A Comparison of COVID-19 Waves in Manitoba

Timothy Appleyard, David Le, Sebastien Pichon, Michelle Simba

Abstract **- COVID-19, a health, social, and economical crisis, has greatly affected the world. COVID-19 has affected many parts of daily life, such as disrupting travel, limiting gathering size, closing down businesses, and severely affecting the global economy. Due to the impact the virus has, extensive research and data has been made, and released for the world to see. In this paper, we have analyzed data from each of the COVID-19 waves in Manitoba, and have compared the waves in relation to each other using various techniques such as time series analysis and frequent pattern mining. The evaluation of these results found will help us understand trends and insights related to the COVID-19 pandemic.**

Keywords **- COVID-19, waves, health restrictions, public health orders, provincial response levels, Manitoba, vaccine, variants**

I. INTRODUCTION

The COVID-19 pandemic has greatly affected the world, changing our daily lives as we know it. In December 2019, beginning with the first known case located in Wuhan, China, COVID-19 has infected over 250 million people by November 2021[1][2]. The sudden increase of cases has created an abundance of information and knowledge [3]. This type of data can then be collected to understand more about the pandemic - whether it be about the virus and it's mutations, preventive measures to prevent the spread and transmission of COVID-19, but to also understand the effect of pandemic may have on the world [4].

On March 13, 2020, the first case of COVID-19 appeared in Manitoba. Since then, the province has been through three waves of the pandemic, and is currently going through a 4th wave. A wave is defined as an increase of COVID-19 cases followed by a period of rest.

In order to protect the health and safety of Manitobans and to minimize the spread of COVID-19, the Manitoba government declared a province-wide state of emergency on March 20, 2020. Under The Emergency Measures Act, the Public Health Orders began in Manitoba [5]. The health orders would restrict gathering sizes, have businesses enforce social distancing, and have capacity limits for stores. Furthermore, non-essential traveling was not recommended, and travelers would have to quarantine even if they showed no symptoms/were not infected with COVID-19. As more cases appeared in Manitoba, restrictions would tighten, closing down non-critical businesses, and K-12 schools.

With all of the closures and restrictions occurring, there are bound to be consequences. While the public health orders may have been brought out to lower the transmission of COVID-19, it had potentially affected the many lives of Manitobans. Unemployment rate was at an all time high, businesses started to struggle to keep up, and many people relied on employment insurance (EI) and the Canada Emergency Response Benefit (CERB).

COVID-19 is not only just a health crisis; it has created social and economical challenges, impacting the world [6]. As a group, we wanted to determine the social and economical challenges created by COVID-19 specifically in Manitoba by examining and comparing selected attributes between the COVID-19 three waves.

II. DATASETS

A. Data collection

With COVID-19 greatly impacting the world, large amounts and a variety of data can be generated and collected from around the world.

Our original dataset consists of several datasets and data merged together in a time series. The data in the dataset consists of both numerical and discrete attributes, and all relate to Manitoba.

We collected general Manitoba COVID-19 case data and vaccination data from Open Data MB [6][7][8], and gathered information such as:

- Daily cases,
- Daily recoveries,
- Daily deaths,
- Current active cases,
- General hospitalization data,
- Daily first and second doses,
- Cumulative first and second doses.

We collected Manitoba public health orders, COVID-19 restriction and intervention data from a variety of sources, but most notably from the Manitoba Pandemic Response System [9] and the Canadian Institute for Health Information (CIHI) [10][11].

Public Health Orders were simplified into the Provincial Response Levels in August 2020, which dictated the restrictions to be set during the pandemic [5]. These Provincial Response Levels were as follows:

- Green: Limited Risk,
- Yellow: Caution,
- Orange: Restricted,
- Red: Critical.

These Provincial Response Levels could be further identified and broken down into:

- Gatherings restrictions,
- Personal and long-term care facilities,
- K-12 schools,
- Child care facilities,
- Retail and personal services, restaurants, beverage room,
- Recreation facilities,
- Casino Facilities and theatres,
- Indoor mask mandate,
- Manitoba travel quarantine/isolation.

