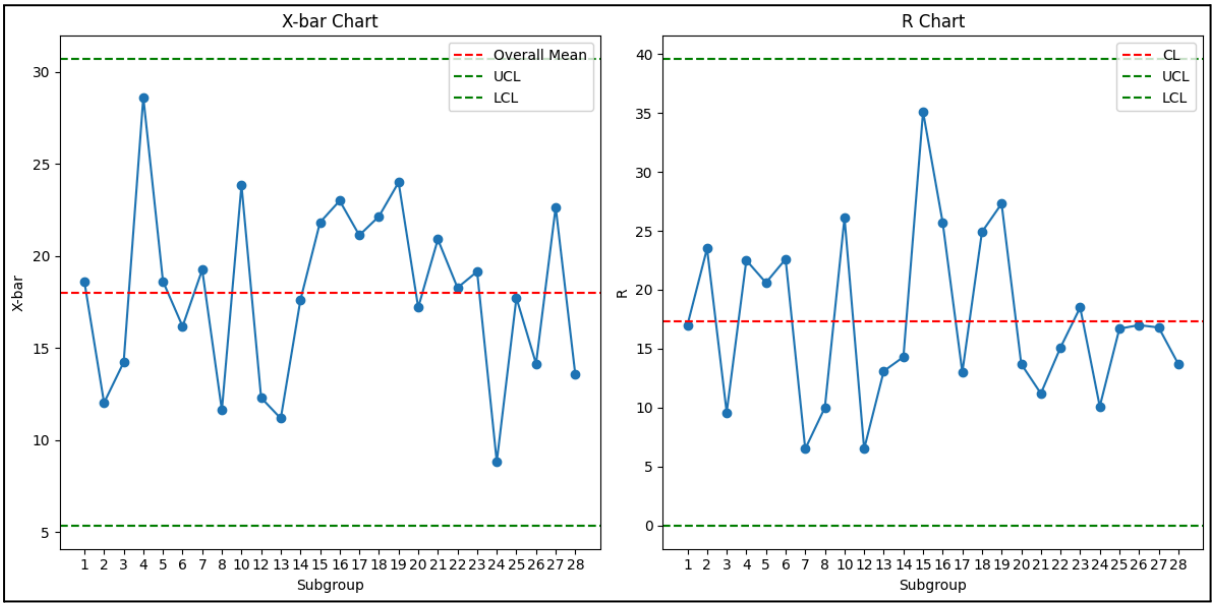

Figure 3. X-bar & R-chart for patient wait times in emergency department.

The X-bar & R-chart in Figure 3 suggests that no waiting time went out of control. In the X-bar chart, sample number 5 has the highest average waiting time amongst other hospitals in the sample. As well, no patient waiting times went out of control in the R-chart, suggesting

that the range of variability of patient waiting time was in control throughout this sample. The closest sample to an out-of-control zone in the R-chart is Hospital 15, with other samples being significantly less variable.

