MFE 634 – Productivity and Quality Engineering

Dr. Jorge Luis Romeu

Implementation of Statewide Lockdown

COVID-19 Pandemic in New York State

Group 1

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Statement of the Problem

Coronavirus is an important human and animal pathogen. At the end of 2019, the novel coronavirus was identified to be the cause of a cluster of pneumonia cases that spread quickly across the world, leading to the present-day COVID-19 pandemic. This particular virus is highly contagious and spreads quickly through respiratory droplets from coughing, sneezing, or talking. To negate the spread of this virus, local states of emergency have been declared throughout many countries, causing governments at both the national and local levels to impose a lockdown.

There are some major advantages to implementing a statewide lockdown that can impact people and all foundations of the state.

- Saving lives – lockdowns would limit physical contact with and protect people from other people who are infected or at risk of getting infected with COVID-19 due to certain health conditions
- Drop in pollution – lockdowns would restrict transportation by having less vehicles travel on public which would lower greenhouse emissions and lessen the effect of global warming and climate change
- Less dependence on natural non-renewable resources – lockdowns would lead to lowered usage of fuel-powered vehicles and less visits to fuel stations for refueling since people are ordered to stay at home

There are also some major disadvantages to implementing a statewide lockdown that can impact people all foundations of the state.

- Economic downturn – lockdowns would restrict transportation, meaning halted trade between countries which would negatively impact the economies of trading countries
- Disruption to education – lockdowns would force students to do virtual education which could impact their learning experience and progress in classes
- Mental health – lockdowns would force people, especially those who are isolated, to remain at home without having contact or interaction with friends and family which could affect their mental behavior
- Delayed completion of projects – lockdowns would stop the progress and delay the completion of important projects

Some objectives to consider with regards to the COVID-19 pandemic include the following:

- Implementing a statewide lockdown
- Ensuring social distancing across the state
- Limiting the spread of COVID-19 between cities and towns
- Reducing the positivity rate of COVID-19 cases
- Imposing and implementing new safe traveling guidelines
- Reaching out and spreading awareness to all neighborhoods
- Ensuring adequate historical data is available for monitoring demand and maintaining safety stock of essential goods

1. Cost of Poor Quality

Cost of poor quality (COPQ) in Six Sigma refers to all the costs associated with a problem. There are four different types of COPQs: appraisal, prevention, internal failure, external failure.

Appraisal refers to any systems, processes, or procedures that exist only to look for problems. Prevention refers to any technique that addresses things going wrong within the system or process. Internal failure is a problem that occur within an organization that may not impact the customer directly. External failure is a cost of any defect that reaches the customer. All of these types of COPQs can be represented in a COPQ chart. Figure 1-1 below is the COPQ chart for implementing a statewide lockdown.

COPQ Chart				
COPQ	**Internal Problems**	**External Problems**	**Appraisal**	**Prevention**
Testing site	➢ Less space ➢ Shortage of testing equipment	➢ Inclement weather ➢ Location ➢ Protests ➢ Long wait lines	➢ Check weather ➢ Ensure adequate supply of testing equipment	➢ Use permanent building ➢ Police presence ➢ Update computers
Confirmed cases	➢ Backlog in reporting positive cases	➢ Delayed update which could mislead people	➢ High-performance IT generals for keeping database updated	➢ Compliance with lockdown guidelines
Hospitals	➢ Shortage of medical equipment and workers ➢ Shortage of beds ➢ Untrained medical workers	➢ More deaths ➢ Improper treatment for patients	➢ Construction of makeshift quarantine centers ➢ Lending support from non-medical companies	➢ Proper training for medical volunteers and hospital staff
Schools and workplaces	➢ Shift to entirely online platforms ➢ Maintaining attendance roster online ➢ Unstable internet connection	➢ Lack of understanding for students ➢ No interaction outside "bubble"	➢ Setting up online database (e.g. online library) ➢ Host weekly inter-department sessions for interactions	➢ Ensure proper internet connection ➢ Free access to recorded online sessions
Travel restrictions	➢ No transportation in case of emergency ➢ Shortage of daily household essentials	➢ Economic shutdown on businesses and transportation ➢ Delayed deliveries of needed supplies and services	➢ Lower operation frequency and occupancy in public transportation ➢ Host weekly food drives	➢ Allow shuttle services for medical emergencies ➢ Allow more food delivery services to homes ➢ Have non-medical volunteers help with delivery

Figure 1-1 – Cost of poor quality (COPQ) chart for implementing a statewide lockdown

Testing sites, confirmed COVID-19 cases, hospitals, schools and workplaces, and travel restrictions are the five factors that are considered to be our COPQs after implementing a lockdown. It is very important to maintain the quality of these factors in order to effectively implement a lockdown. Every factor has internal and external problems and our group attempted to determine some solutions to maintain the quality of these factors.

2. Six Sigma Process

2.1 About Six Sigma

Six Sigma is a statistical approach of addressing process control and quality through the reduction of variation (which is the cause of defects) in a system or a process. Although there are many approaches that can be used to improve a system or a process, the most-used Six Sigma approach is the DMAIC process. DMAIC is an abbreviation of the five components that are key to Six Sigma which are Define, Measure, Analyze, Improve, and Control. The objectives and tools used in each Six Sigma phase will be described in the following sections.

2.2 Define Phase

In the Define phase, the opportunities for improvement of the system or process being analyzed are identified and quantified. Key objectives for the Define phase include defining the problem, determining the desired state, and completing pre-project administrative work. Key tools for the Define phase include the project charter, the cost of poor quality (COPQ) chart, communication plan, SIPOC diagram, and the identification of critical-to-quality characteristics (CTQCs).

The project charter is the initial document that summarizes the findings of the project. It is created in the early stages of the project, revisited frequently, and updated when necessary. Some important components of the project charter include the problem statement, the goals for the project, and the scope of the project. Figure 2-1 below is the project chart for implementing a statewide lockdown.

Project Charter	
Project Name	Implementing a Statewide COVID-19 Lockdown
Problem Statement	The World Health Organization (WHO) has been monitoring the global spread of COVID-19 since November 2019 and publicly declared a pandemic a few months later. As more COVID-19 cases began to accumulate globally, hospitalizations due to COVID-19 exceeded capacities of hospitals and created an overwhelming panic for medical staff. To ensure the protection, health, and safety of every person, the factors and impact of implementing a statewide COVID-19 lockdown are being determined.
Goal Statement	Implement a statewide lockdown by halting physical interactions and movement to limit the spread of the virus and thereby minimize the positivity rate of COVID-19 cases to under 5% for the health and safety of the community within a 2-month period.
Project Scope	The scope of this project will focus on COVID-19 diagnosis testing, continuous calculation of the COVID-19 positivity rate based on state population, and mandating social distancing guidelines and masks

Figure 2-1 – Project charter for implementing a statewide lockdown

For our project, as the main goal is to implement a statewide lockdown, the project charter helps us in identifying the key components which contribute towards achieving the end goal. As the project phases into new stages with added changes to the conditions, our group would have to update the project charter. Also the project charter helps us to stay on track and not drift away from the topic to be achieved.

The communication plan is a planning document that enables effective communication and information delivery to key stakeholders in the project. It is organized into who, what, how, and how frequent to communicate as well as the purpose of the communication. Figure 2-2 below is the communication plan for implementing a statewide lockdown.

Communication Plan					
Audience	**Media**	**Purpose**	**Key Messages**	**Frequency**	**Notes**
People	Television news, public announcement, email updates, Q&A phone session	Buy-in, information, action	Stay updated and aware of pandemic, follow health and safety guidelines	Every day	Needed in all phases for DMAIC process
Health organizations	Television news, email updates, virtual meetings, phone calls	Information, action	Promote public awareness campaigns, find solutions to slow and end pandemic	Every day	Needed in all phases for DMAIC process
Hospitals	Television news, email updates, virtual meetings, phone calls	Information, action	Care for mildly- and severely-infected patients, update on number of positive cases and positivity rate	Every day	Needed in all phases for DMAIC process
Non-medical companies	Email updates, virtual meetings, phone calls	Buy-in, information, action	Create alliances with medical companies and orgs to assist in fight against pandemic	Every week	Needed in Analyze and Improve phases

Figure 2-2 – Communication plan for implementing a statewide lockdown

This chart gives us information about the audience, media, purpose, key messages, frequency, and notes.

The SIPOC diagram is a high-level process map that helps clarify the core process that the project is focused on. SIPOC is an abbreviation of the five components that make the SIPOC diagram which are Supplier, Input, Process, Outputs, and Customers. Figure 2-3 below is the SIPOC diagram for implementing a statewide lockdown.

SIPOC Diagram				
Supplier	**Inputs**	**Process**	**Output**	**Customer**
Government	Leadership Communication	Social-distancing and mask mandates	Compulsory use of masks in public spaces	People Businesses
		Create website and toll-free helpline for COVID-19	COVID-19 updates on government website and toll-free helpline	
		Send stimulus checks to people and medical supply funding to hospitals	Adequate COVID-19 testing kits	Hospitals
Health organizations and hospitals	COVID-19 testing kits Doctors Nurses Health officials Information Communication	Check-in with patients and do COVID-19 nasal RT-PCR diagnosis test	Makeshift hospitals and quarantine centers	COVID-infected patients
		Count positive tests against local area population	Updated weekly regional infection rate	People

Figure 2-3 – SIPOC diagram for implementing a statewide lockdown

In implementing a lockdown, the most important decision is taken by the government and hence the government becomes our supplier. They take decisions for inputs particularly medical and healthcare. In order to obtain an efficient result of the output, the government has to follow some processes which directly or indirectly affects the targeted customers.

The critical-to-quality characteristic (CTQC) is measurable characteristic of the system or process that satisfies the voice of the customer (VOC). VOC information can be vague and difficult to identify the key requirements of the customer. CTQC charts are helpful and useful in providing clarity and structure to the VOC because it provides a visualization of the VOC in which key customer requirements are clearly identified. Figure 2-4 below is the CTQC chart for implementing a statewide lockdown.

Critical to Quality Characteristics (CTQC) Chart			
Customer	**Need**	**Driver**	**CTQC**
People	Protection from getting infected from COVID-19	Social distancing and mask mandates COVID-19 diagnosis testing	Age, race, and gender Medical conditions
Hospitals	More space for caring COVID-infected patients	Makeshift hospitals Quarantine centers COVID-19 testing sites	Average number of hourly drive-thru tests Average number of daily tests Amount of hospital beds in all hospitals Infection positivity rate
Schools	Continued operation during lockdown	Reliable and useful online work platforms	Type of school Student population size Student grade levels Graduation rates
Businesses			Type of business/industry Employment

Figure 2-4 – Critical-to-quality characteristics (CTQC) chart for implementing a statewide lockdown

The CTQC chart helps us to identify the CTQ parameters as they relate to what is important to the customer at large. The end-product parameters and the associated process parameters determine the quality of the end-product parameters that are important to the customer. Once these parameters are identified, our group monitored, controlled, and continuously improved upon these parameters.

2.3 Measure Phase

In the Measure phase, the main problems in the system or process are evaluated. Key objectives for the Measure phase include defining the current state, collecting data on the current state, and identifying any unforeseen problems and opportunities. Key tools for the Measure phase include key performance indicator (KPI) tree diagrams and data collection methods.

A KPI tree diagram is a visual method of displaying a range of process measures that are relevant to the project or process. It brings together a range of measures that are relevant to the project or process. Ideally, the KPI tree diagram should have a balance of measures covering efficiency and effectiveness of a process. Figure 2-5 below is the KPI tree diagram for implementing a statewide lockdown.

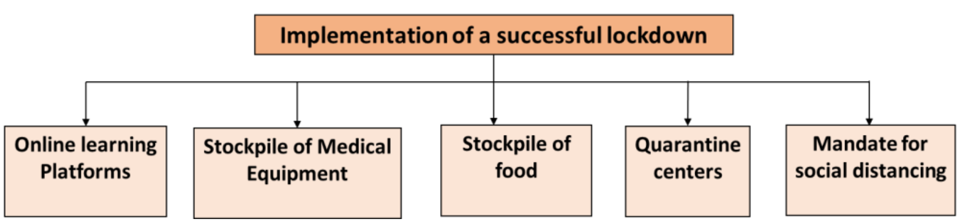


Figure 2-5 – Key performance indicator (KPI) tree diagram for implementing a statewide lockdown

With the lockdown being implemented and limited movement of people, online learning platforms become the most important source of socializing and communicating especially in education and work. To keep the supply chain of food and medical equipment running, our group needs a good amount of stockpile for those items. A lockdown is implemented to avoid the spread of COVID-19 and hence quarantine centers and social distancing mandates become our most important KPIs.

The data collection plan is a planning document that identifies options for finding and collecting data. Once it has been decided what needs to be measured and how to record the data, the amount and the frequency of collected data are specified by the data collection plan. Figure 2-6 below is the data collection plan for implementing a statewide lockdown.

Data Collection Plan				
Performance Measure	**Data Source**	**Who Collects the Data?**	**When Is the Data Collected?**	**How Is the Data Collected?**
Number of positive cases	COVID-19 testing centers	Medical volunteers	Every 7 days	Test reports
Positivity rate	COVID-19 testing centers	Center of Disease Control (CDC)	Every 7 days	Positive test reports per number of tested patients
Compliance with social distancing	Colleges Public places	Non-medical volunteers	Everyday	Non-medical volunteers stationed at colleges and public places
Online work and education platforms	Employees Students	IT services	Every 7 days	Positive test reports per number of tested patients
Availability of essential daily goods and services	Food department Travel department	Regional heads of food and travel departments	Every 7 days	Weekly audits Demand forecasting

Figure 2-6 – Data collection plan for implementing a statewide lockdown

Any process or project is incomplete without correct data. Thus, our group would need a data collection plan which includes the performance measure, data source, who will collect data, the frequency of data collection, and the method of data collection.

2.4 Analyze Phase

In the Analyze phase, the key system or process performance drivers are determined. Key objectives for the Analyze phase include analyzing and reporting on collected data, identifying any bottlenecks in the process, and determining sources of defects and variation. Key tools for the Analyze phase include the process mapping, organizational flow chart, affinity diagram, and Ishikawa (fishbone) diagram.

