Six Sigma to distinguish patterns in COVID-19 approaches

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Abstract

Purpose – COVID-19 has changed life as we know. Data are scarce and necessary for making decisions on fighting COVID-19. The purpose of this paper is to apply Six Sigma techniques on the current COVID-19 pandemic to distinguish between special cause and common cause variation. In the DMAIC structure, different approaches applied in three countries are compared.

Design/methodology/approach – For three countries the mortality is compared to the population to distinguish between special cause variation and common cause variation. This variation and the patterns in it are assessed to the countries' different approaches to COVID-19.

Findings – In the DMAIC problem-solving approach, patterns in the data are distinguished. The special cause variation is assessed to the special causes and approaches. The moment on which measures were taken has been essential, as well as policies on testing and distancing.

Research limitations/implications – Cross-national data comparisons are a challenge as countries have different moments on which they register data on their population. Furthermore, different intervals are taken, varying from registering weekly to registering yearly. For the research, three countries with similar data registration and different approaches in fighting COVID-19 were taken.

Originality/value – This is the first study with Master Black Belts from different countries on the application of Six Sigma techniques and the DMAIC from the viewpoint of special cause variation on COVID-19.

Keywords COVID-19, Corona, Six sigma, DMAIC, Attribute charts, Pandemic

Paper type Research paper

1. Introduction

In a few months' time, COVID-19 has changed life as we know it. The pandemic has an immense economic and operational impact on countries and their healthcare systems (Leite *et al.*, 2020). Countries have reacted to the pandemic in different ways (Pearce *et al.*, 2020) varying from total lockdown to denial. Countries including South Korea and New Zealand are considered successful examples of fighting COVID-19, while Brazil and Sweden are among countries that have been criticized for their approaches. It is important to listen to the specialists and share knowledge.

Fortunately, vaccines have been developed and countries have begun to vaccinate their residents, but this process will take months while a mutated and more infectious variant of COVID-19 is now present (Tang *et al.*, 2020). This more aggressive variant is forcing countries to go into lockdown. Countries are focused on controlling the pandemic and minimizing the effects on the economy and society. Still their approaches are different (Anderson *et al.*, 2020) and proponents and opponents are arguing on measures to be taken or not. As the

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approaches to dealing with COVID-19 differ, this research seeks to determine what we can learn from the data and how Six Sigma can contribute, especially in a time when the mutated variant is rapidly spreading.

Every process is subject to natural variability caused by a number of variables (Premarathna *et al.*, 2016). However, special causes contribute to "uncontrolled" variation (Shewhart, 1931). Reducing process variation and defects is the focus of Six Sigma as a problem-solving approach (Laureani and Antony, 2017). For this purpose, special cause variation is distinguished from common cause variation and for the special cause variation key process variables are identified.

After the identification of the key process variables, root causes can be determined and solved. Statistics are used for both finding root causes and verifying effects. Black Belts and Master Black Belts are trained in finding patterns in the data, used for decreasing process variation and reducing defects (Antony *et al.*, 2020a, b).

Six Sigma offers powerful methods for the testing of conjectured causes (Ashok Sarkar *et al.*, 2013; De Mast and Lokkerbol, 2012) to support the identification of candidate causes, using human judgement and subject-matter knowledge (Allen, 2006) and is characterized by a strong emphasis on the use of advanced statistical tools, compared to other quality management methods like Lean and Total Quality Management (Dahlgaard-Park *et al.*, 2006).

Making decisions on what is known or maybe what is not known is important in times of crisis (Pearson and Clair, 1998), although data will be scarce, judgements are inevitable in conditions of ambiguity (Gunessee and Subramanian, 2020).

The objective of this article is to use Six Sigma to look for the special cause variation in the mortality rates in different countries and relate them to different approaches in fighting COVID-19. These insights can be used by specialists, who can apply them to their own country's context and approach for improved decision making.

The main objective of the research has been converted into the following research questions (RQ):

RQ1. What has been the impact of COVID-19 on the mortality rates in the Countries in the scope of the research?

RQ2. Which countries' approach has been more effective in tackling COVID-19?