X-bar & S-chart

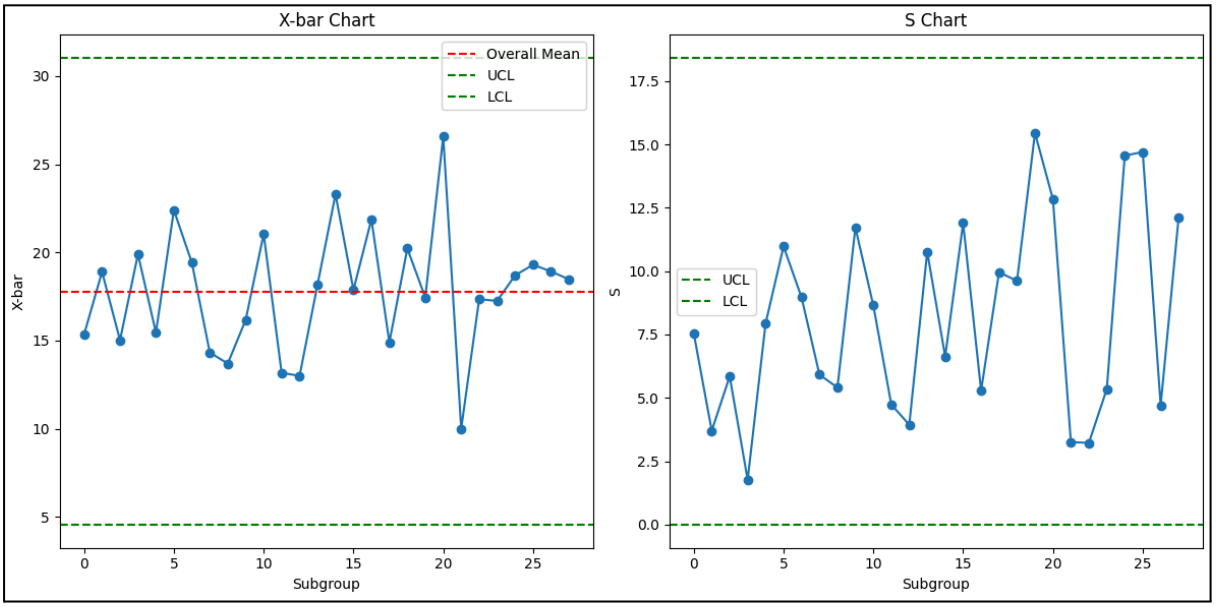

Figure 4. X-bar & S-chart for patient wait times in emergency department.

The X-bar & S-chart in Figure 4 suggests that the process of patient waiting times was in control and therefore consistent. For the X-bar chart, Mackenzie Health - Cortellucci Vaughan Hospital had the highest mean waiting time, although not large enough to alter patient flow and go out of control. As well, other hospitals saw smaller variations in mean waiting time. For the S-chart, there is more variability, with Chatham-Kent Health Alliance - Wallaceburg Hospital having the highest deviation amongst other hospitals in the sample. The variability of the S-chart suggests that there is inconsistent performance or unpredicted fluctuations in patient flow.

NP-chart

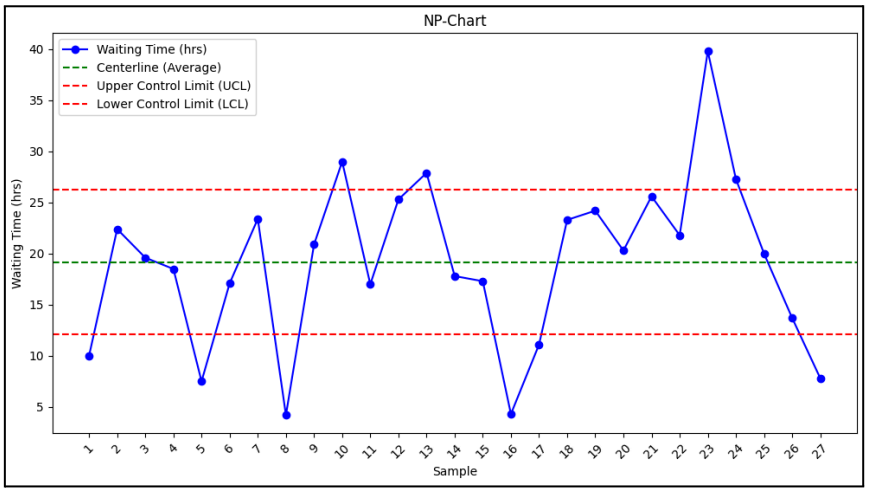

Figure 5. NP-chart for patient wait times in emergency department.

The NP-chart, as seen above in Figure 5, indicates that the process went beyond both the upper and lower control limits. Specifically, samples 10, 13, 23, and 24 exceeded the upper control limit, signifying that the represented hospitals have ER wait times higher than expected and thus are out of control. Likewise, samples 1, 5, 8, 16, 17, and 27 descend below the lower control limit. This, however, is actually preferred as it represents the hospitals that serve patients quicker than expected. In terms of the samples in control, the majority of them hover close to the mean, though in the range closer to the upper control limit, which implies that their service time is also more towards the undesirable side.