Process mapping is a method of visually representing a process that helps in understanding how the process actually works and brings clarity to complex processes. Process maps consist of input, output, decision point, and process step modules that are connected if they are related. Figure 2-7 below is the process map for implementing a statewide lockdown.

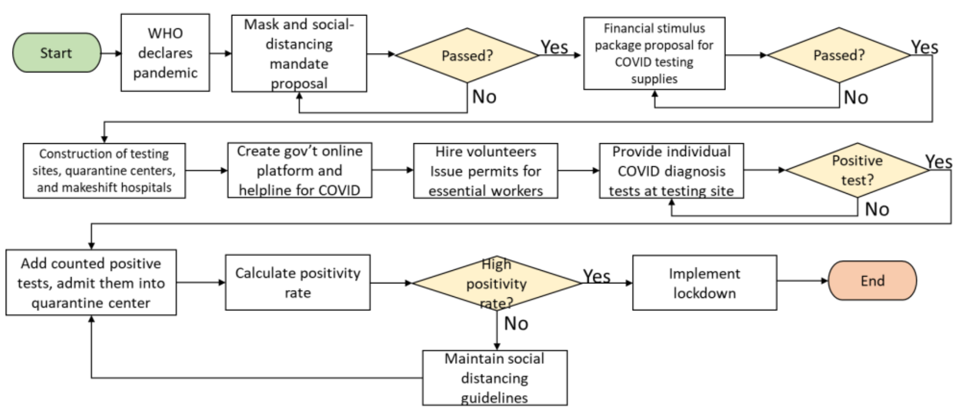


Figure 2-7 – Process map for implementing a statewide lockdown

The process flow chart for implementing the lock down as the first stage where the WHO organization is declaring a worldwide spread of pandemic. The next step in our process is to have the government pass social distancing and mask mandates as well as financial stimulus packages for COVID-19 testing supplies. From there, the construction of testing sites, quarantine centers, makeshift hospitals is also taken into consideration for catering the people affected. Most activities have transitioned to online, where the government creates an online platform and a helpline. During these unprecedented circumstances, our group considered the hiring of volunteers and issuance of permits to the essential workers as travel restrictions would be imposed. Regular testing has also been a key contributor towards keeping the positivity rate as low as possible. If the individuals are tested positive, they are added to the count and admitted to the quarantine centers. Calculating the positivity rate is the most important, as our group would implement the lockdown if it exceeds the safe limit of 5% set by the organization, otherwise maintaining social distancing guidelines will still be enforced.

Organizational flow charts and affinity diagrams are documents that help to identify key categories within textual data. These are useful techniques for finding similar groups within these types of textual sources of data. Figures 2-8 and 2-9 below are the organizational flow chart and affinity diagram for implementing a statewide lockdown, respectively.

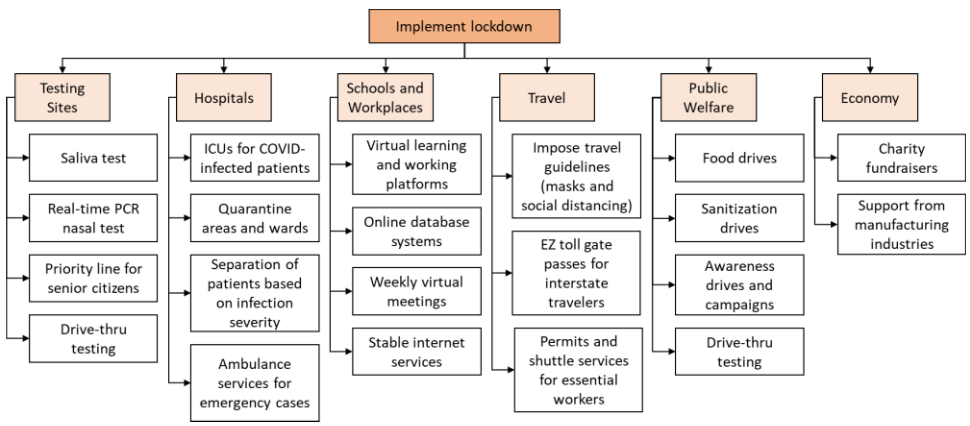


Figure 2-8 – Organizational flowchart for implementing a statewide lockdown

Affinity Diagram (Brainstorming)					
Sl. No.	**Healthcare**	**Public welfare and admin**	**Education**	**Food and essential amenities**	**Production and other services**
1	Stockpile of medical equipment	Mandate for social distancing	Online learning platforms	Stockpile of food	Auditing quality assurance
2	Medical volunteers	Mandate for masks	Faculty training	Food drives	Online work platforms
3	Makeshift hospitals	Permits for essential workers	Library database		Increase production
4	Toll-free helpline	Sanitization drives			Promoting allies for healthcare
5		Travel restrictions			
6		Stimulus packages			
7		Quarantine centers			
8		Admin volunteers			

Figure 2-9 – Brainstorm affinity diagram for implementing a statewide lockdown

A project of implementing a lockdown would require a lot of ideas coming from a lot of experts from different fields, hence an affinity diagram for brainstorming becomes important. After a good session of brainstorming within the team, we came up with five major factors that the government has to deal with: healthcare, public welfare and admin, education, food and essential amenities, and production and other services.

Fishbone or Ishikawa diagrams are a type of chart that is used during brainstorming to identify root causes to the problem in the system or process. These are an effective tool to help facilitate brainstorming sessions and structuring the team's thoughts. Figure 2-10 below is the fishbone diagram for implementing a statewide lockdown.

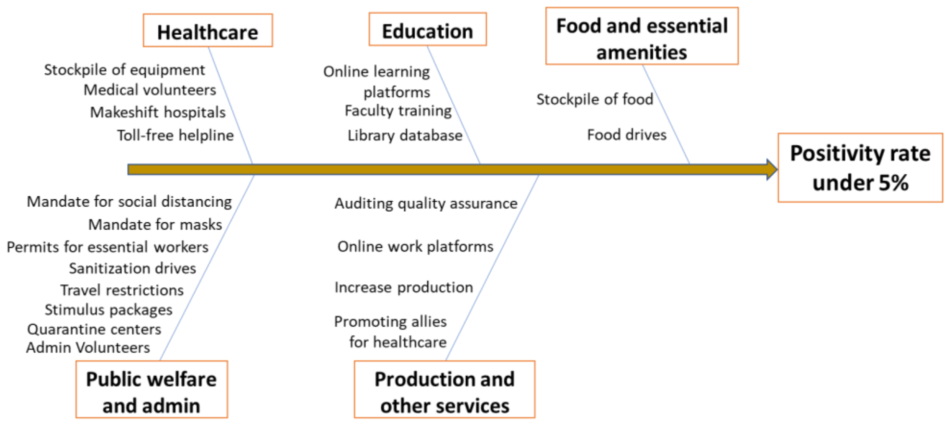


Figure 2-10 – Ishikawa chart for implementing a statewide lockdown

Our Ishikawa chart is developed from the affinity diagram for brainstorming. After determining the five major factors, we tried to find the root causes for those factors which contribute to the decision of implementing a statewide lockdown based on the positivity rate of COVID-19 infections which should be kept under 5%.

To see the effects that the factors of the root causes have on the positivity rate, our group investigated the factors of social distancing mandates, stockpile of food and essential amenities, and unemployment as a result of lockdown. All of these factors are shown in Figures 2-11 to 2-13 below.

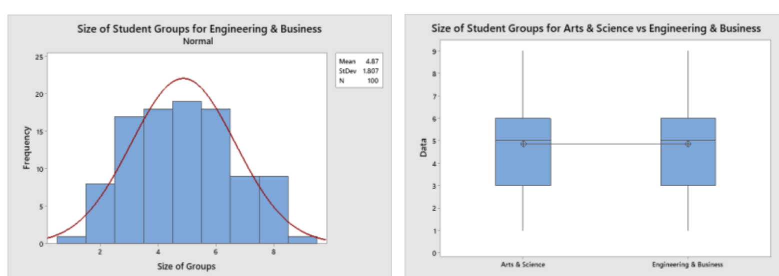


Figure 2-11 – Group sizes of students of different majors

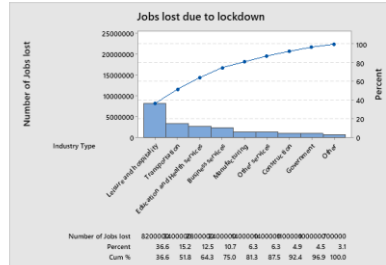


Figure 2-12 – Demand of basic goods before and after lockdown

Figure 2-12 – Unemployment and job losses after lockdown

For social distancing mandates, our group compared the group sizes of arts and sciences students with the group sizes of engineering and business students. As can be seen, the average group size between these two types of students are about 5 persons per group, which is less than the social distancing mandate group size limit of 10 persons. Thus, groups of arts and sciences students as well as engineering and business students are complying with the social-distancing guidelines.

For stockpile of food and amenities, our group analyzed the demand for basic goods before and after lockdown was implemented. Once lockdown is implemented, more people tend to panic-buy basic goods to sustain themselves. As people who are restricted to their homes begin to utilize all of their goods, their supply of these goods will decrease, leading to a demand for more goods. However, it is not clear how much more demand for basic goods will be after lockdown.

For unemployment due to lockdown, our group analyzed the trend of unemployment and job losses from negatively impacted industries after lockdown is implemented. Unemployment follows a positive trend during a lockdown. Most number of jobs lost due to lockdown include leisure and hospitality, transportation, education and health services, business, and manufacturing.

2.5 Improve Phase

In the Improve phase, solutions to improve the system or process are identified and implemented. Key objectives for the Improve phase include brainstorming potential ideas and solutions, evaluating and selecting the best solutions, pilot-testing selected solutions, and implementing solutions. Key tools for the Improve phase include error-proofing/benchmarking and failure modes and effects analysis (FMEA).

Error-proofing refers to the use of solutions and improvements that could completely prevent or reduce the risk of a failure occurring by eliminating the root cause or detect a failure surface after it has occurred. Solutions are particularly suited to repetitive manual tasks that rely on constant vigilance or adjustment. Figure 2-14 below is the error-proofing table for implementing a statewide lockdown.

Error-Proofing			
Factor	**Problem Description**	**Solution**	**Impact Score (0-5)**
Social distancing	In-person classes and meetings Gatherings more than 4 people	Sharing social distance guidelines through emails and text messages Regular inspections at public places and colleges	5
COVID-19 testing	Symptomatic people not willing to get tested	Regular notice to get tested Quarantine themselves if required	4
Travel	Group of people traveling together and disobeying interstate travel guidelines	Follow quarantine rules and get tested if traveling interstate	2
Online platforms	Students and employees facing technical difficulties	Stable internet connection Recorded classes and meetings	3
Quarantine centers	Overpopulated centers	Proper food and medical services provided to patients	4
Testing kits	Shortage of testing kits limiting number of tests per day	Maintaining double stockpiles of testing kits Communicate with other testing centers	5

Figure 2-14 – Error-proofing for implementing a statewide lockdown

Any mistakes happening during or at the end of the process have a very high cost, hence error-proofing the entire process is very important. In our project, our group has determined six factors that can have errors during the process and could have an impact: social distancing, COVID-19 diagnosis testing, travel, online platforms, quarantine centers, and testing kits. Our group described the problem for each factor and proposed solutions with the impact score to understand the severity of the problem.

Failure modes and effects analysis (FMEA) is a risk analysis tool that can be useful in environments where an event should be prevented from happening or there is little opportunity to learn from past failures since the failure rate for the process is low. The FMEA process can identify steps or components of the product, list the different failure modes that might occur, and calculate the risk priority number (RPN) which is the product of the severity, occurrence, and rate of likelihood of detection. Figure 2-15 below is the FMEA chart for implementing a statewide lockdown.

Failure Modes and Effects Analysis (FMEA)						
Failure	**Root Cause**	**Severity**	**Probability of Occurrence**	**Probability of Detection**	**RPN**	**Corrective Action**
Shortage of sanitary equipment	Lack of warehouse space, delayed deliveries	9	5	9	405	Order in advance, maintain standby warehouses
Shortage of hospital beds	Lack of hospital space	9	8	8	576	Makeshift hospitals
Social-distancing compliance	Disobedience of rules and guidelines	6	9	5	270	Fines, awareness campaigns
Online platform failure	Network connectivity issues	9	9	7	567	Stable and fast internet, specialized IT professionals
Shortage of testing kits	Delayed deliveries, demand uncertainties	10	8	8	**640**	Demand forecasting, order from nearby vendors

Figure 2-15 – Failure modes and effects analysis (FMEA) for implementing a statewide lockdown

FMEA is the process of reviewing as many components, assemblies, and subsystems as possible to identify potential failure modes in a system and their causes and effects. The chart lists the various failure models along with their root causes, their severity score, the occurrence score, and the score for detection of failure. Based on those scores, the risk priority number (RPN) score can be calculated which is the product of all the scores. The RPN helps in determining on which failure mode to concentrate as it may affect the project the most. The corrective measures for the failures are included to give us a solution for the problems and avoidance in reducing efficiency in the implementation process.

2.6 Control Phase

In the Control phase, the improved system or process is monitored to ensure sustainability. Key objectives for the Control phase include developing a control plan, continually monitoring performance, taking corrective action, creating a culture around the new process, and considering the reluctance associated with implementing change. Key tools for the Control phase include the control checklist.

The control checklist is a chart that lists preventive measures that a responsible entity must take depending on the factor. Figure 2-16 below is the control checklist for implementing a statewide lockdown.