In this paper, the authors have tried to contribute to what can be learned from a Six Sigma perspective on handling the pandemic. The following sections are arranged to serve this purpose. After this Introduction (1), a review (2) on the literature about the Six Sigma approach is presented followed by the methodology (3) adopted for this research. In the DMAIC approach (4) the results of the research are presented, followed by the discussion, implications and limitations (5). The conclusion (6) summarizes the answers to the research questions.

2. Literature review

The Six Sigma approach measures to what extent a process deviates causing variation (Harry, 1998) and tackles this process variability using statistical and non-statistical tools and techniques (Antony, 2004). Six Sigma is a quality improvement framework taking the form of projects (Goh, 2002) and can be considered as a management philosophy using scientific methods (Tjahjono *et al.*, 2010), tools and techniques.

Although the tools and techniques used in Six Sigma are not dedicated to this methodology, it provides an organizational structure not previously seen (Schroeder *et al.* 2008). Six Sigma is a "top-down approach" (Ray and Das, 2010) enabled by a belt structure. Yellow Belts, Green Belts, Black Belts and Master Black Belts work on improvement projects driving changes as a core activity (Kumar *et al.*, 2009) to define, measure and reduce process defects (Kane, 2020). Some say that this structure is even more important than the ultimate goal of 3.4 defects per million opportunities (De Mast and Bisgaard, 2007).

The Six Sigma method entails a project-based structure (Maleyeff *et al.*, 2012) in reducing variation, using statistics in five phases. These phases are: Define, Measure, Analyse, Improve and Control (DMAIC). The DMAIC is similar to the Juran Quality Improvement sequence (Godfrey and Kenett, 2007) to analyse, diagnose and solve problems based on facts (Defeo, 2017).

In the Define phase the problem is selected, in the Measure phase the current situation is measured and in the Analyse phase key process variables are identified (De Koning and De Mast, 2006). The goal of the Improve phase is to find solutions, recommendations and actions to improve the process so as to achieve the desired performance specifications (Ismyrlis and Moschidis, 2013), while in the Control phase measures are determined for maintaining the improved situation (Gijo *et al.*, 2019).

Measurable indicators are determined at the start of the project (De Koning and De Mast, 2006, 2007) and represent the quality characteristics, referred to as a critical-to-quality (CTQ) that can be monitored over time. Control charts are known to be effective tools for monitoring the quality of processes (Jensen *et al.*, 2006). The goal of a process is to deliver output, this output can be either good or not, as determined by the variation the customer experiences (Adams *et al.*, 2002). The goal of Six Sigma is to reduce the variation in a process to nearly zero (3.4 defects in 1 million opportunities), and to change people's mindset through shifting from reacting to being proactive in problem solving, supported by data and correct analysis (Kumar *et al.*, 2008).

If a process deteriorates because of a sudden environmental change (Goh and Xie, 2003), then it is better to monitor the defects and defectives as these are visible earlier. Whereas defects relate to the parts, defectives concern the item itself (Salentijn, 2017). A defect can be corrected, while a defective is final.

Measuring the key process output variables, collecting data to determine the current process performance (Friday-Stroud and Sutterfield, 2007) is a part of the Measure phase and allows distinctions to be made between common cause variation and special cause variation. The Analyse phase aims to understand this special cause variation from the nature and patterns of the data (Antony, 2006), identifying influence factors that determine the CTQs' behaviour (De Koning and De Mast, 2006).

In the Improve phase the influences of key process variables on the CTQs are quantified and appropriate settings are determined in order to reduce CTQ defect levels. In the Control phase, actions are taken to sustain the improved level of performance (Seow and Antony, 2004).

While the DMAIC can be traced back to Joseph Juran, the statistical approach of reducing variation can be traced back to both Walter Shewhart and William Edwards Deming. In their philosophy, statistical methods of quality control are used to understand the variation and assigning causes of variability by applying control chart techniques (Oakland and Oakland, 2018; Shewhart and Deming, 1945). After these assignable causes are removed, the process will be in a state of control.

The uniformity of quality can be measured either by variable data, such as processing time or by attribute data, such as defects or defectives. The different nature of attribute data must be taken into account when measuring the variation (Oakland and Oakland, 2018). Defects must be considered against the total number of conformities, while defectives have to be considered against the total number of units or the population. The defectives are a subset of the total population and both must be taken into account to understand the proportion between them. As non-academics would say: "Two hairs in your soup is a lot, but on your head?"