C-chart

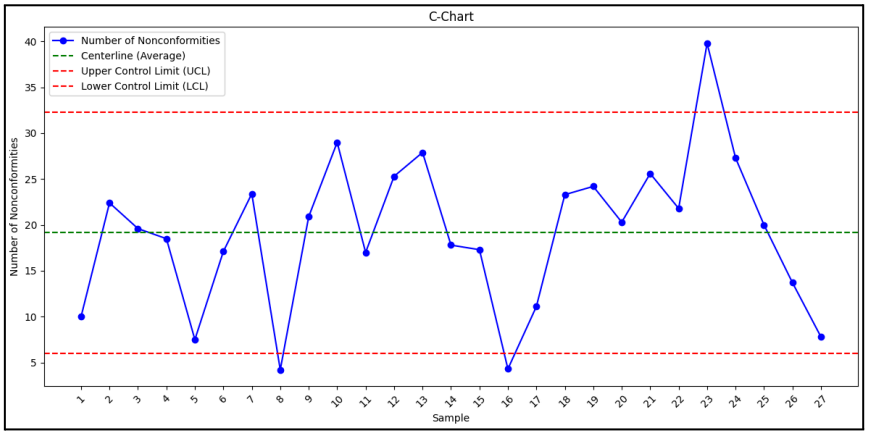

Figure 6. C-chart for patient wait times in emergency department.

The C-chart in Figure 6 saw samples 8,16, and 23 going out of control, with sample 23 going above the upper control limit, and samples 8 and 16 going beyond the lower specification limits. This indicates that this hospital is considered to be a nonconformity in average patient waiting times. This indicates that these samples are deviated from the expected process performance. In terms of samples in control, there were small deviations between them, as many samples were close to the mean. However, some in control samples were deviating towards the lower specification limit, signalling a risk of more hospitals going out of control and not performing within the specified limits.

CUSUM chart

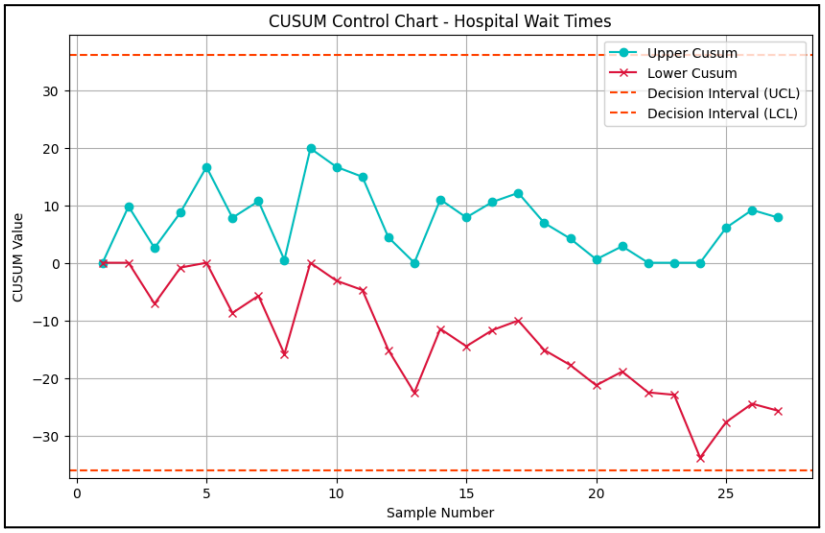

Figure 7. CUSUM chart for patient wait times in emergency department.

For the CUSUM chart in Figure 7, both the upper CUSUM and lower CUSUM graphs experienced no shifts to out-of-control limits. The upper CUSUM graph was fairly consistent in trend and experienced no significant fluctuations. The lower CUSUM graph did experience deviation towards the lower specification limit. There is a spike towards the lower control limit in the negative CUSUM graph around sample 25 but spikes back to a higher CUSUM value. It can be observed that there were variations in patient waiting times across different hospitals.