Control Checklist			
Chk	**Factor**	**Preventive Measures**	**Responsible Person or Organization**
	Stockpile of food	Incentives for farmers and distributors to maintain inventory	Agricultural head Food department
		More distribution centers to reach out to remote areas	
	Stockpile of equipment	Promote allies with non-medical manufacturers	Federation of state medical boards
		Temporary warehouses	
	Online platforms	Zoom and Blackboard	IT specialty services
		Remote servers	
	Social-distancing mandates	Make-shift quarantine centers	Non-medical volunteers
		Social-distancing guidelines	
	Quarantine centers	Provide food and proper medication	Doctors
		Provide adequate beds	Nurses
		Adequate testing kits	Medical volunteers

Figure 2-16 – Control checklist for implementing a statewide lockdown

Our group determined five major factors that need the most attention during lockdown: stockpile of food, stockpile of equipment, online platforms, social distancing mandates, quarantine centers. It is very important that our group continues monitoring and controlling the quality of those five factors.

3. Design for Six Sigma

3.1 About Design for Six Sigma

Another Six Sigma approach to consider is Design for Six Sigma which uses a slightly different process called DMADV process. DMADV is an abbreviation of the five components that are key to Design for Six Sigma which are Define, Measure, Analyze, Design, and Verify. For this project, the criteria for the Define and Measure phases in Design for Six Sigma are the same as those from the Six Sigma DMAIC process. Therefore, new tools for the Analyze, Design, and Verify phases will be discussed in the following sections

3.2 Analyze Phase

Fault tree analysis (FTA) is a top-down failure consequence assessment technique that is useful in identifying safety concerns so that product modifications can be made. Results of analysis on FTA will identify the causes of product failures which may be eliminated through good design practice. Figure 3-1 below is an FTA for implementing a statewide lockdown.

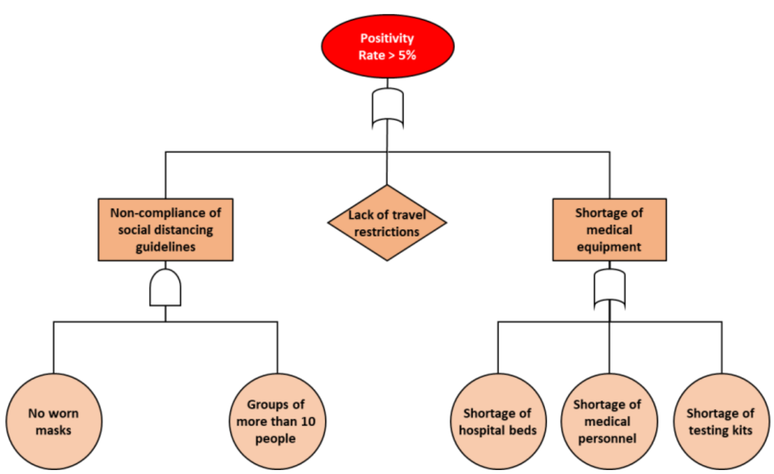
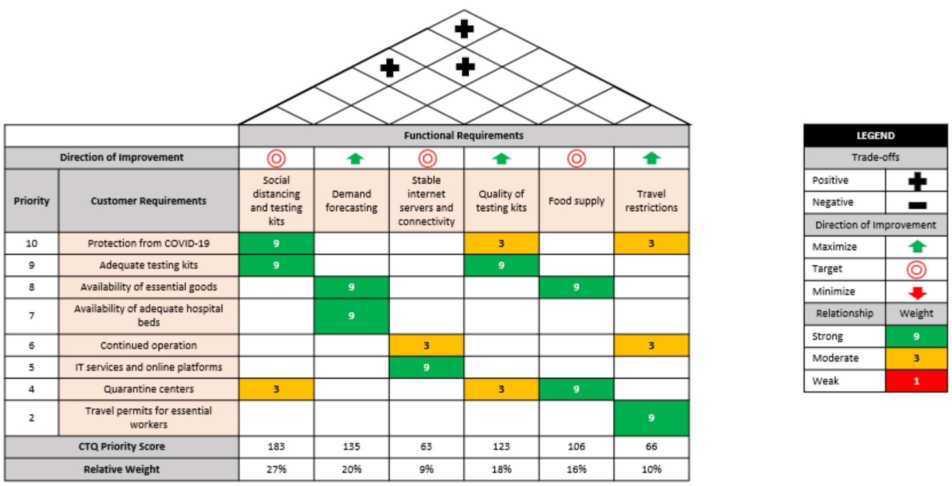


Figure 3-1 – Fault tree analysis (FTA) diagram for implementing a statewide lockdown

The FTA has the positivity rate as the end goal and as our group used various Boolean logics for stating and constructing the FTA chart. We have divided it into first stage where Non-compliance of social distancing guidelines, lack of travel restrictions and shortage of medical equipment are the key contributors. In the second stage we include the highest contributing factors towards the failures and it's root causes from the analysis done previously. These factors have their own contributing factors depending on which the end goal is varied.

3.3 Design Phase

Quality function of development (QFD) is an overall approach for understanding the needs of the customer and translating them into products or services that deliver real value. The most-used tool for QFD is the house of quality which is a type of chart that helps correlate customer requirements with product or service capabilities to ensure that a product or service delivers real value to the customer. It captures the needs of customers, translates the customer needs into general product or service features, assesses the link between the product features and customer requirements along with interactions within product features, and can be used to develop specific requirements for how the product or service will be made. Figure 3-2 below is a house of quality chart for implementing a statewide lockdown.



		Functional Requirements					
Direction of Improvement		◎	↑	◎	↑	◎	↑
Priority	Customer Requirements	Social distancing and testing kits	Demand forecasting	Stable internet servers and connectivity	Quality of testing kits	Food supply	Travel restrictions
10	Protection from COVID-19	9			3		3
9	Adequate testing kits	9			9		
8	Availability of essential goods		9			9	
7	Availability of adequate hospital beds		9				
6	Continued operation			3			3
5	IT services and online platforms			9			
4	Quarantine centers	3			3	9	
2	Travel permits for essential workers						9
CTQ Priority Score		183	135	63	123	106	66
Relative Weight		27%	20%	9%	18%	16%	10%

LEGEND	
Trade-offs	
Positive	✚
Negative	▬
Direction of Improvement	
Maximize	↑
Target	◎
Minimize	↓
Relationship	Weight
Strong	9
Moderate	3
Weak	1

Figure 3-2 – House of quality for implementing a statewide lockdown

We determined a few customer requirements and the weight of their relationships with the functional requirements. Based on that relationship, we calculated the CTQ priority score with the functional requirement of social distancing and testing kits having the highest. The CTQ priority score for each function requirement is the product of all relationship weight with the related customer requirements.

A matrix cascade is a type of chart which Figure 3-3 below is a matrix cascade for implementing a statewide lockdown.

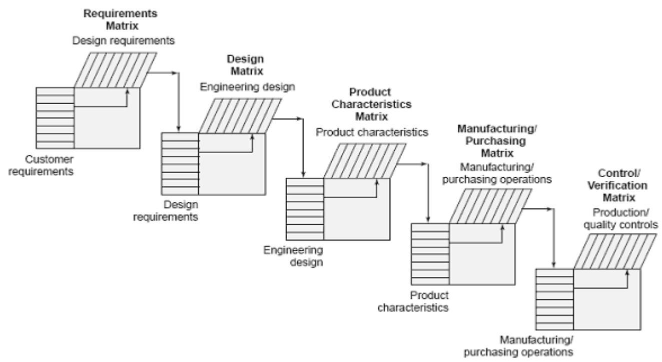


Figure 3-3 – Matrix cascade for implementing a statewide lockdown

The matrix cascade provides information about the factors:

- Customer requirements: public welfare
- Design requirements: protection for COVID-19, availability, and continued operation
- Engineering design: testing kits, hand sanitizers, masks, social distancing, IT services, good and efficient supply chain
- Product characteristics: instructions to use testing kits, groups of 10 people or less, stable internet services, and strategic placement of warehouses
- Manufacturing and purchasing operations: raw materials for testing kits, social distance markings, collaboration between service providers, and portable warehouses
- Production/quality controls: quality analysis plan for testing kits, 6-feet distance, traceability and configuration for IT services.

All these factors help us in focusing towards the implementation of the effectivity of the project implementation.

3.4 Verify Phase

Another FMEA is implemented in Design for Six Sigma in the Verification phase. Figure 3-4 below is the FMEA verification chart for implementing a statewide lockdown.

Failure Modes and Effects Analysis (FMEA) for Verification						
Failure	**Root Cause**	**Severity**	**Probability of Occurrence**	**Probability of Detection**	**RPN**	**Corrective Action**
Shortage of masks	Manufacturing shutdown, delayed deliveries	9	5	9	405	Order in advance, collaboration with other companies for production
IT services failure	Server overload, cyber attack	9	7	8	**504**	Efficient cybersecurity, backup servers
Faulty quality analysis for testing kits	Low quality material	8	3	6	144	Maintain multiple reliable vendors
People traveling without travel permits	Urgent emergencies, students traveling back home	7	7	8	392	Maintain emergency stores in local neighborhoods, planned departure of students

Figure 3-4 – FMEA verification chart for implementing a statewide lockdown

FMEA is the process of reviewing as many components, assemblies, and subsystems as possible to identify potential failure modes in a system and their causes and effects. The chart lists out the various failure models along with their root causes and according to the topic we have given them a severity score. Also the occurrence and detection of the failure probability is included in the improve phase of the project based on that we get a RPN score which is the Risk Priority number which is the multiplication of all the scores. The RPN helps in determining on which failure mode to concentrate as it may affect the project the most. The corrective measures for the failures are included to give us a solution for the problems and avoidance in reducing efficiency in the implementation process.

There also must be design that considers control and verification measures to ensure our process is intended to behave. Figure 3-5 below is a chart for design with control and verification measures.

Design with Control and Verification Measures		
Factor	**Design**	**Control and Verification Measures**
Online working platforms	Good internet speed and connectivity for students and employees	Daily internet speed and configuration tests for schools and businesses
Stockpile of medical equipment	Adequate supply of medicines and testing kits with backup inventory	Daily auditing of inventory and back orders
Stockpile of food	Efficient demand forecasting with backup inventory	Daily auditing of inventory and back orders, city-wide demand analysis of food requirements
Quarantine centers	Proper treatment and adequate space for infected patients	Daily sanitization of space and preparation of makeshift quarantine centers if needed
Social distance mandates	Mandatory wearing of masks, group sizes no more than 10	Recommendation of following social distancing guidelines and wearing masks by non-medical volunteers

Figure 3-5 – Design with control and verification measures for implementing a statewide lockdown

In our attempt to implement a lockdown, it is important that these five major factors were planned and designed to operate flawlessly. We require control and verification measures for each factor to ensure that our design for these factors is working perfectly and under control.

4. Design of Experiment

4.1 About Design of Experiment

Design of Experiments (DOE) is a powerful technique used for exploring new processes, gaining increased knowledge of existing processes, and optimizing these processes for achieving world-class performance. It allows the manipulation of multiple input factors which can determine the contribution of and the interaction between factors that can impact the reliability and capability f the process. This statistical approach can be implemented at any time during the process but is mostly applied to conducted experiments before the process is finalized.

4.2 Design of Experiment in Excel and Minitab

In DOE, our group must find the factors which are causing a high positivity rate of COVID-19 cases and find the optimal value for those factors to ensure consistent quality using Microsoft Excel and Minitab. The reference data table and the full procedure of the DOE analysis for our topic are discussed in detailed in the following sections.

Design of Experiments Analysis: Part I												
Factorial Experiments 2^3 (Three Replications/Treatment)								Run Results				
Run	**A**	**B**	**C**	**AB**	**AC**	**BC**	**ABC**	**G2**	**G3**	**G4**	**Average**	**Variance**
1	-1	-1	-1	1	1	1	-1	-2.42320006	1.7217139	-1.065570	-0.589	4.465
2	1	-1	-1	-1	-1	1	1	0.72755043	6.86826589	3.719142	3.772	9.429
3	-1	1	-1	-1	1	-1	1	-0.75185569	0.72100834	-0.580239	-0.204	0.649
4	1	1	-1	1	-1	-1	-1	11.6355325	13.4964973	12.037245	12.390	0.959
5	-1	-1	1	1	-1	-1	1	4.1222552	8.61166612	7.750157	6.828	5.676
6	1	-1	1	-1	1	-1	-1	17.995741	13.5711024	15.445649	15.671	4.932
7	-1	1	1	-1	-1	1	-1	12.094647	9.99694852	11.093057	11.062	1.101
8	1	1	1	1	1	1	1	15.0225992	20.1942574	18.309584	17.842	6.850
TotSum								58.42	75.18	66.71	66.77	34.06
SumY+	49.67	41.09	51.40	36.47	32.72	32.09	28.24			**TotAvg**	**8.346**	
SumY-	17.10	25.68	15.37	30.30	34.05	34.68	38.53					
AvgY+	12.42	10.27	12.85	9.12	8.18	8.02	7.06					
AvgY-	4.27	6.42	3.84	7.58	8.51	8.67	9.63					
Effect	**8.14**	**3.85**	**9.01**	**1.54**	**-0.33**	**-0.65**	**-2.57**					
Var+	5.543	2.390	4.640	4.488	4.224	5.461	5.651					
Var-	2.973	6.126	3.876	4.028	4.291	3.054	2.864					
F	0.536	2.563	0.835	0.897	1.016	0.559	0.507					
Variance of Model		4.26		**StdDv**	**2.063**							
Variance of Effect		0.71		**StdDv**	0.84							
			Student T (0.025;DF) =	2.473								
			C.I. Half Width =	**2.083**								

Figure 4-1 – Design of experiment (DOE) analysis chart for implementing a statewide lockdown

Based on provided data, the process for our topic has an average of 8.346 units with a standard deviation of 2.063 and a confidence interval half-width of 2.083 units.

1. **Determine the process capability before improvement.**

   The specifications chosen for implementing an effective lockdown are 5 for the lower specification limit (LSL) and 25 for the upper specification limit (USL). Before improvement, the process capability ratio C_{pk} is:

$$\boldsymbol{C_{pk}} = min\left(\frac{\bar{x}-LSL}{3\sigma}, \frac{USL-\bar{x}}{3\sigma}\right) = min\left(\frac{8.346-5}{3(2.063)}, \frac{25-8.346}{3(2.063)}\right) = min(0.541, 2.691) = \mathbf{0.541}$$

Since the calculated C_{pk} is less than the minimum acceptable value of 1.33, **this process is unacceptable**. Our group decided to develop a DOE analysis to investigate improvement measures. The potential process capability ratio C_p is:

$$C_p = \frac{USL - LSL}{6\sigma} = \frac{25 - 5}{6(2.063)} = \mathbf{1.615}$$

Since the calculated C_p is greater than the minimum acceptable value of 1.33, **this process is acceptable if and only if the process is centered**.