Furthermore, we also collected data about the different types of variants that have occurred in Manitoba [12]. We retrieved data for cumulative cases of the following variants:

- B.1.1.7 (Alpha),
- B.1.351 (Beta),
- P.1 (Gamma),
- Uncategorized,
- B.1.617.1 (Kappa),
- B.1.617.2 (Delta).

Finally, we obtained miscellaneous data related to Manitoba which may be helpful to our analysis of comparing waves [13][14]. The data was retrieved from Statistics Canada and includes:

- Monthly unemployment rate,
- Total monthly non-resident travellers,
- Total monthly Canadians returning abroad.

Some shortcomings from gathering data from multiple sources was that the start dates of the data differed with each other. For example, general Manitoba COVID-19 case information started in March 2020, vaccination information started in December 2020, and variant data started in February 2021. Perfect comparisons of waves can't be made, as the first wave does not have any data on vaccinations and variants, while the second wave only had vaccination data near the middle of the wave, and variant data towards the end of the wave. One other issue was inconsistent reporting for the variants data. For example, some days there would be no reports of any variant cases, and at the beginning of the pandemic, no reports could span upwards to a week or two. We alleviated this during the preprocessing phase by converting daily data to weekly, generalizing the data. Thus, potential insights, especially with COVID-19 variants may be difficult to find in order to do comparisons with waves.

B. Data preprocessing

After aggregating the information we found during the data collection step, we further preprocessed the data to make analysis easier.

As the majority of our data was based on daily cases, we decided to convert our cumulative variant data into daily variant data. To calculate the daily variant cases, we subtracted the previous recorded cumulative cases from the current cumulative day cases.

Afterwards, we calculated the total daily variant cases by adding each of the daily variant cases together. Finally, we have each daily variant case to be a ratio of the total variant cases, so we can easily compare a variant case proportional to other variants.

We grouped our daily data into 7-day intervals – a week, in order to account for delays in testing/reporting. We summed up every numeric attribute over a week, and then calculated the average by dividing it by 7. Benefits of grouping dates from a daily to weekly format is that it helps with the discovery of frequent patterns and getting statistically meaningful data mining results [16].

Due to the vastly different ranges and scale of all our data, we decided to normalize our numeric non-percentage data. We re-scaled this data and put it in a new dataset using min-max scaling, with the equation defined as:

$$x' = \frac{x - x_{min}}{x_{max} - x_{min}} \quad (1)$$

By rescaling the numeric data to be from a range of 0 to 1, it should be easier to visually find trends, patterns, and potential insights when performing time series analysis.

As our dataset was a mixture of both numeric and descriptive, discrete data, we wanted to use the descriptive data to help us find trends, patterns, and insights. A way to do that is to employ frequent pattern mining. In order to facilitate the use of frequent pattern mining algorithms, we created a new dataset by discretizing every numeric attribute from our non-normalized dataset. For example, we divided daily cases into three discrete attributes values: one for low, medium, and high amounts of daily cases. Then, we changed the numeric data to map to the attribute values. While most of the data value ranges to map to an attribute value were calculated using percentiles from a dataset with all three waves combined, some were from recommendations, such as recommended positivity rates [17].

ID	Attribute	Data	Attribute Value
1	Daily Cases	0 – 62	Low
2	Daily Cases	> 62 – 182	Medium
3	Daily Cases	> 182	High
…	…	…	…

Fig. 1. Example mapping of our dataset.

After mapping each attribute with its attribute value, we were left with 99 discrete attributes. We then divided each of our datasets into three smaller datasets, one for each wave.
The waves are defined as follows:

1. March 10th, 2020 - May 1st, 2020
2. September 1st 2020 - March 1st, 2021
3. April 1st 2021 - August 1st, 2021

We picked the start and end period of these waves based on the definition of a wave, a period of a large increase in COVID-19 cases followed by a period of rest.

III. PROCESS

We used a mixture of time-series analysis and frequent pattern mining to help find and identify trends and insights. When finding frequent patterns, we used a software called SPMF, which specialized in pattern mining [18]. Algorithms we used in particular were Apriori (for finding small itemsets), negFIN (for finding frequent itemsets fast) and FPclose (for finding larger frequent closed itemsets) [19].