The classic control charts are based on the assumption that the data follow a specific distribution. Defects expressed in a *U*-chart are supposed to follow a Poisson distribution, while defectives in a *P*-chart should follow a binomial distribution. This idea would mean that the distribution is constant over time, but according to Laney (2002) this idea is not true, especially when the total number of conformities (*U*-chart) or the population (*P*-chart) is very large. When dealing with large sample sizes, there is a risk for overdispersion. A Laney *P*-chart makes adjustments for very large sample sizes (Laney, 2002).

However, Six Sigma is about reducing the variation in a process and this variation can be monitored by either variable data or attribute data. For attribute data, it is important to understand how these data relate to the total number of conformities or the population they are part of. Six Sigma is grounded in statistical process control enhancing a methodology and framework for improving quality in projects. Projects follow the DMAIC structure, which is essentially a structure for diagnosing the problem and determining how to eliminate root causes.

3. Methodology

The methodology adopted for this research is discussed in this section. The six stages for quantitative research as described by Cooper and Schindler (2014) were followed. These steps are:

(1) Clarify the research question

(2) Propose research

(3) Design the research project

(4) Collect and prepare data

(5) Analyse and interpret data

(6) Report the results

Public databases were used for this research. Entry criteria for the databases were:

(1) Accessible free of charge

(2) Not commercially driven

(3) Originating from a democratic country with a free press

(4) Data on mortality and population published to date in a monthly sequence

By using freely accessible, non-commercially driven data from democratic countries with a free press, possible government intervention was minimized. By using data published to date, comparisons between different countries could be made.

Databases that met these criteria entry criteria were from the Netherlands, Sweden and South Korea.

Statistical data from the following governmental institutions were used:

(1) Netherlands: CBS (Statistics Netherlands), available at: https://opendata.cbs.nl/statline/#/CBS/nl/dataset/37230ned/table?ts=1610532325087 /(Accessed: 12 January 2021)

(2) Sweden: SCB (Statistics Sweden), available at: https://www.scb.se/en/finding-statistics/statistics-by-subject-area/population/population-composition/population-statistics/#_Keyfigures (Accessed: 12 January 2021)

(3) South Korea: KOSIS (Korean Statistical Information Service), available at: https://kosis.kr/statHtml/statHtml.do?orgId=101&tblId=DT_1B04005N&conn_path=I2&language=en (Accessed: 12 January 2021)

For both the Netherlands and Sweden, mortality and population were taken from January 2017 until November 2020. For South Korea, the data were taken from January 2017 until October 2020. The data were taken for over three years' time to distinguish the effects of the influenza season, as COVID-19 emerged during the cold half of the year in the Northern Hemisphere. Differences in the months are due to the availability of the data. The data were processed with SigmaXL.

4. DMAIC approach

The DMAIC is a problem-solving approach in five phases which are executed in a project. An important distinction from regular projects is that in the DMAIC, Black Belts solve problems with an unknown solution at the start of the project, while typical project managers handle projects with a solution that has been scoped in advance (Lynch *et al.*, 2003).

4.1 Define

The circle of life is about birth, death and life itself. COVID-19 can be considered an environmental change which affects the mortality rate. Comparing longitudinally the total number of deaths to the size of the population support in determining whether more people die due to environmental changes. Since the current pandemic started last year, countries have responded differently to the crisis, due to the different phases of the epidemic and factors like resources, culture and the public domain (Cohen and Kupferschmidt, 2020).

The goal of the Define phase is to identify opportunities for improvement and determine what is critical-to-quality (CTQ). When the goal is to control the number of people dying of COVID-19 and specifically to keep this number as low as possible, reducing the pressure on healthcare systems, the CTQ is the mortality. By contrasting mortality to the historical data registered on deaths and the population, one can determine if the mortality exceeds the normal control limits. Recognizing that cross-national data comparison remains a challenge, data are available today that allow for comparisons of healthcare quality in selected areas of care (Nolte, 2012).

4.2 Measure

Through a comparison of the mortality to the population monitored in time, both the deterioration and the improvement after the measures were taken, should be distinguished in the variation. To this end, statistical data from governmental institutions were taken. These data reflect the number of deaths and the population per month and were entered into an attribute chart to look for patterns in the data. In an attribute chart, either the defects or the defectives are plotted over time. An attribute chart always has a central line for the average and control limits derived from the distribution.