2. Acquire the inputs and outputs being investigated.

There are three factors that can impact the effectiveness of the implementing an effective lockdown due to COVID-19:

A. Percentage of people staying home
B. Percentage of transportation shut down
C. Percentage of the food industry shut down

The response from these three factors is reaching an infection rate of less than 5%.

3. Create a design matrix for the factors being investigated.

Design of Experiments Analysis: Part I							
Factorial Experiments 2^3 (Three Replications/Treatment)							
Run	**A**	**B**	**C**	**AB**	**AC**	**BC**	**ABC**
1	-1	-1	-1	1	1	1	-1
2	1	-1	-1	-1	-1	1	1
3	-1	1	-1	-1	1	-1	1
4	1	1	-1	1	-1	-1	-1
5	-1	-1	1	1	-1	-1	1
6	1	-1	1	-1	1	-1	-1
7	-1	1	1	-1	-1	1	-1
8	1	1	1	1	1	1	1

Figure 4-2 – DOE matrix of factors

4. For each input, determine the extreme but realistic high and low levels to investigate.

Data Manipulation							
Factor	Low	High	Unit	Range	MidPt	Val(-)	Val(+)
A	40	80	%	40	60	-1	1
B	30	60	%	30	45	-1	1
C	30	50	%	20	40	-1	1

Figure 4-3 – Data manipulation table of factors for implementing a statewide lockdown

The design is a 2^3 factorial with 3 replications

5. Perform each experiment and record the results.

Design of Experiments Analysis: Part I												
Factorial Experiments 2^3 (Three Replications/Treatment)								Run Results				
Run	**A**	**B**	**C**	**AB**	**AC**	**BC**	**ABC**	**G2**	**G3**	**G4**	**Average**	**Variance**
1	-1	-1	-1	1	1	1	-1	-2.42320006	1.7217139	-1.065570	-0.589	4.465
2	1	-1	-1	-1	-1	1	1	0.72755043	6.86826589	3.719142	3.772	9.429
3	-1	1	-1	-1	1	-1	1	-0.75185569	0.72100834	-0.580239	-0.204	0.649
4	1	1	-1	1	-1	-1	-1	11.6355325	13.4964973	12.037245	12.390	0.959
5	-1	-1	1	1	-1	-1	1	4.1222552	8.61166612	7.750157	6.828	5.676
6	1	-1	1	-1	1	-1	-1	17.995741	13.5711024	15.445649	15.671	4.932
7	-1	1	1	-1	-1	1	-1	12.094647	9.99694852	11.093057	11.062	1.101
8	1	1	1	1	1	1	1	15.0225992	20.1942574	18.309584	17.842	6.850

Figure 4-4 – DOE matrix of factors with replication results for implementing a statewide lockdown

6. Calculate the effects of each factor and of the interactions.

Design of Experiments Analysis: Part I							
Factorial Experiments 2^3 (Three Replications/Treatment)							
Factors	A	B	C	AB	AC	BC	ABC
SumY+	49.67	41.09	51.40	36.47	32.72	32.09	28.24
SumY-	17.10	25.68	15.37	30.30	34.05	34.68	38.53
AvgY+	12.42	10.27	12.85	9.12	8.18	8.02	7.06
AvgY-	4.27	6.42	3.84	7.58	8.51	8.67	9.63
Effect	8.14	3.85	9.01	1.54	-0.33	-0.65	-2.57
Var+	5.543	2.390	4.640	4.488	4.224	5.461	5.651
Var-	2.973	6.126	3.876	4.028	4.291	3.054	2.864
F	0.536	2.563	0.835	0.897	1.016	0.559	0.507

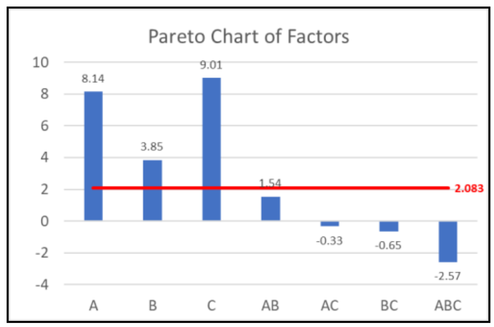
Coded Coefficients

Term	Effect	Coef	SE Coef	T-Value	P-Value	VIF
Constant		8.346	0.421	19.82	0.000	
A	8.144	4.072	0.421	9.67	0.000	1.00
B	3.852	1.926	0.421	4.57	0.000	1.00
C	9.008	4.504	0.421	10.69	0.000	1.00
A*B	1.543	0.771	0.421	1.83	0.086	1.00
A*C	-0.333	-0.166	0.421	-0.39	0.698	1.00
B*C	-0.650	-0.325	0.421	-0.77	0.452	1.00
A*B*C	-2.574	-1.287	0.421	-3.06	0.008	1.00

Figure 4-5 – The effects of each factor and of the interactions from Excel and Minitab

7. Determine the significance of the effects for each factor and for each interaction.

The effects for each factor and for each interaction are compared with the confidence interval half-width. In order for an effect to be significant, the value must be greater than 2.083. The significance of the effects can be represented in a Pareto chart of factors, normal plot and Pareto chart of the standardized effects, and the main effects and interaction plots for responses in Figure 4-6.



Design of Experiments Analysis: Part I							
Factorial Experiments 2^3 (Three Replications/Treatment)							
Factors	A	B	C	AB	AC	BC	ABC
Effect	8.14	3.85	9.01	1.54	-0.33	-0.65	-2.57
Signific.	Yes	Yes	Yes	No	No	No	No
LwrLimit	6.06	1.77	6.93	-0.54	-2.42	-2.73	-4.66
UprLimit	10.23	5.94	11.09	3.63	1.75	1.43	-0.49

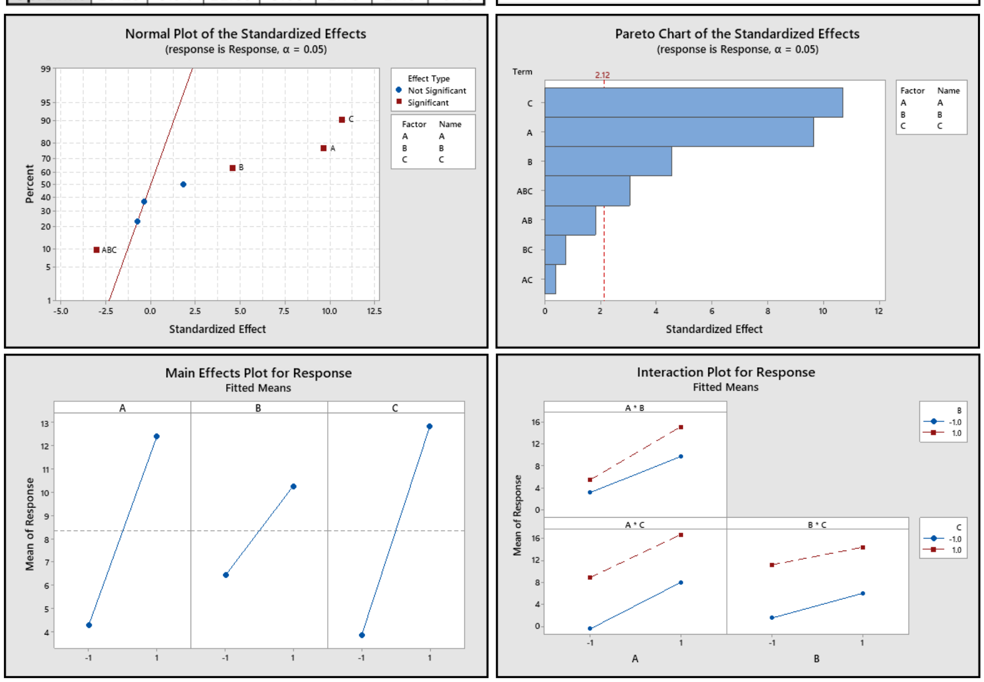


Figure 4-6 – The significance of the effects of each factor and of the interactions from Excel and Minitab

8. Determine the regression equation for the process.

For the three replications, the regression parameters from the significant factors are:

$$\boldsymbol{a_0 = \bar{x} = 8.346}$$

$$\boldsymbol{a_1} = \frac{1}{2}(Eff_A) = \frac{1}{2}(8.144) = \boldsymbol{4.072}$$

$$\boldsymbol{a_2} = \frac{1}{2}(Eff_B) = \frac{1}{2}(3.852) = \boldsymbol{1.926}$$

$$\boldsymbol{a_3} = \frac{1}{2}(Eff_C) = \frac{1}{2}(9.008) = \boldsymbol{4.504}$$

The regression parameters are half of the effects because the half-width of the confidence interval is being considered. Thus, the regression equation is:

$$\boldsymbol{Response} = a_0 + a_1A + a_2B + a_3C = \boldsymbol{8.346 + 4.072A + 1.926B + 4.504C}$$

9. Determine the new mean and target value for the process.

To accomplish this goal, our group decided to change the coded values of factors A and C to the maximum of its range as well as the coded value of factor B to 0.6 times of its range.

Coding the Data			De-Coding back	
Factor	Coded	Data	Data	Coded
A	1	80	80	1
B	0.6	54	54	0.6
C	1	50	50	1

Figure 4-7 – Coded and decoded values of factors

Thus, the new mean $\bar{x}_2$ with these changes will be:

$$\boldsymbol{\bar{x}_2} = 8.346 + 4.072(1) + 1.926(0.6) + 4.504(1) = \boldsymbol{18.078}$$

Our target value T is calculated as:

$$\boldsymbol{T} = \bar{x}_2 + \frac{1}{2}(USL - LSL) = 18.078 + \frac{1}{2}(25 - 5) = \boldsymbol{28.346}$$

10. Determine the process capability before improvement

Using the new mean and the target value, our group then verified that the newly achieved Taguchi process capability ratio C_{pm} is:

$$\boldsymbol{C_{pm}} = \frac{USL - LSL}{6\sqrt{\sigma^2 + (T - \bar{x}_2)^2}} = \frac{25-5}{6\sqrt{(2.063)^2 + (18.346 - 18.078)^2}} = \boldsymbol{1.602}$$

Since the calculated C_{pm} is greater than the minimum acceptable value of 1.33, **this process is acceptable**. Thus, our group can perform the corresponding DOE unit transformations with coded values to obtain the real values by applying the formulas to the corresponding coded values:

$$\boldsymbol{Real\ A} = 0.5 \cdot A \cdot Range_A + MidPt_A = 0.5(1)(40) + 60 = \boldsymbol{80\%}$$

$$\boldsymbol{Real\ B} = 0.5 \cdot B \cdot Range_B + MidPt_B = 0.5(0.6)(30) + 45 = \boldsymbol{54\%}$$

$$\boldsymbol{Real\ C} = 0.5 \cdot C \cdot Range_C + MidPt_C = 0.5(1)(20) + 40 = \boldsymbol{50\%}$$

Thus, to implement an effective lockdown (i.e. an infection rate of less than 5%), our group would want **80**% of people to follow stay-at-home restrictions, **54**% of transportation shut down, and **50**% of the food industry shut down.

5. Supply Chain Management

5.1 About Supply Chain Management

Supply chain management (SCM) is the active management of supply chain activities to maximize customer value and achieve a sustainable competitive advantage. It represents a conscious effort by the supply chain firms to develop and run supply chains in the most effective and efficiency ways possible. Supply chain activities cover everything from product development, sourcing, production, and logistics as well as the information systems needed to coordinate these activities. SCM can boost customer service, reduce operating costs, and improve a company's financial position. Other benefits include reduced inventory costs, better information sharing between partners, improved process integration, and improved quality.

Supply chain management is modeled by using a supply chain network. Figure 5-1 below is the supply chain network to describe a supply chain scenario which will be discussed later.

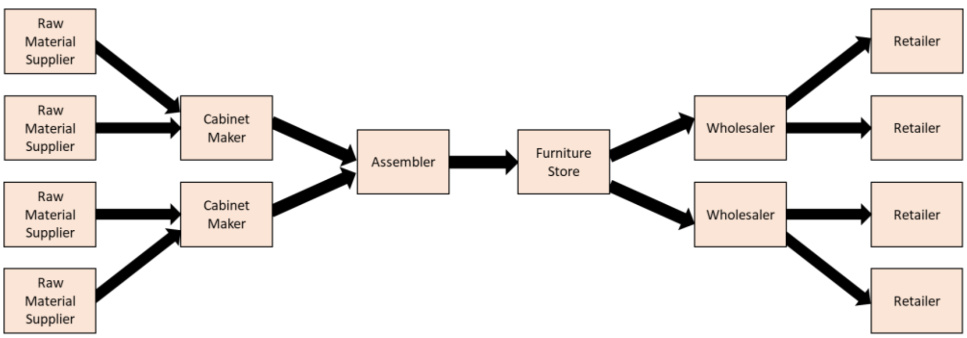


Figure 5-1 – Supply chain network as a model for supply chain management

5.2 Supply Chain Game

The supply chain game gives a better understanding of the flow of materials and costs involved. Assume you manage a store that sells furniture. Your furniture supplier assembles it, by receiving the parts from his own supplier who cuts and prepares the necessary parts of wood. The weekly supply chain flow information is as follows:

Item	Cabinet Maker	Assembler	Furniture Store
Production/Sale	0 to N1	0 to N2	0 to N3
Inventory Max	9	10	8
Cost of Inventory	1	2	5
Cost of Overflow	3	4	10
Cost of Shortage	7	6	7
Random/Selection	Judgement	Judgement	Distribution J

Figure 5-2 – Supply chain flow of the supply chain network

We must determine how many items produced weekly by the cabinet maker and assembler, the amount of inventory in the furniture store weekly, and the costs per subsystem and for the entire system. Assume that inventories are initially full and weekly sales are random. Here, two cases will be analyzed: limitation on maximum inventory and no limitation on maximum inventory. The conditions and results for both cases are shown in Figures 5-3 to 5-5 below:

Item	Cabinet Maker	Assembler	Furniture Store
Minimum Production Sale	0	0	0
Maximum Production Sale	8	9	7
Inventory Max	9	10	8
Cost of Inventory	$1	$2	$5
Cost of Overflow	$3	$4	$10
Cost of Shortage	$7	$6	$7
Random / Selection	Judgement	Judgement	Distribution J

Figure 5-3 – Supply chain flow with limitation on maximum inventory

Item	Cabinet Maker	Assembler	Furniture Store
Minimum Production Sale	0	0	0
Maximum Production Sale	8	9	7
Inventory Max	7	8	4
Cost of Inventory	$1	$2	$5
Cost of Overflow	$3	$4	$10
Cost of Shortage	$7	$6	$7
Random / Selection	Judgement	Judgement	Distribution J

Figure 5-4 – Supply chain flow without limitations on maximum inventory

In the case of a limitation on maximum inventory, we are given the maximum inventory limit for the cabinet maker, assembler, and furniture store which are 9, 10, and 8, respectively. Using those numbers, we calculated all the costs for each of the workers and the total cost of the system. The furniture store has the highest cost of inventory because it is the final product output delivery. If the product is a final product as inventory, then it would have the highest cost.