IV. ANALYSIS

A. Wave 1

Wave 1 started from March 10 2020, to May 1st 2020, lasting a total of 8 weeks. Some notable things about the first wave was that there were no vaccines available at the time, and no information about any COVID-19 variants.

1) General Covid Trends

During the first wave, there were very few daily cases, compared to wave 2 and 3. As weekly cases peaked at 111, so did other categories relative to this wave such as: recoveries, deaths, ICU and non-ICU hospitalizations, non-hospitalized active cases,

positivity rates, and daily tests. Looking at closed itemsets we find the pattern {low daily cases, low daily recoveries, low daily deaths, low ICU and non-ICU hospitalizations, low non-hospitalized active cases, low positivity rate}:8 (support of 8 or 100%), which means it was frequent for the entirety of the wave.

2) Restrictions/Interventions

Between March 31, 2020 and April 6, 2020, 111 new cases were reported. This same week, Manitoba entered a state of emergency and had public health orders put into place. This meant that theatres, recreation and casino facilities were promptly closed while other public facilities had reduced gathering sizes to contain further transmissions of COVID-19 [9].

3) Miscellaneous

The first wave had significant social and economical implications in Manitoba. Unemployment rate during March was only 6.7%, but by April was at an all-time high of 11.3%. Travel had been impacted significantly as well, with 13359 total non-resident travellers and 71838 total canadian travellers returning abroad in March, to only 1593 total non-resident travelers and 3275 canadians returning abroad in April.

B. Wave 2

Wave 2 started from September 1st 2020, to March 1st 2021, which lasted a total of 26 weeks. The COVID-19 pandemic response system was introduced in August 2020, which would classify COVID-19 transmission based on various factors, and simplified the ways restrictions and interventions are handled. Vaccines were introduced in December 2020, but were administered very slowly during the wave.

1) General Covid Trends

At peak cases of Wave 2, several categories peaked between December 1, 2020 and December 7, 2020. These categories included: ICU and non-ICU hospitalizations, recoveries, deaths and unemployment rates.

The general trend for the following weeks, several categories decreased as the categories of cumulative first and second doses of the vaccine increased. The decreased categories include: daily cases, recoveries, deaths, current and non-ICU hospitalizations, active cases and daily tests.

We found patterns related to vaccines, {low 1st doses given}:23, {medium 1st doses given}:3, {low 2nd doses given}:21, {medium 2nd doses given}:5, {low cumulative 1st dose %, low cumulative 2nd dose %}:26. Here, we see that {low 1st doses given}:23 accounts for 23 weeks (or 88.5% of the wave) in which there were low amounts of the first vaccine administered. Likewise, 11.5% of the wave had a medium amount of 1st doses given, 80.8% low amount of second doses given, 19.2% medium amount of second doses given, and 100% of low cumulative first and second doses total.

2) Restrictions/Interventions

For the first 9 weeks, the provincial response level was yellow. There were minor restrictions, and every business was open. Afterwards on week 10, due to a large spike in cases and positivity rates, the provincial response level changed to orange. Closing casinos and theatres, and placing stricter restrictions on gatherings and businesses. During the 11th week, Manitoba entered the provincial response level of red. This meant that recreation facilities were promptly closed, non-essential retail and restaurants became delivery/pick-up, and other public facilities had significantly reduced gathering sizes to contain further transmissions of COVID-19 [18].

By observation, the restrictions were put into place before the peak of Wave 2 hit. We can assume that the restrictions had less of an effect on containing the transmissions of COVID-19.

3) Miscellaneous

There was a general increase over the following weeks for total Canadian travellers returning from abroad.

4) Variants

Wave 2 had very little recorded variant data, with a singleton pattern of {Majority alpha}:3. From this, we see during the 3 weeks on December 15, 2020 to January 4, 2021 all cases were of B.1.1.7 (Alpha) variant.

C. Wave 3

Wave 3 started from April 1st 2021, to August 1st 2021, and consists of 18 weeks.