Defects are monitored in a *U*-chart and defectives are monitored in a *P*-chart. When dealing with large sample sizes, there is a risk for overdispersion. A Laney P'chart makes adjustments for very large sample sizes (Laney, 2002). With the charts, special cause and common cause variation can be distinguished. By comparing the mortality to the population size, differences between countries can be distinguished. These differences are related to the different approaches to the environmental change. For each country, a Laney *P'*chart was made on the mortality rate measured in numbers of deceased people by month against the population size.

4.2.1 Dutch approach. On March 9, 2020, the first measures in the Netherlands were taken after the outbreak in Brabant, a Dutch province. Brabant went into lockdown and shaking hands was discouraged. On March 15, the 1.5 m rule was introduced and amongst others schools, daycare centres and restaurants were required to close. People were advised to stay at home and when going out, to keeping an 1.5 m distance from others. Facial masks were only required on public transport. From May 6, the measures were eased, starting with contact jobs. From 1 June, the government announced the possibility for people to test for COVID-19 when they had symptoms (COVID-19, 2020).

On 30 September, the Dutch government strongly advised people to wear facial masks, without requiring them to do so. The Dutch government called for people to take responsibility for themselves and practice good behaviour. Shop workers were advised to wear facial masks and local measures were taken. On December 15 a lockdown was imposed in the country, and this lockdown was then extended on January 12, 2021. On January 6 the first coronavirus vaccination was given to a nursing home employee in Veghel.

4.2.2 Swedish approach. Sweden has not imposed a lockdown and opted for self-regulation to prevent the transmission of the virus. This approach has led to recommendations for people, to maintain distance and take social responsibility, to avoid crowds of people or sitting too closely together in restaurants and to keep an arm's length distance between them. Facial masks are deemed not necessary (Folkhalsomyndigheten, 2020). Overall, the Swedish government appealed to the population to take responsibility and act accordingly. On December 27, 2020, the first coronavirus vaccination was given to a 91-year-old woman living in an elderly care home in Mjölby.

4.2.3 South Korean approach. On February 4, 2020, the Korean government applied its Special Entry Procedure to all travellers from China and it expanded this to other countries in the weeks that followed (Ministry of Health and Welfare, 2020). From March 19, 2020 all inbound travellers were required to receive temperature screening and install an app to check on their condition. From April 1, 2020 all travellers were subject to a 14-day quarantine from the day after arrival.

South Korea began testing in February 2020 and for all confirmed cases family members, housemates and other contacts were traced and subject to a 14-day quarantine (Coronavirus Disease-19, Republic of Bank of Korea, 2020). In January 2021 South Korea expanded a ban on private gatherings of more than four people to the whole country. South Korea announced that it will begin COVID-19 vaccination from February 2021.

4.3 Analyse

In the Laney P'charts, it is clear that the increase in both the Netherlands (Figure 1) and Sweden (Figure 2) constitutes special cause variation, as the mortality goes through the upper control limit (UCL). The measures in both the Netherlands and Sweden have had an effect, leading to a decrease in the number of deaths in the summer.

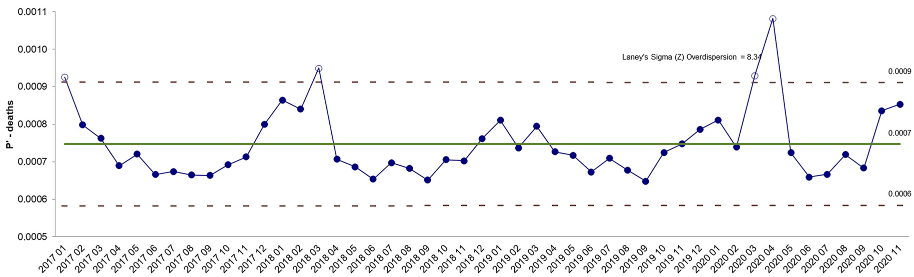

Figure 1.
Laney's *P*-chart on the mortality compared to the population size for the Netherlands

In September however there was a clear increase in Sweden. An assignable cause could be that Sweden did not change its policies and consistently made appeals regarding people's behaviour. The Netherlands in contrast started testing in June and experimenting with several measures, like wearing facial masks. The Swedish government did not consider changing its policy until October 2020 (Time, 2020). In the Laney *P*-charts, the difference between the Dutch approach and the Swedish approach is clear.