Process Capability

The performance of a process in a state of statistical control is known as process capability. A process is considered in statistical control when the only sources of variation in the system are common causes. It is determined by the total variability that exists because of all common causes present in the system. Process capability analysis estimates process capability and it involves approximating the process mean and standard deviation of the quality characteristic. Additionally, the form of the relative frequency distribution of the characteristic of interest is estimated and if specification limits are known, a process capability analysis will also estimate the proportion of nonconforming metrics. In this context, the analysis can be conducted with the specification limits being a certain threshold, such as the hospital's target wait time or a benchmark set by regulatory authorities.

The process capability index C_p compares the process spread to the specification spread and is denoted as such with the following criteria.

$$C_p = \frac{USL - LSL}{6\sigma},$$

Where if $C_p \geq 1$, the process is likely within specification. However, if $C_p = 1$, then it is adequate, though any changes with cause it to go out of specification. Lastly, if $C_p > 1$, then it is a non-capable system and there are many samples out of specification.

Discussion & Conclusion

X-bar & R-chart

Based on the results obtained from analyzing the constructed X-bar & R-chart, it is evident that no waiting time data point went out of control, implying a stable patient waiting time process across sampled hospitals. This stability suggests that the variation in waiting time is consistent and predictable. In addition, the R-chart illustrates that the variation within each hospital's waiting times is consistent. Sample number 5 in the X-bar chart and sample number 15 are identified as the closest samples to the out-of-control zones, indicating concerns about the waiting times going out of control in the future. This variability highlights further investigations and potential improvements to the infractures of the hospitals, in efforts to enhance patient flow and optimize delivery of services. To optimize services, a hospital

should ensure that enough resources and staff are allocated to handle patient demand effectively, especially during peak hours.

X-bar & S-chart

With quantitative and qualitative results obtained from the X-bar & S-chart, it is evident that the patient waiting time is in control and consistent. It suggests that the variation in waiting times follows a consistent pattern and does not exhibit any deviations from the expected mean or standard deviation. The S-chart reveals more variability in patient waiting times, suggesting some unpredicted fluctuations in patient flow to the hospital, which could potentially impact waiting times in the feature. However, these deviations were not significant enough to make the process go out of control, indicating that waiting times are fairly balanced. To promote stability, hospitals should implement strategies to optimize patient flow throughout the facility, such as minimizing wait times between different stages of the ER. This implementation will require real-time monitoring systems, as well as using analytical tools to forecast demand.

NP-chart

By analyzing the NP-chart it is evident that a few samples are exceeding the upper control limit, suggesting that these hospitals are experiencing prolonged wait times. These hospitals might face challenges such as overcrowding. To overcome overcrowding, actions need to be taken to address root causes of prolonged wait times, such as resource allocations, and enhanced strategies for patient management. As well, some samples fall below the lower specification limit, indicating that some ER wait times are quicker than expected. However, this might be a problematic circumstance as a short wait time doesn't compromise high-quality patient care. For inspections, hospitals need to perform further analysis on the outcomes of shorter ER wait times to avoid issues like inadequate patient care.

C-chart

With one sample going above the upper specification limit, it signifies longer waiting time and raises potential issues such as inefficiency in patient flow. Some samples fall below the lower specification limit, raising concerns about the quality of patient care. However, most samples remain within control limits, with small deviations. This indicates that patient wait

times are relatively stable and consistent. To overcome concerns, the hospital should consider the importance of proactive monitoring of staff and quality care to address the samples that fall beyond the lower specification limit. As well, the hospital that went over the UCL should implement strategies to reduce patient wait times, such as increasing the number of queues for patient care and registration.

CUSUM chart

The upper CUSUM chart illustrates a steady performance in average patient waiting time, highlighting that the samples did not experience any systematic issues related to prolonged waiting times. As well, the lower CUSUM graph indicates similar results, with samples not going out of bounds. However, samples start to deviate from the mean and move towards the LCL in the lower CUSUM chart, which can be caused by factors such as patient volume and staffing levels. To address concerns, the hospitals which deviated from the mean should implement strategies of resource allocation, staff monitoring, and enhanced patient care.