In the case of no limitations on maximum inventory, we change the maximum inventory limit for the cabinet maker, assembler, and furniture store which are 7, 8, and 4, respectively. Using those numbers, we calculated the new costs for each of the workers and the new total cost of the system. The cost of inventory for cabinet maker and assembler remained the same but is lowered for the furniture store since we lowered the inventory limit.

Comparing both cases, the total costs of inventory and of the system decreases from Case 1 to Case 2 due to a lower limit on the maximum inventory.

6. Value Stream Mapping

6.1 About Value Stream Mapping

Value-stream mapping (VSM) is a mapping tool that consists of all activities (both value-added and non-value-added) to bring a product from conception through delivery to the customer. It is a lean manufacturing technique used to analyze and design the flow of materials and information required to bring a product or service to a customer. Defining the value stream scope will help determine the value stream that needs to be improved. Then, documenting the current state will help in understanding how things currently operate. Next, designing a future state will help design a new process with a lean flow that eliminates wastage. Then, creating an implementation will help form a basis that would help support objectives. Once the implementation plan has been tested successfully, the plan will be implemented.

6.2 Current-State Value Stream Mapping – 67 Days

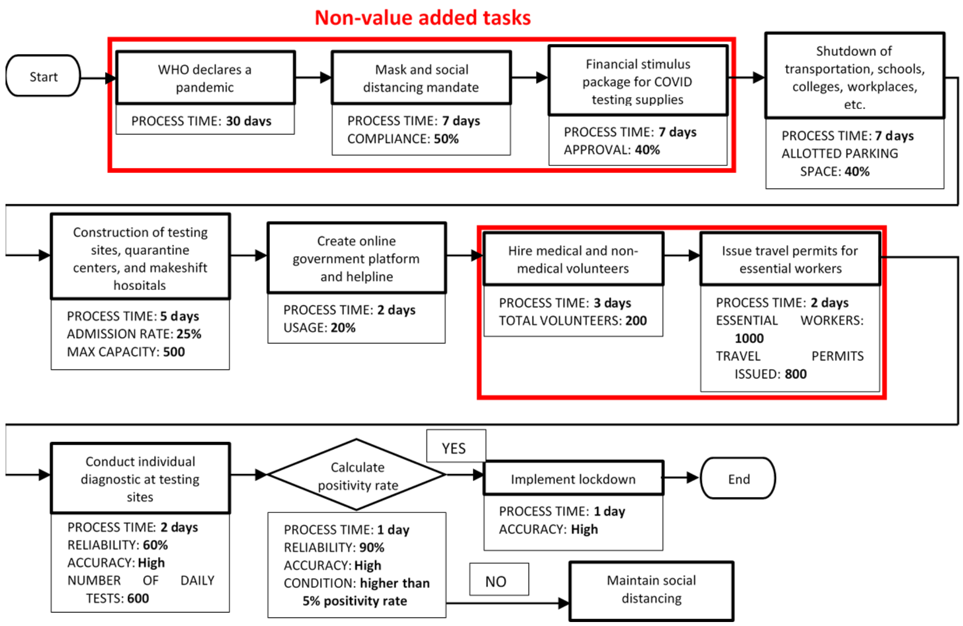


Figure 6-1 – Current-state value stream map for implementing a statewide lockdown

In the current state, the time length of the value stream map is 67 days. Each step in the value stream map has a process time with other factors considered. There are five non-value added tasks within the value stream map: the WHO declaration of a pandemic, the compliance with mask and social distancing mandate, the approval of a financial stimulus package for COVID testing supplies, the hiring process of medical and non-medical volunteers, and the issuance of travel permits for essential workers. The first three non-value added tasks can be grouped as one step and the last two non-value added tasks can be grouped as another step.

6.3 Future-State Value Stream Mapping – 51 Days

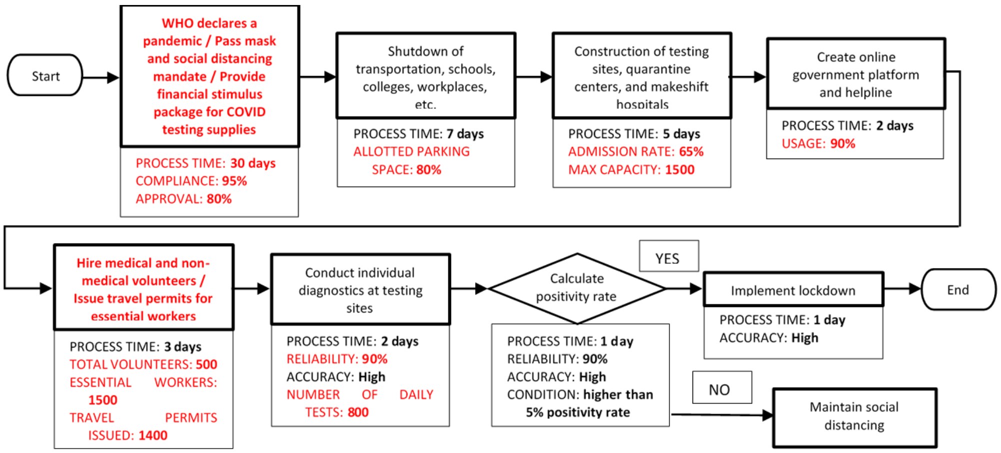


Figure 6-2 – Future-state value stream map for implementing a statewide lockdown

Using the recommendations for the current-state value stream map, changes can be made to create the future-state value stream map. Combining the WHO declaration of a pandemic, the compliance with mask and social distancing mandate and the approval of a financial stimulus package for COVID testing supplies would decrease the process time to 30 days, increase the compliance to 95%, and increase the approval to 80%. Shutdown of transportation, schools, colleges, and workplaces, and other industries increase allotted parking space to 80%. Construction of testing sites, quarantine centers, and makeshift hospitals increase admission rate to 65% and maximum capacity to 1500. Creation of online government platforms and helpline increase usage to 90%. Combining the hiring process of medical and non-medical volunteers and the issuance of travel permits for essential workers increase total volunteers to 500, essential workers to 1500, and travel permits issued to 1400. Conducting individual diagnostics at testing sites increase reliability to 90% and number of daily tests to 800. As a result of these changes, the time length of the value stream map decreased from 67 days to 51 days which is a 24% improvement.

7. Measurement System Analysis

7.1 Continuous Gage R&R Study

A gage repeatability and reproducibility (gage R&R) study measures precision error by taking one part and measuring it several times with several different people (operators) and quantifies the precision errors of a measurement system to determine its acceptability. The group considered the factors for implementing a COVID-19 lockdown as the parts for the gage R&R study. These parts include the percentage of transportation shutdown, the percentage of food industry shutdown, and the percentage of people staying home. The group also determined who are the operators for each part in the gage R&R study. These operators include transport service providers for transportation shutdown, food distributors for food industry shutdown, and the general public for people staying at home. A Gage R&R Study (Crossed) is implemented in Minitab which produced the results shown in Figures 7-1 to 7-5 below:

Two-Way ANOVA Table With Interaction

Source	DF	SS	MS	F	P
Part	9	88.3619	9.81799	492.291	0.000
Operator	2	3.1673	1.58363	79.406	0.000
Part * Operator	18	0.3590	0.01994	0.434	0.974
Repeatability	60	2.7589	0.04598		
Total	89	94.6471			

α to remove interaction term = 0.05

Figure 7-1 – Two-way ANOVA table with part-operator interaction

Two-Way ANOVA Table Without Interaction

Source	DF	SS	MS	F	P
Part	9	88.3619	9.81799	245.614	0.000
Operator	2	3.1673	1.58363	39.617	0.000
Repeatability	78	3.1179	0.03997		
Total	89	94.6471			

Figure 7-2 – Two-way ANOVA table without part-operator interaction

Variance Components

Source	VarComp	%Contribution (of VarComp)
Total Gage R&R	0.09143	7.76
Repeatability	0.03997	3.39
Reproducibility	0.05146	4.37
Operator	0.05146	4.37
Part-To-Part	1.08645	92.24
Total Variation	1.17788	100.00

Figure 7-3 – Variance components with percent contribution

Gage Evaluation

Source	StdDev (SD)	Study Var (6 × SD)	%Study Var (%SV)
Total Gage R&R	0.30237	1.81423	27.86
Repeatability	0.19993	1.19960	18.42
Reproducibility	0.22684	1.36103	20.90
Operator	0.22684	1.36103	20.90
Part-To-Part	1.04233	6.25396	96.04
Total Variation	1.08530	6.51180	100.00

Figure 7-4 – Gage evaluation with percent study variation

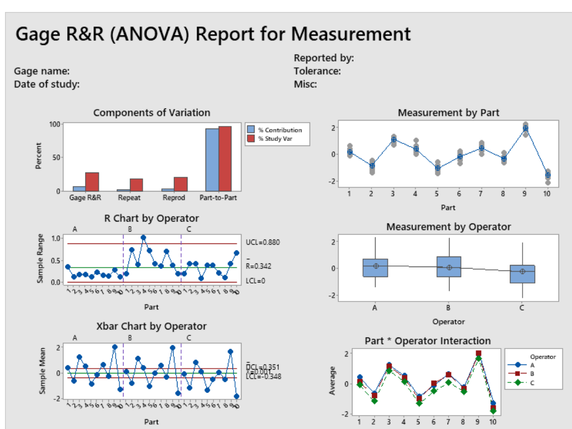


Figure 7-5 – Gage R&R (ANOVA) report for measurement

In Figures 7-1 and 7-2, an ANOVA table is used to assess which sources of variation are statistically significant. In this case, the part-operator variation is not significant because its P-value

(0.974) is greater than 0.05. However, the part variation and the operator variation are significant because their P-values (both 0.000) are less than 0.05.

In Figure 7-3, the dataset represents the gage R&R in terms of its contribution towards variance. The percent contribution for part-to-part variation is 92.24%, which is obtained by dividing the part-to-part variance component value (1.0864) by the total variation (1.17788) multiplied by 100%. This is greater than the percent contribution for operator variation which is 4.37% which indicates that part-to-part variability contributes more to the total variability of the process.

In Figure 7-4, the dataset provides the detail behind the top left graph of the graphical output in Figure 7-5. An acceptable level of gage R&R variation is when the total gage R&R as a percentage of total variation is 10% or less. The percentage study variation for total gage R&R is 27.86% which is between 10% and 30%. This indicates that the process is acceptable depending on the application, the cost of the measuring device, the cost of repair, and other factors.

In Figure 7-5, the graphical output for the gage R&R study provides six different graphs: the components of variation, the R chart by operator, the Xbar chart by operator, the measurement by part, the measurement by operator, and the part * operator interaction.

- From the Components of Variation chart, the percentage contribution of part-to-part is larger than total gage R&R which means that much of the variation is due to the difference between the parts (i.e. percentage of transportation shutdown, percentage of food industry shutdown, and percentage of people staying home).
- The R chart by Operator indicates if the operators could measure consistently as all the points would fall within the control limits. In the above R chart, there is only one point falling outside of the upper control limit which means Operator B measures just one point outside the upper control limit.
- The Xbar chart by Operator indicates whether most points fall beyond the control limits or not. The parts chosen for the gage R&R study represent the typical part-to-part variability. Thus, we must expect more variation between part averages with the graph indicating most points falling outside the control limits as in this case.
- The Measurement by Part graphs indicates if multiple measurements for each part are close together which indicates smaller variation between the measurements of the same part. In the above graph, we can see little variation at points 4 and 10.
- From the Measurement by Operator graph, the differences between operators are smaller than the differences between parts but are significant (p-value = 0.00). Measurements from Operator C are slightly lower than the measurements of the other operators. A straight horizontal line across operators indicates that the mean measurements for each operator are similar.
- The Part * Operator Interaction graph indicates if the lines that connect the measurements from each operator are similar or if the lines intersect each other. Lines that are coincident indicate the operators measure similarly. Lines that are not parallel indicate that an operator's ability to measure a part consistently, depending on which part is being measured. In the above graph, line C is consistently higher or lower than the other lines, which indicates that an operator adds bias to the measurement by consistently measuring high or low.

7.2 Attribute Gage R&R Study

An attribute gage R&R study measures the acceptability of several different products (or services) decided by several different appraisers for several trials. The Kappa values are emphasized for attribute gage R&R study, which range from -1 to +1 with a higher value having a stronger agreement.

- When Kappa is equal to 1, perfect agreement exists.
- When Kappa is equal to 0, the agreement is the same as expected by chance.
- When Kappa is less than 0, the agreement is weaker as expected by chance.