While the peak in excess mortality in April for both the Netherlands and Sweden is obvious, there is no special variation from February 2020 until October 2020 in South Korea (Figure 3). It is clear that South Korea has been able to absorb the mortality due to COVID-19. South Korea began taking measures earlier than the Netherlands and Sweden and made testing the focal point of its approach starting in February 2020.

While a *P*-chart compares the proportion of a variable to a group, a run chart is very suitable for measuring variation in healthcare (Perla *et al.*, 2011). In Figure 4, the registered deaths for each country in absolute numbers were entered into an overlay run chart through September 2020 for the Netherlands and Sweden and August for South Korea. In the overlay run chart, the increase in mortality for the Netherlands (NL) and Sweden (SW) is clear, while there is a normal pattern for South Korea (SK). In comparing countries, the total population must be taken in consideration (Table 1).

As the countries have different population sizes, the mortality can be compared by dividing the number of deaths in a country by its population, thus scaling the deaths to the population. To determine whether the differences amongst the countries are significant, an analysis of variance (ANOVA) is used to test for differences among the population means (King, 2010). The difference in the mortality rates between the Netherlands, Sweden and South Korea for the years 2017, 2018 and 2019 is significant (p = 0.0000), with South Korea having better rates. As there was no COVID-19 in these years, one can deduce that people in South Korea have a better life expectancy (Kontis *et al.*, 2017), allowing for a peak in January 2018, one of the coldest winters in the history of South Korea.

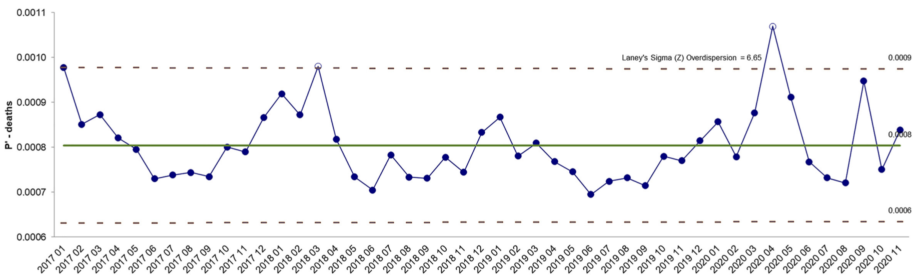

Figure 2.
Laney's *P*-chart on the mortality compared to the population size for Sweden

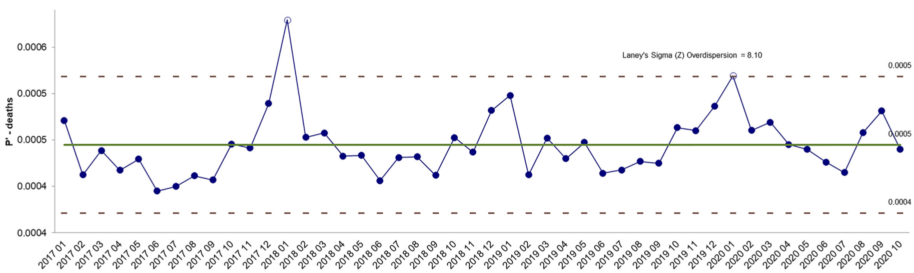

Figure 3.
Laney's *P*-chart on the mortality compared to the population size for South Korea