Process Capability

Conducting the process capability analysis across all of the hospitals and health centres across Ontario, the target time was set to 8 hours, as indicated by Health Quality Ontario. This target behaves as a threshold and as such, can be considered as the upper specification limit for the process capability analysis. The lower specification limit was set to 0 hours, as that would be the ideal case. It was therefore found that with a mean of 17.79 hours, more than twice the target, and a standard deviation of 8.52 hours, the process was out of specification. This was reinforced by the process capability index C_p = 0.156, which being less than 0, indicated an undesirable situation. The recommended solution is to centre the process average on the target value at the minimum, though lower is preferred.

Takeaway

Based on the analysis of various control charts, it is evident that there are areas for improvement in managing patient waiting times across hospitals in Ontario. The presence of deviations such as prolonged wait times and variability raised concerns about the healthcare system. Analysis suggests that hospitals should implement strategies to optimize patient flow, allocate resources efficiently, and enhance staff monitoring for consistent delivery of services.

References

[1] K. Born, "The risks of emergency department overcrowding," Healthy Debate, https://healthydebate.ca/2011/07/topic/politics-of-health-care/ed-wait-times/ (accessed Apr. 12, 2024).

[2] HQ Ontario, "System performance," Emergency Department Time Spent by Patients in Ontario – Health Quality Ontario (HQO), https://www.hqontario.ca/system-performance/time-spent-in-emergency-departments (accessed Apr. 12, 2024).

Appendix

Appendix A: Dataset for ER waiting times until admitted to hospital, sourced from: https://www.hqontario.ca/system-performance/time-spent-in-emergency-departments.

Hospital	Hours
Chatham-Kent Health Alliance - Wallaceburg	4.2
St. Joseph's Health Care London - St. Joseph's Hospital	4.2
St. Thomas-Elgin General Hospital	4.3
Temiskaming Hospital	5.1
South Bruce Grey Health Centre - Durham	5.3
Huron Perth Healthcare Alliance: Clinton Public Hospital	5.8
West Parry Sound Health Centre	6.9
Glengarry Memorial Hospital	7
Joseph Brant Hospital	7.4
South Bruce Grey Health Centre - Kincardine	7.5
Huron Perth Healthcare Alliance: Seaforth Community Hospital	7.7
Alexandra Hospital	7.8

Huron Perth Healthcare Alliance: Stratford General Hospital	7.8
Strathroy Middlesex General Hospital	8
South Bruce Grey Health Centre - Walkerton	8.2
Grey Bruce Health Services - Meaford Site	8.2
Dryden Regional Health Centre	8.2
Woodstock General Hospital	8.3
Renfrew Victoria Hospital	8.8
Headwaters Health Care Centre - Orangeville Site	9.2
Hanover And District Hospital	9.2
Pembroke Regional Hospital	10
Notre Dame Hospital	10.1
The Hospital For Sick Children	10.2
Cornwall Community Hospital - Mcconnell Avenue Site	10.2
Collingwood General And Marine Hospital	10.4
Quinte Healthcare Corporation - Picton	10.5
West Nipissing General Hospital	10.8
Grey Bruce Health Services - Lions Head	10.8
Humber River Health - Wilson Site	11.1
Lennox And Addington County General Hospital	11.3
Timmins And District General Hospital	11.7
Hamilton Health Sciences Corp - McMaster Children's Hospital	11.7
Halton Healthcare Services Corp - Milton	11.9
Hopital Montfort	12.4
Northumberland Hills Hospital	12.6
Perth And Smiths Falls District Hospital - Smiths Falls Site	12.8