An Attribute Agreement Analysis is implemented in Minitab which produced the results shown in Figures 7-6 to 7-10 below:

Within Appraisers

Assessment Agreement

Appraiser	# Inspected	# Matched	Percent	95% CI
1	20	20	100.00	(86.09, 100.00)
2	20	18	90.00	(68.30, 98.77)

 # Matched: Appraiser agrees with him/herself across trials.

Fleiss' Kappa Statistics

Appraiser	Response	Kappa	SE Kappa	Z	P(vs > 0)
1	go	1.0000	0.223607	4.47214	0.0000
	no	1.0000	0.223607	4.47214	0.0000
2	go	0.6875	0.223607	3.07459	0.0011
	no	0.6875	0.223607	3.07459	0.0011

Figure 7-6 – Attribute agreement analysis within appraisers

Each Appraiser vs Standard

Assessment Agreement

Appraiser	# Inspected	# Matched	Percent	95% CI
1	20	19	95.00	(75.13, 99.87)
2	20	18	90.00	(68.30, 98.77)

 # Matched: Appraiser's assessment across trials agrees with the known standard.

Assessment Disagreement

Appraiser	# no / go	Percent	# go / no	Percent	# Mixed	Percent
1	1	20.00	0	0.00	0	0.00
2	0	0.00	0	0.00	2	10.00

 # no / go: Assessments across trials = no / standard = go.
 # go / no: Assessments across trials = go / standard = no.
 # Mixed: Assessments across trials are not identical.

Fleiss' Kappa Statistics

Appraiser	Response	Kappa	SE Kappa	Z	P(vs > 0)
1	go	0.856631	0.158114	5.41781	0.0000
	no	0.856631	0.158114	5.41781	0.0000
2	go	0.856631	0.158114	5.41781	0.0000
	no	0.856631	0.158114	5.41781	0.0000

Figure 7-7 – Attribute agreement analysis of each appraiser versus standard

Between Appraisers

Assessment Agreement

# Inspected	# Matched	Percent	95% CI
20	18	90.00	(68.30, 98.77)

 # Matched: All appraisers' assessments agree with each other.

Fleiss' Kappa Statistics

Response	Kappa	SE Kappa	Z	P(vs > 0)
go	0.84375	0.0912871	9.24282	0.0000
no	0.84375	0.0912871	9.24282	0.0000

Figure 7-8 – Attribute agreement analysis between appraisers

All Appraisers vs Standard

Assessment Agreement

# Inspected	# Matched	Percent	95% CI
20	18	90.00	(68.30, 98.77)

 # Matched: All appraisers' assessments agree with the known standard.

Fleiss' Kappa Statistics

Response	Kappa	SE Kappa	Z	P(vs > 0)
go	0.856631	0.111803	7.66194	0.0000
no	0.856631	0.111803	7.66194	0.0000

Figure 7-9 – Attribute agreement analysis on all appraisers versus standard

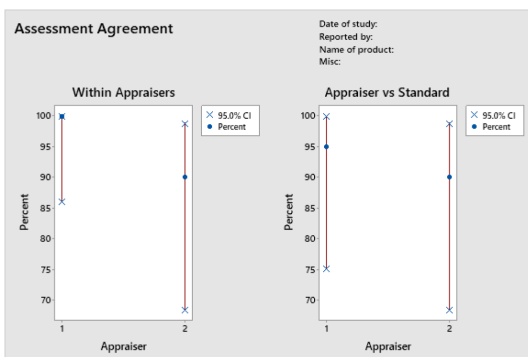


Figure 7-10 – Assessment agreement within appraisers and for each appraiser versus

In Figure 7-6, an attribute agreement analysis within appraisers is implemented. The Kappa values for Appraiser 1 are 1, indicating a perfect agreement within the appraiser between trials. The Kappa values for Appraiser 2 are 0.6875, which is close to 1 indicating a strong association within the appraiser ratings.

In Figure 7-7, an attribute agreement analysis on each appraiser versus the standard is implemented. The Kappa values for both Appraisers 1 and 2 are 0.856631, which is close to 1 indicating a near perfect agreement within an appraiser trial.

In Figure 7-8, an attribute agreement analysis between appraisers is implemented. The Kappa values for both responses are 0.84375, which is close to 1 indicating a near perfect agreement within an appraiser trial.

In Figure 7-9, an attribute agreement analysis on all appraisers versus the standard is implemented. The Kappa values for both responses are 0.856631 which is close to 1 indicating a near perfect agreement within an appraiser trial.

In Figure 7-10, assessment agreements within appraisers and for each appraiser versus the standard are implemented. The Within Appraisers graph indicates:

- Appraiser 1 has the most consistent ratings with the blue dot indicating the confidence interval, which is near 100% indicating most consistent ratings.
- Appraiser 2 has the least consistent ratings with the blue dot indicating the confidence interval, which is not near 100% indicating least consistent ratings.

The Appraiser vs Standard graph indicates:

- Appraiser 1 has the most correct ratings.
- Appraiser 2 has the least correct ratings.

8. Acceptance Sampling

8.1 About Acceptance Sampling

Acceptance sampling is a statistical method that assesses the quality of a lot by randomly picking a number of samples from the lot. The information yielded by the samples will be used to determine whether the lot should be accepted or rejected. It is an approach between no inspection and full inspection whose purpose is to decide whether or not the lot is likely to be acceptable. Typically, acceptance sampling by attributes is used. This method determines the quality of a lot with a certain level of statistical certainty without having to evaluate all samples in the lot.

8.2 Sampling Plan

In creating an acceptance sampling plan, there are five parameters to consider:

1. **The producer's risk (α probability):** the probability of deciding that the alternative hypothesis (H_1) is true, when in fact the null hypothesis (H_0) is true (e.g. risk of rejecting a group of people infected with COVID-19, when they are not infected)
2. **The consumer's risk (β probability):** the probability of deciding that the null hypothesis (H_0) is true, when the alternative hypothesis (H_1) is true (e.g. the risk of accepting a person infected with COVID-19)
3. **Acceptable quality level (AQL):** the percent defective that is the base line requirement for the quality of the producer's product.
4. **Lot tolerance percent defective (LTPD):** a pre-specified high defect level that would be unacceptable to the consumer
5. **Lot size (N):** the total number of people tested

The five parameters for our sampling plan in implementing an effective lockdown due to COVID-19 are:

Acceptance Sampling Plan	
Parameter	**Value**
AQL	0.01
LTPD	0.05
α	0.1
β	0.2
N	1000

Figure 8-1 – Acceptance sampling plan for implementing a statewide lockdown

8.3 Nomogram for Binomial Distributions

Assuming a very large lot size N, the distribution of the accepted number of defectives c in a random sample of n items is approximately binomial with n and LTPD. In an acceptance sampling plan with a producer's risk α and a consumer's risk β, the sample size n and the accepted number of defectives c are determined by a chart called a binomial nomogram. The following is the procedure of determining n and c from AQL, LTPD, α, and β on a binomial nomogram.

1. Draw a line connecting the AQL value on the left side with the corresponding $1 - \alpha$ value on the right side.
2. Draw another line connecting the LTPD value on the left side with the corresponding β value on the right side.

3. The point of intersection of the two lines gives the sample size n and the accepted number of defectives c.

Based on the parameters, our group determined n and c in the binomial nomogram shown below.

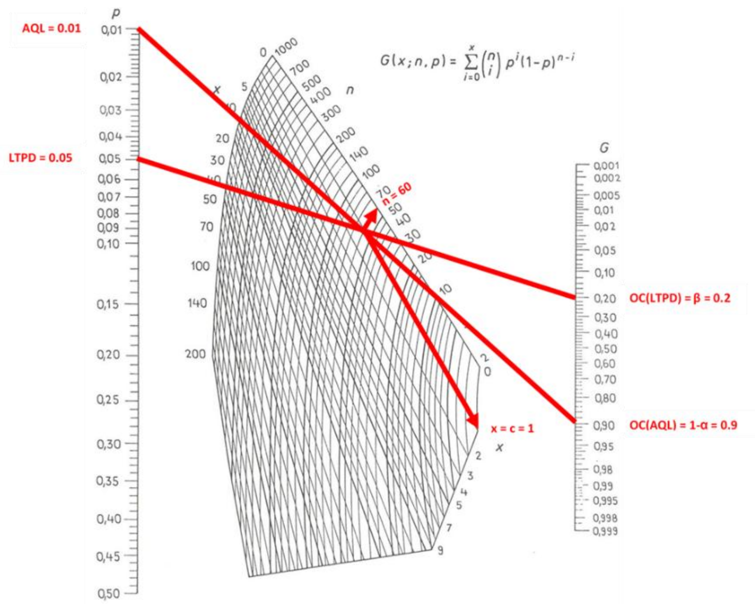


Figure 8-2 – Binomial nomogram for acceptance sampling

With an AQL value of 0.01, a LTPD value of 0.05, a $1-\alpha$ value of 0.9, a β value of 0.2, and a N value of 1000, the sample size n is 60 and the accepted number of defectives is 1. In context of implementing a lockdown, 60 random workers for multiple industries are tested with 1 worker being infected with COVID-19.

8.4 Operating Characteristic Curves

The **operating characteristic (OC) curve** is a probability curve for a sampling plan that shows the probabilities of accepting lots with various LTPDs. The probability of acceptance P_a describes the chance of accepting a particular lot based on a specific sampling plan and incoming proportion defective. It is based on the binomial distribution.

$$P_a = \sum_{d=0}^{c} \frac{n!}{d!(n-d)!} p^d (1-p)^{n-d}$$

8.5 Average Outgoing Quality Curves

The **average outgoing quality (AOQ)** is the average defective rate in a released lot, assuming rejected lots are 100% inspected and all defectives are removed. It is a relationship between the quality of incoming and outgoing materials.

$$AOQ = \frac{P_a p(N-n)}{N}$$

8.6 Average Total Inspection Curves

The **average total inspection (ATI)** per lot depends on the incoming quality, the acceptance probability of the lot, the sample size, and the lot size. It is a relationship between the quality of incoming materials and the number of items that need to be inspected.

$$ATI = n + (1 - P_a)(N - n)$$

8.7 Binomial Distribution in Minitab

Defective lots that pass or fail (attributes) can have OC curves defined by the binomial distribution, AOQ curves, and ATI curves. Minitab is able to create a sampling plan based on the parameters (AQL, LTPD, α, and β) as well as the sample size n and the accepted number of effectives c from the nomogram. Below are the numerical and graphical outputs from Minitab.

Method

Acceptable Quality Level (AQL)	0.01
Producer's Risk (α)	0.1
Rejectable Quality Level (RQL or LTPD)	0.05
Consumer's Risk (β)	0.2

Generated Plan(s)

Sample Size	86
Acceptance Number	2

Accept lot if number of defects in 86 items ≤ 2; Otherwise reject.

Defects Per Unit	Probability Accepting	Probability Rejecting	AOQ	ATI
0.01	0.944	0.056	0.00862	137.6
0.05	0.197	0.803	0.00902	819.6

Average Outgoing Quality Limit(s) (AOQL)

AOQL	At Defects per Unit
0.01457	0.02639

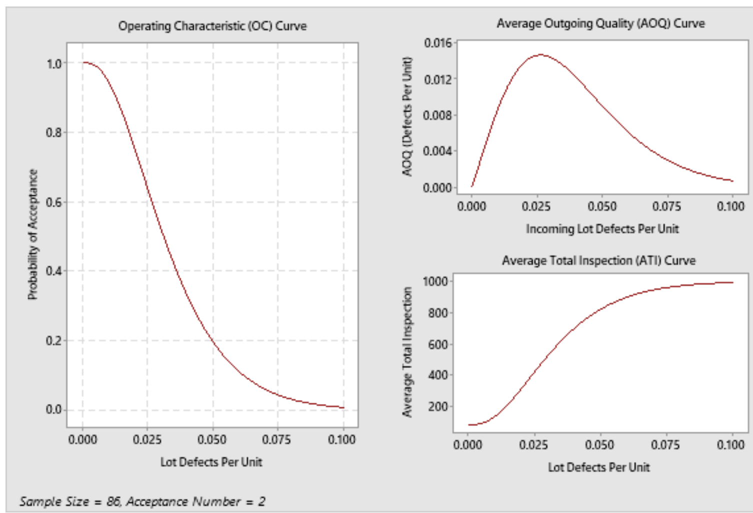


Figure 8-3 – Minitab graphical and numerical output for acceptance sampling

From examining the OC curve, it is observed that the probability of acceptance for each lot decreases as the fraction of defective lots per unit increases. With an AQL value of 0.01, the lots of COVID-19-infected people have a 94.4% probability of acceptance and a 5.6% probability of rejection. With an LTPD value of 0.05, the lots of COVID-19-infected people have a 19.7% probability of acceptance and an 80.3% probability of rejection.

From examining the AOQ curve, it is observed that the outgoing quality is also very good (i.e. a very small fraction of outgoing defectives) when the incoming lot quality is very good (i.e. a very small fraction of incoming defectives). Most of the lots are rejected and then inspected when the incoming lot quality is very bad. The defective samples are eliminated or replaced by non-defective samples to make the AOQ better. The average outgoing quality limit (AOQL) is the worst possible quality that results from the rectifying inspection program which is numerically 0.01457 at 0.02639 defects per unit or graphically the maximum of the AOQ curve.

From examining the ATI curve, it is observed that the average total inspection for each lot increases as the fraction of defective lots per unit increases. With an AQL value of 0.01, approximately 137 people out of the total sample size of 1000 people are inspected. With an LTPD value of 0.05, approximately 819 people out of the total sample size of 1000 people are inspected.

8.8 Binomial Distribution in Excel

Defective lots that pass or fail (attributes) can have OC curves defined by the binomial distribution, AOQ curves, and ATI curves. Excel is able to compare the OC, AOQ, and ATI curves for n and c between the binomial nomogram and the Minitab output. Below are the numerical and graphical outputs from Excel.