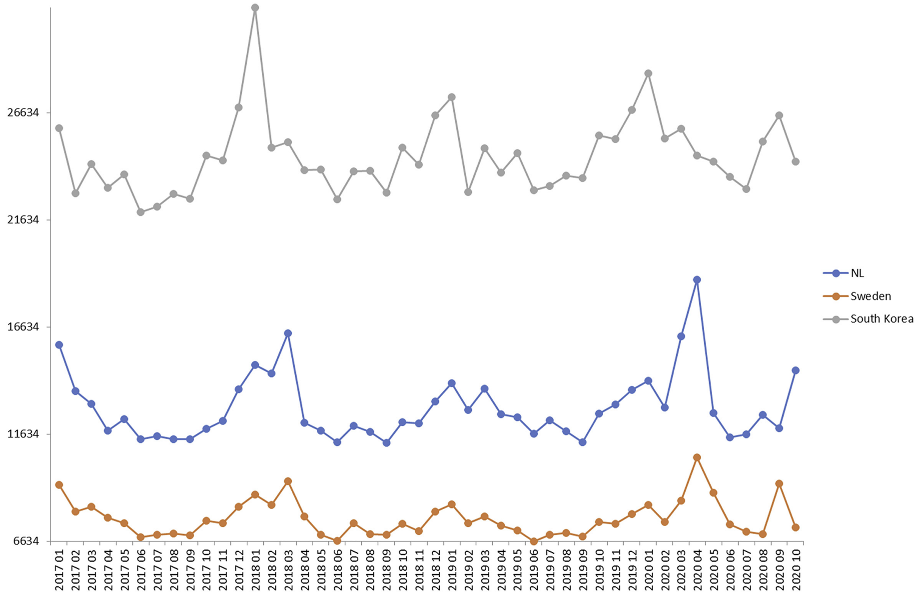

Figure 4.
Overlay run chart on the registered deaths for each country in absolute numbers

Table 1.
Population in the three countries as registered in October 2020

Country	Population
Sweden	10,380,701
Netherlands	17,461,543
South Korea	51,838,016

Still, this deduction does not explain why confronted with COVID-19 the mortality does not change significantly over time in South Korea. For the Netherlands and Sweden, the increase in mortality during the pandemic and the decrease after the measures were taken is clear (Figure 4). However, in Sweden there is a clear increase in September, equivalent to the level in May.

Taking into consideration the different approaches, South Korea differs from the other countries in its testing policy and tracking people who have been in contact with confirmed patients. South Korea initiated these measures in the first days of February 2020. In the Netherlands measures like social distancing and staying at home were announced in March 2020, while Sweden was mainly encouraging the right behaviour.

Looking at the different timelines and the process behaviour for the mortality against the population over time, it is clear a matter of the sooner the “better”. South Korea began to test and track people in February 2020. In the Netherlands, widespread testing was possible from 1 June 2020.

While greater measures like social distancing were taken in March 2020 in both the Netherlands and Sweden, in South Korea measures were taken earlier. For both the Netherlands and Sweden, the increase in deaths is visible, demonstrating the special cause variation.

When examining the number of deceased people over time in the three different countries, the excess mortality in the Netherlands and Sweden is significant, while South Korea seems to have absorbed the pandemic.

4.4 Improve and Control

In the Improve phase, it is determined how the root causes identified in the Analyse phase can be addressed in order to change the performance (Snee, 2004). Looking at the data from the past years (2017–2019), it is obvious that South Koreans have a better life expectancy. Proportionally fewer people die in South Korea. Still, based in this data, the South Korean approach to COVID-19 was far more effective than the Dutch and Swedish approaches.

In the Control phase, a system is installed for sustaining and improving performance (Snee, 2004). In the case of COVID-19, an approach must be chosen and a system must be maintained to sustain results until a vaccine has been widely administered. The DMAIC has given a structure for goal setting and analysing different approaches (Table 2).

Choosing the right approach regarding COVID-19 is not only about considering the mortality rate. Each country must consider to what extent healthcare services can be burdened while also accounting for the economy, demography, social factors and legislation amongst other factors. The gross domestic product (GDP) is generally considered a measure of the pulse of the economy (Landefield *et al.*, 2008). Looking at last year's second quarter one can distinguish the impact of COVID-19 on countries' economies and determine their resilience.

The Dutch GDP fell by 8.5% in the second quarter of 2020 compared with the previous quarter according to the first estimate conducted by Statistics Netherlands (CBS, 2020). In Sweden, the GDP decreased by 8.3% in the second quarter of 2020, seasonally adjusted and compared with the first quarter of 2020 (SCB, 2020). In South Korea, the GDP decreased by 3.2% in the second quarter of 2020 compared to the previous quarter (Bank of Korea, 2020).

