



Developing Optimal Policies to Fight Pandemics and COVID-19 Combat in the United States

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Abstract. The world has faced many outbreaks and pandemics with hundreds of millions of deaths throughout its history. Those epidemics are global health concerns and as well as serious economic issues. There is certain need to allocate scarce sources efficiently to fight such epidemics in both personal and global dimensions. Here we develop and propose two optimization models to maximize the total protection from any epidemic, pandemic or bioterror attacks; the first one is personal protection model or protocol and the other one is mass protection model that is inspired by the well-known weapon-target assignment problem of operations research. These efforts are optimal allocation of scarce medical and economic resources to save millions of lives- gift of life. We implement our general mathematical programming models with real-world data to fight the coronavirus pandemic for a person and the United States. Our personal protection protocol provides 99.99% protection from COVID-19 for an American through personal strategies when the mass protection model supplies 96.961% protection on average from coronavirus pandemic for the United States through countrywide policies. The mass protection model which recommends general policy frame for health care policy makers could be applied for any epidemic at any level from county to city, to state and country as well as in global scale. The mathematical relation between the personal protection protocol and the mass protection model also highlights the fact of *unus pro omnibus, omnes pro uno* (one for all, all for one) for fighting epidemics- particularly the moving enemy, novel coronavirus which is double invisible due to its viral nature and the availability of the high level of asymptomatic cases. Recognize the enemy, as protecting yourself means protecting people, love life, follow the rules and stay at home. That is the greatest ever social impact.

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1. Introduction

The world has faced an important number of outbreaks and pandemics with death tolls of hundreds of millions throughout its history such as The Great Plague of London in 1665, the Spanish Flu in 1918, 1957-1958 Pandemic (H2N2 virus), 1968 Pandemic (H3N2 virus) and 2009 H1N1 Pandemic [7]. More recently, there have been other epidemics that are serious threats to global public health including Severe Acute Respiratory Syndrome (SARS-CoV) which was recognized in February 2003 and Middle East Respiratory Syndrome (MERS-CoV) which was recognized in September 2012. Both SARS-CoV and MERS-CoV are caused by a large family of viruses called coronaviruses (CoV)[36]. A novel coronavirus (2019-nCoV or SARS-CoV-2) was first publicized from Wuhan, China, on 31 December 2019 as a new strain[39]. This new viral disease outbreak that struck mainly China and spreads across countries was re-named as Coronavirus Disease (COVID-19) on 11 February 2020.

The Virus Has Been Going Viral

World Health Organization (WHO) declared COVID-19 is a Public Health Emergency of International Concern on 30 January 2020. As number of infected countries grows, the WHO defined the COVID-19 outbreak as a pandemic on 11 March 2020. It is the first pandemic caused by a coronavirus and the first pandemic which is also controllable[37]. WHO Risk Assessment is currently “Very High” at Global Level as of 18 April 2020 03:00 GMT+3, there are 2,160,207 globally confirmed cases with a death toll of 146,088, and the virus is now in 213 countries[35]. A combination of false and misleading information, fake news and true information about the coronavirus has been circulating especially on social media which causes an *infodemic* that has already become a pandemic much earlier than the novel coronavirus itself. Based on experts’ opinions, The Economist reports a broad guess that 25-70% of the population of any infected country may catch the disease and that the virus could kill 60,000 Americans in a worse-scenario year when the death toll could be in the millions across the world[11]. In a more recently official guess, the White House forecasts the novel coronavirus death toll may be 100,000 to 240,000 despite the measures taken in the US[19] which is a new epicenter for the novel coronavirus.

Weapons to Fight Pandemics and COVID-19

Fighting tools for any pandemic may be classified into two categories in general which are also valid for the COVID-19 outbreak: pharmaceutical that are both treatment and protection instruments and nonpharmaceutical tools.

The pharmaceutical methods include vaccines and antiviral drugs. WHO says that, to date, there is no vaccine and no specific antiviral medicine to prevent or treat COVID-19[40], and that globally more than 20 vaccines are in development, and several therapeutics are in clinical trials[8]. It is well known that the availability of approved medications will take months when vaccines optimistically take a year.