1) General Covid Trends

Between May 6, 2021 and May 26, 2021, several categories peaked: daily cases, current ICU hospitalizations, positivity rates, daily tests and as well as first doses of the vaccine.

Compared to the previous waves, Several categories reached all-time highs. Weekly cases reached 3268 cases, ICU hospitalizations also reached 412 cases, and positivity rates reached an all-time high of approximately 13.8%. Weekly tests were at 25410, and about 89079 first doses of the vaccine were administered in a week.

The general trend for other categories was decreasing except for the cumulative first and second doses, as well as second doses of the vaccine administered. 167601 second doses were given in the week of June 24, 2021 to June 30, 2021. Deaths proportionate to new cases were significantly lower compared to other waves.

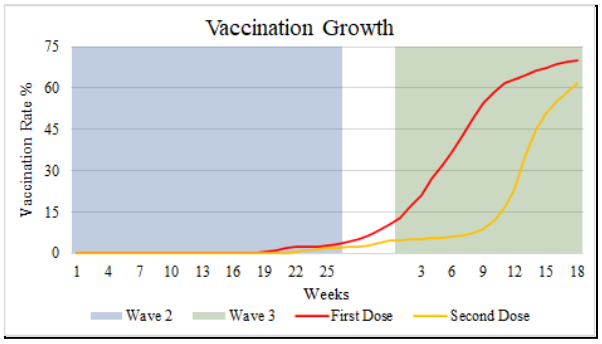

Fig 2. Vaccination growth from wave 2 to wave 3

2) Restrictions/Interventions

In comparison to the previous waves, Wave 3 entered the provincial response level of red at the very beginning of the wave, during the week of April 1, 2021 to April 7, 2021. This meant that theatres, recreation and casino facilities were promptly closed while other public facilities had reduced gathering sizes to contain further transmissions of COVID-19 [16].

During the week of June 24, 2021 to June 30, 2021, Manitoba entered the provincial response level of orange, which loosened restrictions and had Manitoban's regain limited access to the previously mentioned facilities. To note, this was also the same week as reaching the peak of second doses of the vaccine administered.

3) Miscellaneous

During each month from April to July, the unemployment rate went from 7.4%, 7.2%, 7.6%, and 6.1%. Similarly, there were 3204 non-resident travelers in April, 2646 in May, 1912 in June, and 2155 in July. 4476 Canadians returned abroad in April, 4879 in May, 5229 in June, and 4229 in July.

4) Variants

Wave 3 has the most information on the different COVID-19 variants that existed in Manitoba. During the first 4 weeks, The B.1.1.7 (Alpha) variant was the predominant variant, averaging 89.5% of all reported variant cases, while P.1 (Gamma) was 0.43%, and 10.07% were uncategorized.

For week 5 to 6, the Alpha variant only accounted for an average of 58.2% of all reported variant cases, while the Gamma variant was 0.86%, and 40.84% were uncategorized. A new variant, B.1.351 (Beta) was introduced in week 5, averaging only 0.17% of total variant cases during the period of week 5 to 6.

On week 7, two new variants, B1.617.1 (Kappa) and B1.617.2 (Delta), were introduced. From week 7 to 10, Alpha averaged 32.88% of all cases, Beta 0.24%, Gamma 7.29%, Kappa 1%, Delta 0.86%, and 63.32% were uncategorized.

From week 11 to 14, Alpha was 52.25%, Beta 1.13%, Gamma 2.45%, 0.1% Kappa, 11.65% Delta, and 32.43% were uncategorized. On week 15 to 18, Alpha was 16.53%, Gamma 1.31%, Delta 15.46%, and 66.69% were uncategorized. There were no cases of Beta or Gamma during this period.

To summarize, the Alpha variant was the most dominant **categorized** strain during the first half of the wave. When the Delta variant was introduced in week 7, Delta cases started to grow. Eventually, by week 16 to 18, Delta had overtaken Alpha as the dominant strain out of all **categorized** cases. The major variants that affected Manitobans this wave

were Alpha, and Delta. One issue is that in the second half of the wave, there were significantly more uncategorized cases compared to the first half. As we don't know what kind of variants these uncategorized cases were, we cannot make an accurate assumption that the Delta variant was the most dominant out of all strains towards the end of the wave since these uncategorized cases could possibly be any strain.