The impact of COVID-19 on the countries' economies is clear, although South Korea has experienced a smaller decrease than the Netherlands and Sweden. A decrease in GDP is logical as COVID-19 has put the world in the deepest recession since the Second World War. According to World Bank forecasts, the global economy will shrink by 5.2% (Worldbank, 2020). Although the problems are global, South Korea seems to be hit less hard, which is due to the country's approach to COVID-19.

5. Discussion, implications and limitations

This study demonstrated how to use Six Sigma to distinguish between special cause variation and common cause variation. As this pandemic is new, judgements must be based

Stage	Goal in the research	Outcome
Define	The objectives in the form of measurable indicators are determined	Excess mortality as a proportion of the population is the objective of the research
Measure	Data for the measurable indicators are collected to determine existing process performance	Databases were selected and based on the entry criteria data were collected from official databases in the Netherlands, South Korea and Sweden
Analyse	Distinction is made between common cause variation and special cause variation	Special cause variation over time was determined, mapped to the Covid-19 crisis and measures taken
Improve	The influences of key process variables on the special cause variation are quantified and appropriate settings are determined	The moment of implementing the first measures is distinctive as is the robustness of the measures taken
Control	Actions are proposed to sustain the improved settings	Countries can learn from South Korea and its early and swift approach

Table 2. The DMAIC stages and the goals and objectives of the study

on what little is known. By using Six Sigma techniques and models, patterns in the data can be distinguished. The translation to practical implications must be made in consultation with the experts.

From this study, it is clear that both the moment on which measures were taken and its robustness are crucial. South Korea began testing and tracking people in February, while other countries did not move forward until March. Waiting to respond on the threat of a pandemic will lead to a further increase in infections and mandatory measures are more effective than voluntary measures.

The question however is how the South Korean measures on testing, tracking and isolating people empowered by smartphone apps would work in Western Europe and North America.

It would have been helpful if data on more countries had been available. However, many countries do not register to date, like Ireland and Italy, so data are only registered concerning 2019 and earlier. Countries like Germany and the United Kingdom register the mortality to date, but not the population. Still, comparing countries with different approaches and similar data registration has yielded useful insights.

For future research it is recommended to compare more countries and look for the special cause variation and the factors related to it. In this way insights and best practices can be collected to prepare for the next pandemic. The call to be prepared for the next pandemic has arisen in the recent years (Sambala *et al.*, 2018; Webby, 2003; Wright, 2008) with warnings like Ebola and SARS. Still, last year revealed there is a lack of preparedness for a pandemic (Villa *et al.*, 2020).

It is important to realize that this study has examined excess mortality in a time in which COVID-19 is present. People are dying from COVID-19, without these events being registered or known. From the perspective of special variation, excess mortality is a better indicator. Still, while on one hand mortality could increase due to COVID-19, on the other hand, due to "staying at home" measures, fewer people will be involved in, for example, car accidents.

6. Conclusion

In this study, the Six Sigma problem-solving approach was applied to look for special cause variation on excess mortality in three countries and relate them to different approaches in fighting COVID-19. The mortality in the Netherlands and Sweden is shown to have expanded the upper control limit and decreased after measures were taken.

However, in South Korea despite COVID-19, mortality rates are far more controlled (Table 3). Using statistics to determine what works better and what works less, the DMAIC provides a framework for transferring this knowledge to practical insights.

Country	First response to the pandemic	Measures taken in response	Mortality exceeded the statistical upper control limit
Netherlands	March 2020	Lockdown in March (1); advising social distancing (2)	Yes
Sweden	March 2020	self-regulation and encouraging the right behaviour (1)	Yes
South Korea	February 2020	Special Entry Procedure for travellers (1); widespread testing and contact tracing (2); obligation to self-quarantine after contact with a confirmed patient (3)	No

Table 3.
Measures, outcomes and timelines for the different countries

This study has shown that when comparing the data using Six Sigma techniques, the South Korean approach is found to be more effective and efficient in fighting COVID-19. Furthermore, this study reveals that reaction speed and robustness of the measures predict the effects. South Korea had an advantage by taking measures in February, these measures were also more robust than the less strict measures in the Netherlands and Sweden. In a time when the British variant of COVID-19 has paralyzed society, swift and robust measures will be necessary to control the overburdening of the national healthcare services.

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