Apart from vaccines and drugs, nonpharmaceutical interventions may cover basic personal protection tools such as frequently washing hands, hand hygiene[38], using facemasks and N95 masks and social mitigation strategies including social distancing, life style education like avoiding close contact and cover coughs and sneezes, and school closure as well as more strict measures like travel restriction, isolation and quarantine[3] and stay-at-home order.

Quarantine as it is now employed is a public health tool and a collective action for the common good. Modern quarantines are more likely to involve a few people exposed to contagion in a small area, such as at a hospital, on an airplane or at a public gathering, and only unusually are applied to entire cities or communities[18]. Although it is rare and new to science and modern applications to quarantine a whole city or country, which seems to be a 'new normal' in fighting epidemics. Some whole countries are on lockdown to contain COVID-19. The lockdown goes viral as the novel coronavirus does. One third of the world is currently on lockdown as if the planet earth has been closed. Also, 2020 Tokyo Olympics has been postponed to 2021 due to the coronavirus pandemic. Besides, a major number of countries have currently shutdown their borders, and implemented airlines cancelling and cancelling sailings with some infected countries. As a remarkable instance, the US cancels all travel to and from continental Europe as of 13 March 2020 for the next 30 days except US citizens since the new epicenter of the coronavirus pandemics has become Europe. The UK and Turkey are exempted.

Almost all countries and governments as well as major international actors including United Nations (UN), The World Bank, International Monetary Fund (IMF), International Chambers of Commerce, World Economic Forum, and FIFA have been working to fight the novel coronavirus in collaboration with WHO. The WHO massively supports countries in all dimensions of knowledge, mentoring, financial, medical supplies. Also, almost all countries and international agents declare financial supports for fighting COVID-19. As instances, the World Bank reports up to \$12 Billion immediate support for country response[31] when the IMF makes available \$50 Billion[15]. United Nations Foundation, the Swiss Philanthropy Foundation and WHO launches Solidarity Response Fund to support the work of the WHO and partners to help countries respond to the COVID-19 pandemic[41].

The COVID-19 pandemic has also been damaging economy, stock markets, finance sector, businesses and as well as supply chain processes of many products- shaking the world as if chains of heavy global economic and health earthquakes. The IMF states the global economy is projected to contract sharply by -3% in 2020, much worse than during the 2008–09 financial crisis. The U.S. economy is projected to shrink this year by 5.9% and the euro area by 7.5% as a result of COVID-19[16].

As the coronavirus *infodemic* spreads, WHO calls on industry and countries to increase manufacturing of personal protective equipment such as N95 respirators, facemasks, gowns and gloves by 40% to meet rising global demand due to the COVID-19 and associated panic buying. There would be a global shortage to meet the demand even from frontline health responders.

All pharmaceutical and nonpharmaceutical fighting measures for all epidemics and as

well as COVID-19 pandemic are already scarce resources and carrying costs, and thus naturally have limitations. In a nutshell, fighting costs and constraints are always matter for any epidemic, outbreak, pandemic or bioterror attack.

The WHO also strictly encourages countries to innovate and improve to find new ways to prevent infections, save lives and minimize impact in addition to basic efforts like detection, prevention and reduction[42].

It is an undoubtedly inevitable must to put efforts to maximize personal and overall protection from a pandemic, and hence save lives under some functional and resource constraints. That is optimal allocation of scarce resources to save millions of lives- gift of life.

In this work, we propose two mathematical programming models for fighting any pandemic at micro and macro levels, respectively; the first one is personal protection model or protocol and the other one is mass protection model for a country. We also apply these theoretical models to COVID-19 pandemic with real-world data for a person and the United States of America. In other words, we put the general policy framework for maximum protection of a person and the United States of America from COVID-19 pandemic on the stage.

The literature in mathematical models in epidemiology is relatively scarce in comparison with the huge literature in epidemiology and a major part of the existing quantitative epidemiological studies is generally about the understanding and predicting the behavior of viruses and epidemics. The works involving mathematical modeling on the protection and fighting against epidemics and pandemics are much more limited as they shape a small subset in the literature. To mention a few, as instances, Yurt[43] derives a country-based protection model from pandemic A(H1N1) with a real data implementation for Turkey. Peng et al.[26] discuss the prevention of epidemics by public vaccination and individual protection. Also, as a part of protection matter, Myers et al.[23] develop a mathematical model for assessing the effectiveness of protective devices such as respiratory protective devices in reducing risk of infection by inhalable droplets.