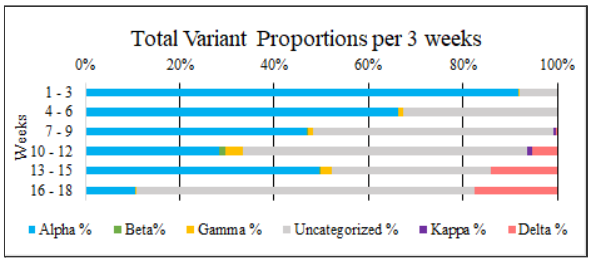

Fig.3. Proportion of variant cases per 3 weeks.

D. Comparisons between waves

1) Daily cases vs cumulative doses

By comparing the daily cases found in each of the three waves vs. the cumulative first and second doses of the vaccine, we can assume that with the increase of cumulative doses, the daily cases were to decrease faster. In other words, where there were more cumulative vaccine doses, there was a steeper downward slope on the daily cases. To calculate the downwards slope of each wave, the equation shown below was used:

$$slope = \frac{x_{Highest\ Point\ in\ Daily\ Cases} - x_{Lowest\ Point\ in\ Daily\ Cases}}{\#\ of\ Weeks\ from\ Highest\ to\ Lowest\ Point} \quad (2)$$

The downward slopes calculated for each of the waves were as follows:

- Wave 1 Slope = 0.006
- Wave 2 Slope = 0.05
- Wave 3 Slope = 0.07

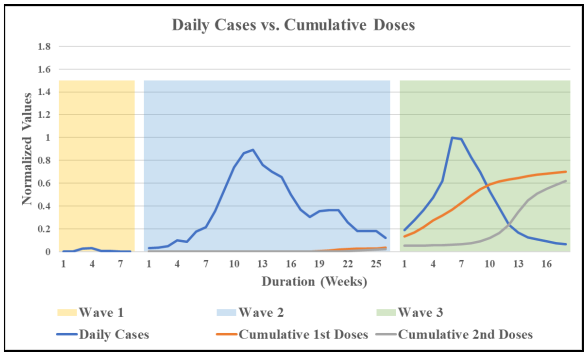

Fig 4. Daily cases vs. cumulative doses over the 3 waves

2) Death, vaccines, and hospitalizations

One insight we saw was that despite wave 3 having a very similar frequency of daily cases compared to wave 2, wave 3 had significantly less deaths compared to wave 2. In wave 2, the highest deaths over a week was at a high of 92 while in wave 3 was only at 30 deaths. During each week of wave 2 from October 27, 2020 to January 25, 2021, the count of weekly deaths was higher than the peak of deaths in wave 3. Those weeks had a death count of more than 30. After calculating the mortality rate by dividing cumulative cases to cumulative deaths in each wave, wave 1 had a mortality rate of 2.16%, wave 2 had 2.93%, and wave 3 had 1.02%.

One attribute that may have played a factor was the vaccine dosage. During the week of peak deaths in wave 2, the first dosages of the first vaccines were given out, with only 2 people out of the entire province being given the vaccine. We can likely infer that all the deaths at that time were from *unvaccinated* people. Comparatively in wave 3, during the peak week of deaths, 54.7% of the population of Manitoba has received their first dose, while 9.1% received their second dose.

For all high daily cases in wave 2, we see {daily cases, high deaths}:6, and {daily cases, medium deaths}:2. In wave 3, {daily cases, low deaths}:7. Wave 3 did not have any high daily cases with medium or high deaths. From this, we see that for high daily cases, wave 2 had 6 weeks of high deaths and 2 weeks of medium deaths, while week 3 only had 7 weeks of low deaths.

Hospitalizations also differed between the waves. Wave 2 had higher rates of non-ICU hospitalizations

and non-hospitalized cases, and a slightly lower rate of ICU hospitalizations compared to wave 3. This may be due to a variety of factors, such as introduction of various variants in wave 3, or the rapid administering of both first and second vaccines. The lower rate of death in wave 3 could also be attributed to high ICU hospitalization, as more people may have recovered than died while in the ICU.