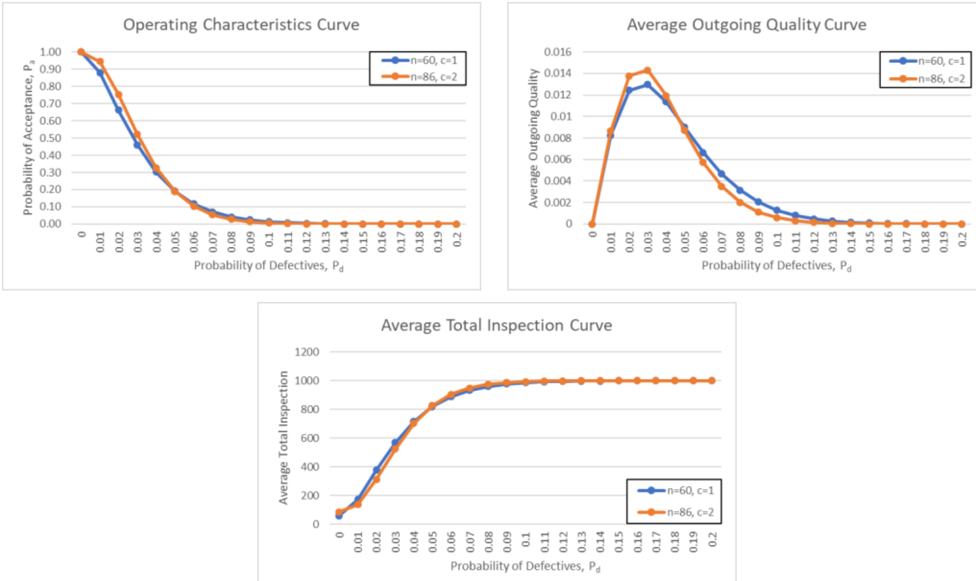


Figure 8-4 – Comparison between acceptance sampling plan and Minitab output for OC, AOQ, and ATI curves on graphs

OC, AOQ, and ATI for Implementing a Lockdown						
n	60			86		
c	1			2		
N	1000			1000		
P_d	P_a	AOQ	ATI	P_a	AOQ	ATI
0	1.000000	0	60	1.000000	0	86
0.01	0.878767	0.00826	173.9593	0.944466	0.008632	136.7579
0.02	0.661904	0.012444	377.8103	0.752698	0.013759	312.034
0.03	0.459211	0.01295	568.3419	0.521236	0.014292	523.5904
0.04	0.302233	0.011364	715.9009	0.326512	0.011937	701.5679
0.05	0.191553	0.009003	819.9398	0.190008	0.008683	826.3329
0.06	0.117923	0.006651	889.1522	0.104476	0.005729	904.5087
0.07	0.070894	0.004665	933.3594	0.054888	0.003512	949.8325
0.08	0.041771	0.003141	960.735	0.027762	0.00203	974.6259
0.09	0.024181	0.002046	977.27	0.013591	0.001118	987.5781
0.1	0.013777	0.001295	987.0495	0.006465	0.000591	994.0913
0.11	0.007736	0.0008	992.7286	0.002996	0.000301	997.2613
0.12	0.004284	0.000483	995.9727	0.001356	0.000149	998.7604
0.13	0.002342	0.000286	997.7982	0.000600	7.13E-05	999.4512
0.14	0.001265	0.000166	998.8111	0.000260	3.33E-05	999.762
0.15	0.000675	9.51E-05	999.3657	0.000111	1.52E-05	999.8989
0.16	0.000356	5.35E-05	999.6656	0.000046	6.75E-06	999.9578
0.17	0.000185	2.96E-05	999.8257	0.000019	2.93E-06	999.9827
0.18	0.000096	1.62E-05	999.9102	0.000008	1.25E-06	999.9931
0.19	0.000049	8.69E-06	999.9542	0.000003	5.2E-07	999.9973
0.2	0.000025	4.61E-06	999.977	0.000001	2.12E-07	999.9989

Figure 8-5 – Comparing between acceptance sampling plan and Minitab output for OC, AOQ, and ATI curves on table

Comparing the OC, AOQ, and ATI curves between Excel and Minitab, both are approximately equal to each other. Although it is difficult to exactly obtain the sample size n and the accepted number of defectives c, our group had to approximate those values.

9. Statistical Process Control

9.1 About Statistical Process Control

Statistical process control (SPC) charts enable the stability of the process and the type of variation involved to be understood. Applicable for a much wider range of purposes and to all industries, the traditional role of SPC charts is to detect changes in process average, changes in process variation, and one-off changes. SPC charts are used primarily for ongoing control in the Control Phase of Six Sigma but can also be used for historical analysis in the Measure and Analyze phases of Six Sigma to assess process stability.

In SPC, there are three types of data that can determine what kinds of control charts to work with: continuous data, count data, and attribute data.

- **Continuous data** – a type of data resulting from measuring a product or service characteristic. Some defining characteristics of continuous data include the calculation of averages and variations as well as a limitation on the data resolution by how good the measurement system is.
- **Count data** – a type of data resulting from counting things. Some defining characteristics of count data include the counting of whole things and data as only integers.
- **Attribute data** – a type of data resulting from classifying things. A defining characteristic of attribute data include the categorization of different things that do not necessarily have any numerical value or order.

Depending on the type of data used for SPC, there are a total of seven kinds of control charts:

- **Continuous data**
  - $\boldsymbol{I\text{-}MR}$ **chart (for individual data)** – a control chart that analyzes individual data points
  - $\boldsymbol{\bar{X}\text{-}R}$ **chart (for subgroup data)** – a control chart that analyzes the averages of small subgroups of subgroup sizes 2 to 9
  - $\boldsymbol{\bar{X}\text{-}S}$ **chart (for subgroup data)** – a control chart that analyzes the averages of large subgroups of subgroup sizes at least 10
- **Count data**
  - $\boldsymbol{U}$ **chart** – a control chart that analyzes counts or defects per unit
  - $\boldsymbol{C}$ **chart** – a control chart that analyzes counts or defects per unit of a constant subgroup size
- **Attribute data**
  - $\boldsymbol{P}$ **chart** – a control chart that analyzes proportions or percentages
  - $\boldsymbol{NP}$ **chart** – a control chart that analyzes proportions or percentages of a constant subgroup size

9.2 Binomial Distribution

We will use the binomial distribution to represent the positivity rate each day. In Minitab we can use the random number generator function to create 100 such rates which gave a mean value of 0.83. This means in our process we would expect on average over time to see 0.83% positivity rate per day.

Reference Data and Chart

The following random set of data in Figure 9-1 was generated using Minitab. Since counting the number of people infected with COVID-19 per 100 people is considered an attribute, we will use a C-chart to represent the data.

Positivity Rate of COVID-19 Cases per Day									
D 1-10	D 11-20	D 21-30	D 31-40	D 41-50	D 51-60	D 61-70	D 71-80	D 81-90	D 91-100
3	3	1	1	0	0	0	0	1	1
1	0	0	1	0	0	0	2	0	0
0	0	0	1	0	2	1	0	0	1
0	0	0	1	0	1	1	0	0	0
0	1	1	3	2	1	0	1	4	1
1	1	0	1	1	1	0	0	1	0
2	0	1	2	1	2	1	0	0	1
1	1	3	0	2	1	0	3	2	0
2	0	1	1	2	1	0	1	1	2
0	2	1	0	0	2	2	0	0	0

Figure 9-1 – Binomial-distributed data for daily COVID-19 positivity rate

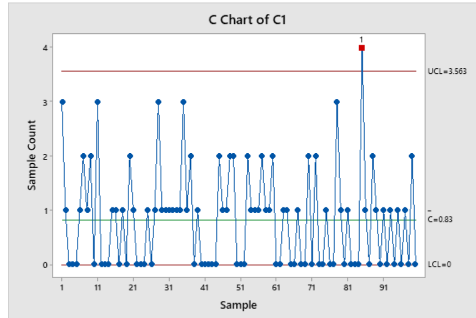


Figure 9-2 – Attribute statistical process control chart for binomial distribution of daily COVID-19 positivity rates

In Figure 9-2, we see that Minitab has generated our two control limits (which are based on calculation about the data) as well as the $\bar{C}$ line which is equal to our mean. Within a 100-day period, the daily average COVID-19 positivity rate is 0.83%. This control chart can now represent our expectations of our process. Over time, we can perform additional analysis as we have done here to check for variation in our process.

Detecting Process Changes

The control charts in Figure 9-3 below represent samplings from our process over time. We see that over time our process is out of control at a few points. It can be recognized that points lie outside of the reference control limits (upper and lower set limits) and Minitab indicates various areas where points fall in patterns that indicated a problem.

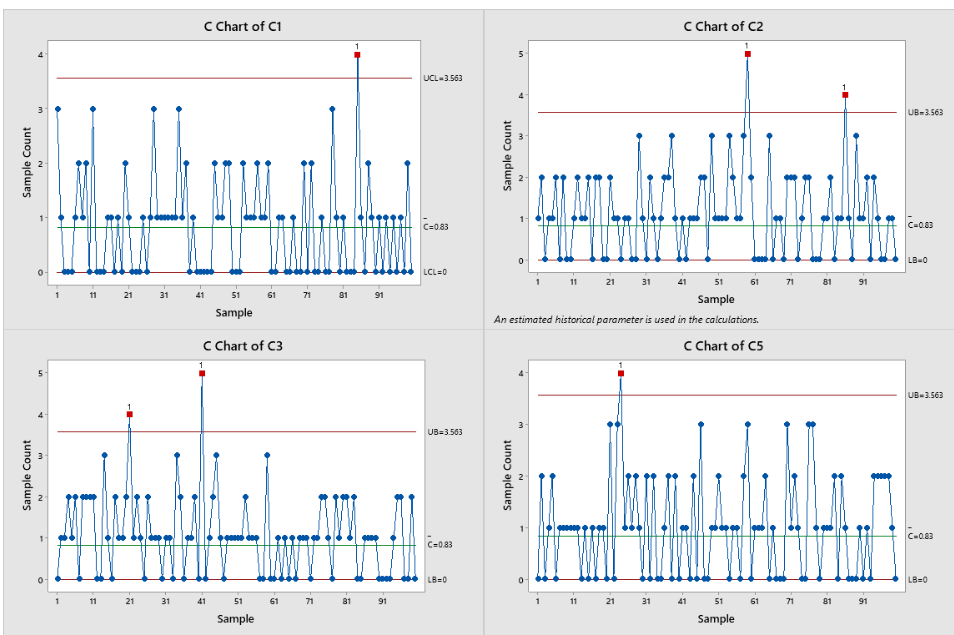


Figure 9-3 – Comparison of processes for binomial distribution of daily COVID-19 positivity rates

Over time, our sampling plots are moving farther from the mean. While one or two points may indicate a random cause that can be looked into these charts show a process that is not performing within controls. From all of the above C charts, it is evident that the positivity rate is mostly within the controllable limits (that is between LB and UB) and is out of control only at some points over time.

9.3 Normal Distribution

We will use the Normal distribution to represent the percentage of social distancing compliance. In Minitab we can use the random number generator to create 100 such percentages with a mean of 50 and a standard deviation of 10. This means in our process we would expect on average over time to see our process produces a social distancing compliance rate of 50% with standard deviation of 10%.

Reference Data and Chart

The following random set of data in Figure 9-4 was generated using Minitab. Since counting the number of people infected with COVID-19 per 100 people is considered an attribute, we will use a C-chart to represent the data.

Statistics

Variable	N	N*	Mean	SE Mean	StDev	Minimum	Q1	Median	Q3	Maximum
C1	100	0	49.58	1.09	10.94	6.79	41.83	50.87	57.13	70.05

Percentage of Social Distancing Compliance per Day									
D 1-10	D 11-20	D 21-30	D 31-40	D 41-50	D 51-60	D 61-70	D 71-80	D 81-90	D 91-100
32.237	39.0082	46.1854	49.2164	49.4968	45.2431	45.6511	51.9666	26.6458	41.4112
36.7944	57.2059	51.4532	54.8669	55.7082	58.9915	46.0228	50.6957	60.8995	56.8945
47.7146	53.8007	62.4974	69.3469	61.4685	49.6313	35.886	51.5273	6.7863	29.5022
47.1068	61.6451	35.6614	53.0237	47.1204	57.982	32.9617	53.8816	56.3437	66.2395
55.5753	38.9603	59.8161	48.4042	45.7741	65.6502	58.1827	59.5019	48.9122	55.7261
41.7914	57.2708	64.7067	51.4885	51.7856	47.272	40.6409	51.8596	41.9396	50.2816
58.521	67.5194	44.218	28.2864	41.4098	54.2163	49.6948	39.3572	52.3737	50.01
29.3883	67.2231	38.5626	45.9133	29.0935	48.9921	56.013	34.3703	58.8012	62.0295
39.8327	66.8985	45.7501	47.9183	63.8141	38.337	41.4281	48.7757	52.1092	57.6127
67.7725	70.0525	51.6197	51.0453	40.09	53.2492	37.3106	52.0728	51.4682	53.0801

Figure 9-4 – Attribute statistical process control chart for normal distribution of daily COVID-19 positivity rates

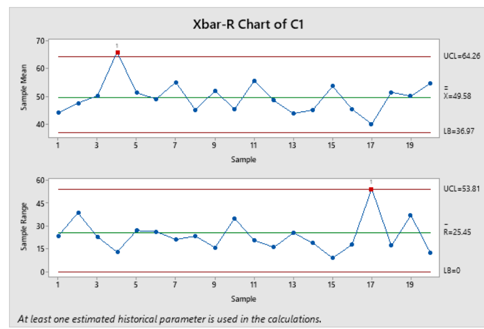


Figure 9-5 – Attribute statistical process control chart for normal distribution of daily COVID-19 positivity rates

In Figure 9-5, we see that Minitab has generated our two control limits (which are based on calculation about the data) as well as the $\overline{X}$ and R line which is equal to mean of the samples and the mean of the ranges (note we use sample group sizes of 5). This control chart can now represent our expectations of our process. Over time we can perform additional charting as we have done here to check for variation in our process.