2. Developing the Models

We develop a personal protection model or protocol that maximizes total protection probability of a person subject to required number of tools and budget. We also propose a mass protection model that maximizes total weighted protection probability in a population and that can be applied to any county, city, state, country, continent and the world.

2.1. Formulating Personal Protection Model

We propose maximum personal protection protocols for combating epidemics, pandemics or bioterror attacks. The recipe that is a binary nonlinear programming model can be originated in the following way.

As a personal point of view, a person can adopt protection and treatment tools from the sets of pharmaceutical and nonpharmaceutical instruments such as vaccine, antiviral medicines, use of hand hygiene products, 50% social distancing and voluntary self-quarantine during a reasonable planning horizon.

The notations are defined as in;

w : the number of weapons; pharmaceuticals and nonpharmaceutical tools,

$i = 1, 2, \dots, v, \dots, f, \dots, w$: weapon index; treatment and protection tools index,

v : the number of vaccine types,

f : the number of pharmaceutical tool types,

$f - v$: the number of tools other than vaccines; eg, antiviral medicine types,

$w - f$: the number of nonpharmaceutical tool types; eg, use of surgical mask,

B : total budget,

T : total number of required agents,

T_{ph} : total number of required pharmaceutical agents,

T_{nph} : total number of required nonpharmaceutical agents,

p_i : estimated probability of protection of the person by use of a single tool i per agent (per dose or unit)

A personal protection protocol can be defined by a w -dimensional binary vector x that satisfies

$$x_i = \begin{cases} 1 & \text{if a tool } i \text{ is adopted,} \\ 0 & \text{otherwise.} \end{cases}$$

From the definition of x_i , we have

$$(1 - p_i)^{x_i} = \begin{cases} 1 & \text{if } x_i=0, \\ 1 - p_i & \text{if } x_i=1. \end{cases}$$

Hence, $(1 - p_i)^{x_i}$ represents the probability that a protection protocol x will not protect the person if tool i adopted, that is, fail probability.

In general, under the assumption of statistically independence, the probability that a protection protocol x protects the person is

$$1 - \prod_{i=1}^w (1 - p_i)^{x_i}$$

It follows that the personal protection protocol that maximizes the probability of protection from epidemic disease solves the objective function

$$\max 1 - \prod_{i=1}^w (1 - p_i)^{x_i}$$

Subject to following constraints. Total assignment must not exceed the total budget;

$$\sum_{i=1}^w c_i x_i \leq B, \forall i = 1, \dots, w.$$

There are required numbers of pharmaceutical, nonpharmaceutical and total agents, respectively;

$$\sum_{i=1}^f x_i \geq \underline{T}_{ph}, \quad \forall i = 1, 2, \dots, f.$$

$$\sum_{i=f+1}^w x_i \geq \underline{T}_{nph}, \quad \forall i = f + 1, \dots, w.$$

$$\sum_{i=1}^w x_i \geq \underline{T}, \quad \forall i = 1, 2, \dots, w.$$

Some agents particularly pharmaceuticals may not be used at the same time; as an instance, all antivirals cannot be adopted simultaneously, we impose this using either-or constraints;

$$x_i x_j = 0, \text{ for appropriate pair of } i \text{ and } j, \text{ and } i \neq j, i, j \in \{1, \dots, w\}$$

All decision variables are binary variables,

$$x_i \in \{0, 1\}, \forall i = 1, 2, \dots, w.$$

2.2. Building Mass Protection Model

We propose a general mathematical model that maximizes mass weighted protection probability of people from an epidemic, pandemic or bioterror attack under some certain scarce resources, functional constraints and budget. The model could work at the levels from county to city, to state and across country as well as in the global scale. Our mass fighting model is inspired by the weapon-target assignment (WTA) problem of operations research. Further details and related literature about the WTA are available in Çetin and Tolun Esen[9] and Kline, Ahner and Hill[17].