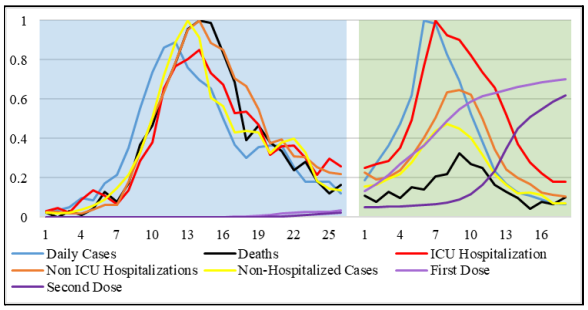

Fig 5. Normalized time-series of wave 2 (in blue) and 3 (in green) with categories related to deaths, vaccines and hospitalizations

3) Health orders, restrictions, and interventions

Health orders, restrictions and interventions changed throughout each wave. On the first week of wave 1, there were no restrictions or health orders in place. In the second week, a state of emergency was declared, restricting gathering sizes and enforcing capacity limits. While the pandemic response system wasn't implemented until August, in terms of severity, the health orders and restrictions that occured can be generalized to red (critical).

When observing provincial response levels in wave 2 and 3, wave 2 had frequent singleton patterns of {yellow}:9, {orange}:1, {red}:16, while wave 3 had {red}:16, and {orange}:6. Since support to weeks is one-to-one (*e.g.*, support of 5 means 5 weeks), and that our data is organized in a time series, then we can observe that wave 2 was at yellow for 9 weeks, changed to orange for 1 week, and then became red for the next 16 weeks. Wave 3 started at red and stayed red for 16 weeks, and then changed to orange for 6 weeks. Proportionately, wave 2 was at yellow for 34.62% of the wave, orange for 3.85%, and then red for 61.54%. Wave 3 was at red for 66.67% of the wave, and then orange for 33.33%.

As for Wave 2, the quick escalation of provincial response levels from yellow to red can be due to several concerning factors rapidly increasing. This includes: daily cases, positivity rates, deaths, active cases not hospitalized and both non-ICU and ICU hospitalizations. As Manitoba moved into red, the factors increased for a couple weeks, before steadily declining in numbers.

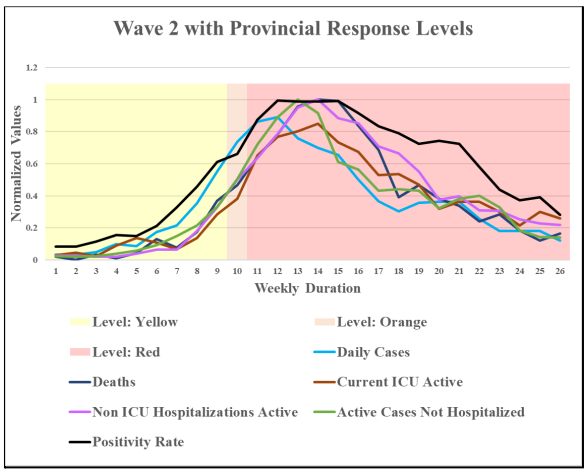

Fig 6. Wave 2 with Provincial Response Levels

As for Wave 3, several factors steadily increased, similar to Wave 2. These factors included: daily cases, positivity rates, deaths, active cases not hospitalized and both non-ICU and ICU hospitalizations.

However, in Wave 3 the provincial response levels moved from red to orange. The only potential factor for this was that the cumulative first and second doses were steadily increasing during this transition. We see on the week when the level moved from red to orange, that 64.6% of the Manitobans had gotten at least one dose, while 34.8% have gotten their second. Along with the increase of first and second doses, there was a decrease seen in these categories: daily cases, positivity rates, deaths, active cases not hospitalized and both non-ICU and ICU hospitalizations.