Detecting Process Changes

The control charts in Figure 9-5 to 9-6 below represent samplings from our process over time. We see that over time (charts 1-4) our process begins to become unstable. It can be recognized that points lie outside of the reference control limits (upper and lower set limits) and Minitab indicates various areas where points fall in patterns that indicated a problem.

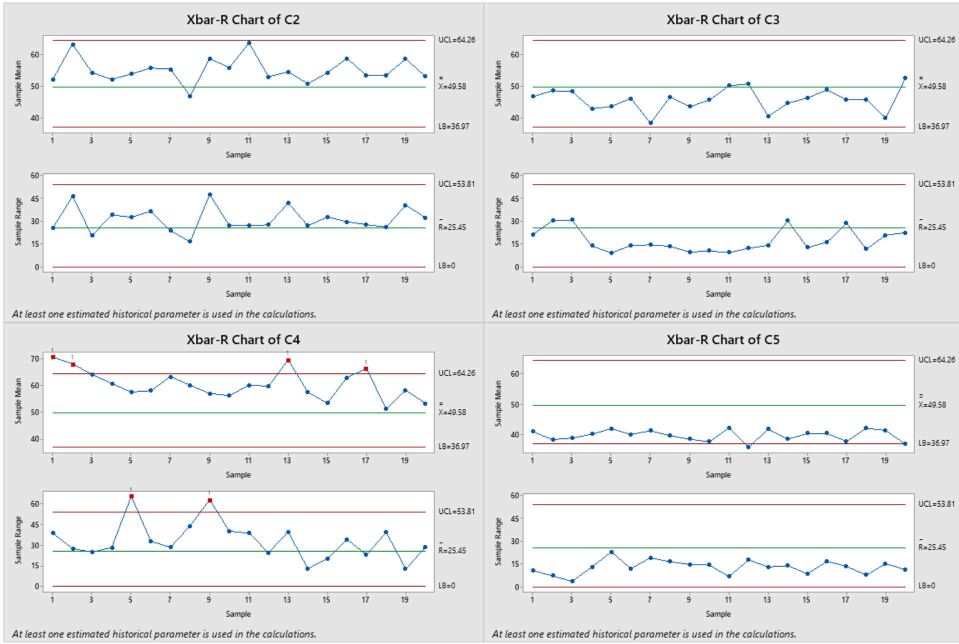


Figure 9-3 – Comparison of processes for normal distribution of daily COVID-19 positivity rates

Over time, our sampling plots are moving farther from the mean. While one or two points may indicate a random cause that can be looked into these charts show a process that is not performing within controls. From all of the above $\bar{X}$-R charts, it is evident that the percentage of social distancing compliance is mostly within the controllable limits (that is between LB and UCL) and is out of control only at some points over time.

10. Reliability

10.1 About Reliability

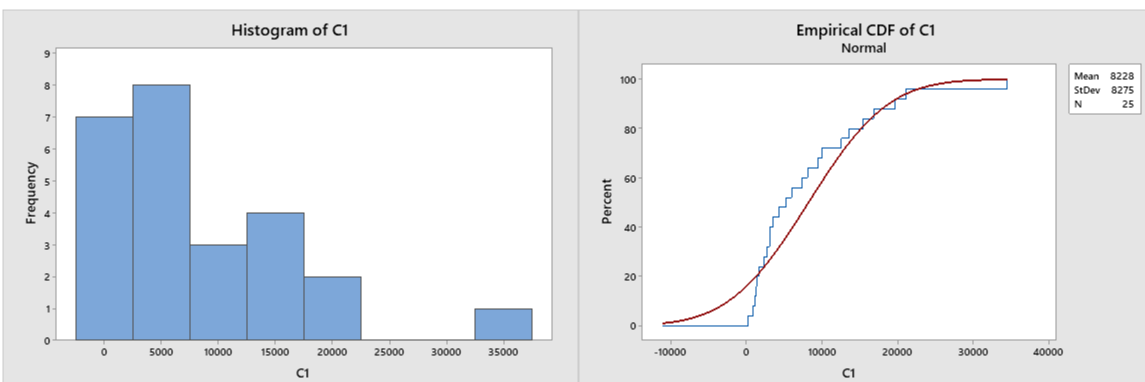
Reliability is the probability that a device will function within its specifications for a period of time without failure. Information about the device and its distribution are used to examine the reliability of the device and predict the performance of the device from confidence intervals. Here, our group will use the exponential and binomial distributions to examine the Mean Time To Failure (MTTF) of a sample of devices.

The Mean Time To Failure (MTTF) is the amount of time in which the device is expected to last before failure. A chi-squared distribution for a confidence level and a sample size is used to determine the MTTF, the failure rate (FR), and the reliability of the device (Rel).

In reliability analysis, the exponential distribution consists of one parameter – the mean life of the device. The device reliability can be determined from the mean life (or failure rate) of the device. The confidence interval for the mean life of the device induces a confidence interval for the reliability or the confidence interval for the failure rate. The three components needed for reliability data analysis are the reference data, a statistic, and the underlying statistical distribution.

10.2 Exponential Distribution

Our group uses the exponential distribution to represent our MTTF. In Minitab, the random number generator is used to create 25 times to failure with a mean of 10000. Our generated data along with some of its descriptive statistics and goodness-of-fit information is shown below. It is verified as exponential by the goodness-of-fit tests. In performing this test, the histogram below is observed for data.



When a test run is implemented, the data is used for the calculations of MTTF. There are 20 failures with the total MTTF. Minitab is used to calculate the probability distribution for the experiment. The numerical output from Minitab indicates: Total time to failure is 205697 and degrees of freedom are based on the generated data.

$$N = 25, \alpha = 0.05, T = 205697$$

$$\chi^2_{2N,\alpha/2} = \chi^2_{40,0.025} = 32.3574$$

$$\chi^2_{2N,1-\alpha/2} = \chi^2_{40,0.975} = 71.4202$$

$$MTTF = \left(\frac{2T}{\chi^2_{40,0.975}}, \frac{2T}{\chi^2_{40,0.025}}\right) = \left(\frac{2(205697)}{71.4202}, \frac{2(205697)}{32.3574}\right) = (5760.20, 12714.06)$$

$$FR = \frac{1}{MTTF} = \left(\frac{1}{12714.06}, \frac{1}{5760.20}\right) = (0.0000787, 0.0001736)$$

$$Rel(T) = e^{-FR \cdot \mu} = \left(e^{-(0.0001736)(10000)}, e^{-(0.0000787)(10000)}\right) = (0.176215, 0.455422)$$

When a test run is truncated and implemented, the data is used for the estimation of calculations of MTTF at the fifth failure. The numerical output from Minitab indicates: Total time to fifth failure is 1431.3 and degrees of freedom are based on the generated data (n=5).

$$n = 5, \alpha = 0.05$$
$$T = 181.3 + 899.7 + 1113.2 + 1323.8 + (25 - 5 + 1)1431.3 = 33575.3$$
$$\chi^2_{2n,\alpha/2} = \chi^2_{10,0.025} = 3.24697$$
$$\chi^2_{2n,1-\alpha/2} = \chi^2_{10,0.975} = 20.4832$$
$$MTTF = \left(\frac{2T}{\chi^2_{10,0.975}}, \frac{2T}{\chi^2_{10,0.025}}\right) = \left(\frac{2(33575.3)}{20.4832}, \frac{2(33575.3)}{3.24697}\right) = (3278.33, 20681.00)$$
$$FR = \frac{1}{MTTF} = \left(\frac{1}{20681.00}, \frac{1}{3278.33}\right) = (0.0000484, 0.0003050)$$
$$Rel(T) = e^{-FR \cdot \mu} = \left(e^{-(0.0003050)(10000)}, e^{-(0.0000484)(10000)}\right) = (0.0473429, 0.616600)$$

When a test run is truncated and implemented, the data is used for the estimation of calculations of MTTF at 0.2*MTTF. The numerical output from Minitab indicates: Total time to 0.2*MTTF is 2000 and degrees of freedom are based on the generated data (n=10).

$$n = 10, \alpha = 0.05, T = 2000$$
$$\chi^2_{2n,\alpha/2} = \chi^2_{20,0.025} = 9.59078$$
$$\chi^2_{2n,1-\alpha/2} = \chi^2_{20,0.975} = 34.1696$$
$$MTTF = \left(\frac{2T}{\chi^2_{20,0.975}}, \frac{2T}{\chi^2_{20,0.025}}\right) = \left(\frac{2(2000)}{34.1696}, \frac{2(2000)}{9.59078}\right) = (117.063, 417.067)$$
$$FR = \frac{1}{MTTF} = \left(\frac{1}{417.067}, \frac{1}{117.063}\right) = (0.0023977, 0.0085424)$$
$$Rel(T) = e^{-FR \cdot \mu} = \left(e^{-(0.0085424)(2000)}, e^{-(0.0023977)(2000)}\right) = (0.0000000, 0.0082678)$$

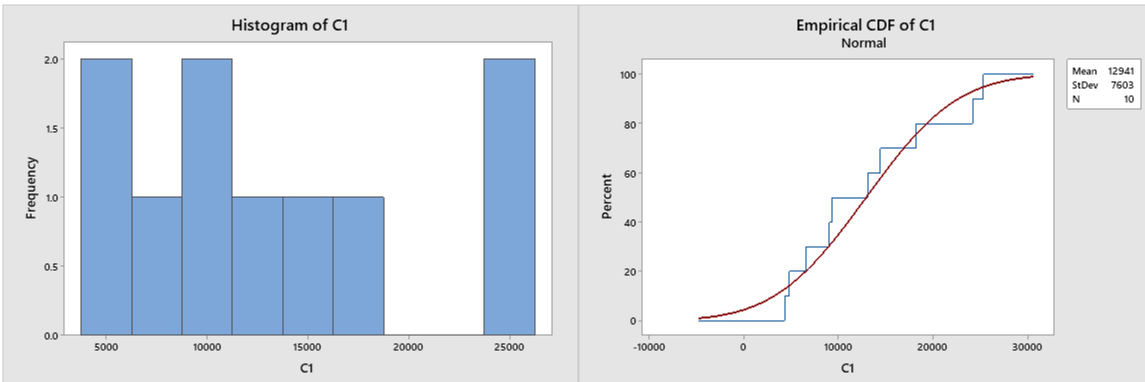
A summary of the calculations from sections 2.2-2.4 are shown below.

	Reference Data	Truncated Data at 5th Failure	Truncated Data at 0.2*MTTF
95% CI for MTTF	(5760.20, 12714.06)	(3278.33, 20681.00)	(117.063, 417.067)
95% CI for FR	(0.0000787, 0.0001736)	(0.0000484, 0.0003050)	(0.0023977, 0.0085424)
90% CI for MTTR and FR	(0.176215, 0.455422)	(0.0473429, 0.616600)	(0.0000000, 0.0082678)

Based on the calculations above, the truncated data at the 5th failure has the largest confidence interval on the MTTF and the truncated data at 0.2*MTTF has the largest confidence interval on the FR.

10.3 Binomial Distribution

Our group uses the binomial distribution to represent our MTTF. In Minitab, the random number generator is used to create 10 times to failure with a mean of 4000. Our generated data along with some of its descriptive statistics and goodness-of-fit information is shown below. It is verified as exponential by the goodness-of-fit tests. In performing this test, the histogram below is observed for data.



When a test run is implemented, the data is used for the calculations of MTTF. There are 10 failures with the total MTTF. Minitab is used to calculate the probability distribution for the experiment. The numerical output from Minitab indicates: Total time to failure is 129414 and degrees of freedom are based on the generated data.

$$N = 10, \alpha = 0.05, T = 129414$$
$$\chi^2_{2N,\alpha/2} = \chi^2_{20,0.025} = 9.59078$$
$$\chi^2_{2N,1-\alpha/2} = \chi^2_{20,0.975} = 34.1696$$
$$MTTF = \left(\frac{2T}{\chi^2_{40,0.975}}, \frac{2T}{\chi^2_{40,0.025}}\right) = \left(\frac{2(129414)}{34.1696}, \frac{2(129414)}{9.59078}\right) = (7574.79, 26987.1)$$
$$FR = \frac{1}{MTTF} = \left(\frac{1}{26987.1}, \frac{1}{7574.69}\right) = (0.0000371, 0.0001320)$$

$$k = 4$$
$$p = 1 - e^{-\bar{T}/\mu} = 1 - e^{-4000/10000} = 0.32968$$
$$P(k \le 4) = B(4,10,0.32968) = \sum_{k=0}^{4} C_k^{10} (0.32968)^k (1 - 0.32968)^{10-k} = 0.794294$$
$$P(k > 4) = 1 - P(k \le 4) = 1 - 0.794294 = 0.205706$$

The two approaches used for deriving CI for the exponential mean when only the total test time t and total number of failures k are known, are good examples but are seldom used practically. Instead, we used more practical procedures. There are still ways in which the probability failure, MTTF, the FR, etc. can be obtained even when dealing with censored data. However, the degree of difficulty in obtaining such parameters increases as the distribution of the test data departs from the exponential. Moreover, the device operation time is often non-overlapping, and devices will have been working in full periods of time. Thus, for practical purposes, the preceding assumptions work as if the time of operation occurred simultaneously.

Conclusions

Our project was to implement an effective state-wide lockdown and the condition we considered to implement a lockdown was positivity rate more than 5%. Initially we performed the design of experiment to understand the capability of the process and the significant factors that would contribute majorly to the lockdown. Once the process was capable, we made a value stream map to understand the total number of days it will take to complete the entire process and created a future state value stream map with an intention to reduce the total duration of the process. The total duration was reduced from 67 days to 51 days. Gage R&R analysis was performed to see if there are any errors while the same process is being repeated all over the state. Part to part variability was the most significant indicating that different COVID-19 testing sites have different practices. After analyzing our measurement system, we created statistical process control charts considering Binomial distribution for COVID-19 cases and normal distribution for percentage of people complying with the social distancing guidelines. The control charts indicated that the process was under control over time since people have started taking the lockdown and social distancing guidelines seriously. Hence, to make a final decision on whether to implement a state-wide lockdown we calculate the positivity rate which includes a capable process, correct measurement system with less variability and statistically controlled process with few out of control events during the entire process.