Chatham-Kent Health Alliance - Chatham	13
Stevenson Memorial Hospital	13.1
Children's Hospital Of Eastern Ontario	13.6
Brockville General Hospital - Charles ST Site	13.7
Groves Memorial Community Hospital	14.3
Grey Bruce Health Services - Markdale Site	14.4
Queensway Carleton Hospital	14.8
Lake Of The Woods District Hospital	14.8
Grey Bruce Health Services - Owen Sound	14.9
Grand River Hospital Corp - Waterloo Site	15.3
Thunder Bay Regional Health Sciences Centre	15.4
St. Mary's General Hospital	15.7
Erie Shores Healthcare	15.8
North York General Hospital - General Site	15.9
Lakeridge Health - Port Perry	16.3
Halton Healthcare Services Corp - Georgetown	16.5
Unity Health Toronto - St. Michael's	16.7
Guelph General Hospital	16.7
Royal Victoria Regional Health Centre	17
Scarborough Health Network - Scarborough General Site	17.1
Orillia Soldiers' Memorial Hospital	17.3
Toronto East Health Network - Michael Garron Hospital	17.3
Norfolk General Hospital	17.5
London Health Sciences Centre - Victoria Hospital	17.7
Quinte Healthcare Corporation - Belleville	17.8

Perth And Smiths Falls District Hospital - Perth Site	17.8
Scarborough Health Network - Birchmount	18.5
Muskoka Algonquin Healthcare - Bracebridge	18.5
Unity Health Toronto - St. Joseph's	19.6
Kingston Health Sciences Centre - Kingston General	19.8
The Ottawa Hospital - Civic Campus	20
St. Joseph's Health Care System Hamilton - Charlton Campus	20.2
Scarborough Health Network - Centenary	20.2
Tillsonburg District Memorial Hospital	20.3
The Ottawa Hospital - General Campus	20.4
Georgian Bay General Hospital - Midland Site	20.6
Hamilton Health Sciences Corp - Hamilton General Hospital	20.7
Quinte Healthcare Corporation - Trenton	20.9
Oak Valley Health - Markham Stouffville Hospital	20.9
Mackenzie Health - Cortellucci Vaughan Hospital	20.9
University Health Network - Toronto Western Hospital	21.1
Trillium Health Partners - Mississauga Hospital	21.8
Health Sciences North - Ramsey Lake Health Centre	21.9
Lakeridge Health - Bowmanville	22
Southlake Regional Health Centre	22.3
Halton Healthcare Services Corporation - Oakville-Trafalgar Memorial Hospital	22.4
Grey Bruce Health Services - Wiarton Site	23.2
London Health Sciences Centre - University Hospital	23.3
Mackenzie Health - Richmond Hill	23.4
Oak Valley Health - Uxbridge Hospital	24

Niagara Health System - St Catharines General	24.1
Hamilton Health Sciences Corp - Juravinski Hospital	24.2
Brant Community Healthcare System - Brantford General Hospital	24.3
Sunnybrook Health Sciences Centre	24.8
University Health Network - Toronto General Hospital	25
Hawkesbury And District General Hospital	25.2
St. Marys Memorial Hospital	25.3
Sault Area Hospital - Sault Ste Marie	25.6
Muskoka Algonquin Healthcare - Huntsville District Memorial Hospital	25.9
William Osler Health System - Etobicoke General	26.5
Quinte Healthcare Corporation - North Hastings	26.8
Sinai Health System - Mount Sinai Hospital	27.3
Grey Bruce Health Services - Southampton	27.8
North Bay Regional Health Centre - North Bay Site	27.9
Ross Memorial Hospital	29
Lakeridge Health - Oshawa Site	30.5
Peterborough Regional Health Centre	31.8
Cambridge Memorial Hospital	32.7
William Osler Health System - Brampton Civic	33.2
Campbellford Memorial Hospital	33.4
Hamilton Health Sciences Corp - West Lincoln Memorial Hospital	35.5
Niagara Health System - Greater Niagara	37.4
Lakeridge Health-Ajax Site	38.5
Trillium Health Partners - Credit Valley Hospital	39.8
Niagara Health System - Welland County	45.6