We can assume that the increase in vaccinations has helped protect people from COVID-19, despite the restrictions loosening. As shown with the provincial response levels transitioning from red to orange, in comparison to the other waves, where they

did the opposite; moved from orange to red close to the peaks of each wave.

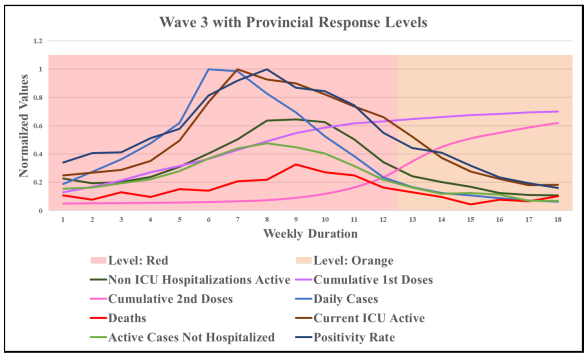

Fig 7. Wave 3 with Provincial Response Levels

4) Daily cases, restrictions and unemployment

One thing to note is that changes in the provincial response level, which changes the severity of restrictions, also affects unemployment rate. The more severe the restrictions the higher unemployment rate gets.

In the first wave, unemployment was at 6.7% in March, and when restrictions were introduced on March 20, and significantly strengthened on March 30, unemployment went to an all time high of 11.3%.

Wave 2 started in September 2020 with a provincial response level of yellow, and an unemployment rate of 7.1%. It stayed yellow in October with an unemployment rate of 7%. From November 3 to 9, the response level changed to orange, and then between November 10 to 16, it changed to red until the end of the wave. The November unemployment rate spiked to 7.5%, 8.3% in December, 8% in January 2021, and 6.8% in February.

Wave 3 started in April 2021, lasted 4 months and started at a red provincial response level. From April until June 23, it stayed red, and then From June 24 until the end of the wave, it changed to orange. Unemployment rate from April to July was 7.4%, 7.2%, 7.6%, and 6.1% respectively.

We noticed a trend of unemployment rate increasing when restrictions become more severe, and decreasing as restrictions become eased. Spanning from wave 1 to wave 3, the average trend of unemployment has been decreasing.

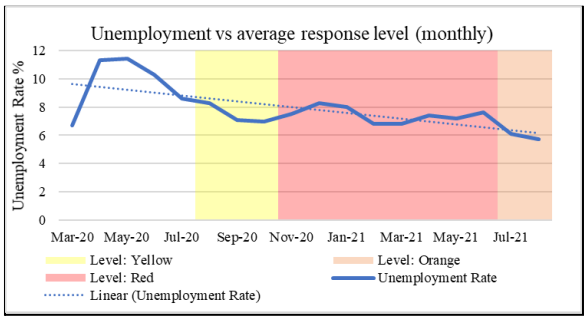

Fig 8. monthly unemployment vs the average response level on that month with a linear trend line.

V. CONCLUSIONS

We see that health restrictions and vaccinations helped alleviate the impact of the three COVID-19 waves, impacting attributes such as the amount of daily cases, people in the ICU, deaths, and unemployment. With increasing strictness with health restrictions, there were consequences of increased unemployment rates due to businesses having to close their doors. A tradeoff was assumed to be made for the public's health, favoring it over employment. Future waves of the pandemic could be mitigated by placing stricter restrictions earlier. Placing stricter restrictions earlier could produce both shorter waves and shorter restriction periods. Businesses would also be able to keep their doors open more often, also reducing the unemployment rate.

With insights on Wave 3, hospitals were able to categorize almost all variants affecting Manitobans at the beginning. As the wave went on, more cases went uncategorized. In the future with the appearance of new variants such as the B.1.1.529 (Omicron) variant, it will become important for hospitals to categorize COVID cases so they can properly treat their patients, as they may have different symptoms from already existing variants. Categorization of cases is also important to see the efficacy of vaccines against the various variants in an area.

REFERENCES

[1] WHO coronavirus disease (COVID-19) dashboard, [online] Available: https://covid19.who.int/.

[2] "COVID-19 Variant of Concern Cases in Manitoba: Cases by Variant and Regional Health Authority," Data MB. [Online]. Available: https://geoportal.gov.mb.ca/apps/95badc9cb5c3408ca2eb562ab61af51b/explore.

[3] Haleem, A., Javaid, M., Khan, I.H. et al. Significant Applications of Big Data in COVID-19 Pandemic. JOIO 54, 526–528, 2020.

[4] B. Roussin, "The Public Health Act: Orders Under The Public Health Act", 2021.

[5] Marchand-Senécal et al., "Diagnosis and management of first case of COVID-19 in Canada: lessons applied from SARS-CoV-1", Clinical Infectious Diseases, 2020.

[6] "Manitoba COVID-19 Vaccinations - Daily Statistics," Data MB, 10-Dec-2021. [Online]. Available: https://geoportal.gov.mb.ca/datasets/manitoba::manitoba-covid-19-vaccinations-daily-statistics/about.

[7] "Manitoba COVID-19 - Variant of Concern Cases," Data MB, 26-Nov-2021. [Online]. Available: https://geoportal.gov.mb.ca/datasets/manitoba-covid-19-variant-of-concern-cases/about.

[8] 1. "Manitoba COVID-19 – Daily Cases and Hospitalizations (historical)," Data MB, 10-Dec-2021. [Online]. Available: https://geoportal.gov.mb.ca/datasets/manitoba::manitoba-covid-19-daily-cases-and-hospitalizations-historical/about.

[9] "RESTARTMB Pandemic Response System," Government of Manitoba, 07-Jan-2021. [Online]. Available: https://www.gov.mb.ca/asset_library/en/restartmb/pandemic_response_system.pdf.

[10] C. K. Leung, Y. Chen, S. Shang and D. Deng, "Big Data Science on COVID-19 Data," 2020 IEEE 14th International Conference on Big Data Science and Engineering (BigDataSE), 2020, pp. 14-21, doi: 10.1109/BigDataSE50710.2020.00010.

[11] "COVID-19 Intervention Timeline in Canada," *Canadian Institute for Health Information*, 20-Jul-2021. [Online]. Available: https://www.cihi.ca/en/covid-19-intervention-timeline-in-canada.

[12] 1. "The COVID-19 variant of concern cases in Manitoba," CTV News, 14-May-2021. [Online]. Available: https://winnipeg.ctvnews.ca/the-covid-19-variant-of-concern-cases-in-manitoba-1.5428185.

[13] "International travellers entering or returning to Canada, by type of transport," Statistics Canada, 22-Oct-2021. [Online]. Available: https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=2410004101.

[14] "Labour force characteristics by province, monthly, seasonally adjusted," Statistics Canada, 08-Oct-2021. [Online]. Available: https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=1410028703.

[15] WHO Headquarters (HQ), "Considerations for implementing and adjusting public health and social measures in the context of COVID-19," *World Health Organization*, 14-Jun-2021. [Online]. Available: https://www.who.int/publications/i/item/considerations-in-adjusting-public-health-and-social-measures-in-the-context-of-covid-19-interim-guidance.

[16] Indranil Chakraborty, Prasenjit Maity, COVID-19 outbreak: Migration, effects on society, global environment and prevention, Science of The Total Environment, Volume 728, 2020, 138882, ISSN 0048-9697, https://doi.org/10.1016/j.scitotenv.2020.138882.(https://www.sciencedirect.com/science/article/pii/S0048969720323998)

[17] "Pandemic Response System," Government of Manitoba. [Online]. Available: https://www.gov.mb.ca/covid19/prs/index.html.

[18] Fournier-Viger, P., Lin, C.W., Gomariz, A., Gueniche, T., Soltani, A., Deng, Z., Lam, H. T. (2016). The SPMF Open-Source Data Mining Library Version 2. Proc. 19th European Conference on Principles of Data Mining and Knowledge Discovery (PKDD 2016) Part III, Springer LNCS 9853, pp. 36-40.

[19] N. Aryabarzan, B. Minaei-Bidgoli, M. Teshnehlab, "negFIN: An efficient algorithm for fast mining frequent itemsets", Elsevier, 2018