The model which is a nonlinear integer programming model for fighting pandemics, epidemics or bioterror attacks to maximize total weighted protection probability in a population stemming from well-known weapon-target assignment problem in the following way.

We segment whole population into medical protection targets of sub-populations, and partitions of target segments are persons in our model language as well. Those target segments may be chronic patients, pregnant women, health care workers, infants and other specific groups, and the remaining people. Our weapons are treatment and protection instruments; pharmaceuticals such as vaccines and antiviral drugs and nonpharmaceutical tools including use of surgical masks, N95 respirators, hand hygiene products, airlines cancelling, voluntary self-quarantine and lockdowns. In this work, *a priori* tools are designated as the tools that have been previously decided for adopting. As instance, quarantine regions, border shutdown, airline cancelling, and cancelling sailings may be previously decided for implementation. Their decisions are independent of the model, but affects the model components. In the model, we assume the contributions of the people characterized by *a priori* decisions to related target segments are only compactly

represented by their segment protection probabilities. Also, an agent means an appropriate one of a person, a unit or quantity of dose. The model outputs can be implemented during a planning horizon.

We define the notations as follows;

w : the number of weapons; pharmaceuticals and nonpharmaceutical tools,

t : the number of target segments,

$i=1,2,\dots,v,\dots,f,\dots, a,\dots,w$: weapon index; treatment and protection tools index,

$j=1,2,\dots,r,\dots,t$: target segment index,

v : the number of vaccine types,

f : the number of pharmaceutical tool types,

$f-v$: the number of tools other than vaccines; eg, antiviral medicine types,

$w-f$: the number of nonpharmaceutical tool types,

$w-a$: the number of *a priori* tool types; already adopted tools like quarantine regions,

$a-f$: the number of non *a priori* nonpharmaceutical tool types,

r : the number of target segments for featured segments like risk groups for diseases,

P : total population,

P_j : population of target segment j ,

P_i : population characterized by *a priori* tool i , eg, population of quarantined county,

U_j : priority weight for target j ; relative importance,

p_{ij} : estimated probability of protection of target segment j by use of a single tool i per agent (per dose, person or unit); ie, estimated protected amount of partitioned target j by assigning tool i per agent,

x_{ij} : the number of assigned agents (person, unit, quantity of dose,) i to target segment j ,

c_{ij} : unit variable cost of assigning tool i to target segment j ,

B_s : budget allocated by the government,

B_p : budget allocated by the non-government resources; people or private sector,

B : total budget,

\overline{W}_i : available amount of tool i ; upper bound for tool i ,

\underline{W}_i : total number of required agents of tool i ; lower bound for tool i ,

\overline{T}_j : maximum allowable total number of agents for target segment j ,

T_j : total number of required agents for target segment j ,

\underline{T}_j : the number of required agents from selected tool to target segment j ,

ρ : the ratio of all cost that non-government resources should meet,

The objective function is the maximization of weighted estimated protection probability of the total population from the pandemic under the constraints, which can be expressed as;

$$\max \sum_{j=1}^t U_j \left(1 - \prod_{i=1}^w (1 - p_{ij})^{x_{ij}} \right)$$

There are naturally some constraints. There is a total budget for all assignment operations. A certain ratio ρ of the total cost must be met by non-government resources for any

appropriate tool h , and where the total budget is $B = \sum_{j=1}^t \sum_{i=1}^w c_{ij}x_{ij}$; for all $i = 1, \dots, w$, and $j = 1, 2, \dots, t$.

$$\rho \sum_{j=1}^t \sum_{i=1}^w c_{ij}x_{ij} \leq B_p, h \in i = \{1, \dots, w\},$$

$$\sum_{j=1}^t \left(\sum_{i=1}^w c_{ij}x_{ij} - \rho \sum_{i=1}^h c_{ij}x_{ij} \right) \leq B_s, h \in i = \{1, \dots, w\}$$

The sum of government and non-government budgets cannot exceed the total budget;

$$B_p + B_s \leq B,$$

There are upper bounds for the available agents;

$$\sum_{j=1}^t x_{ij} \leq \overline{W}_i, \quad \forall i = 1, 2, \dots, w.$$

There may be some required amounts of selected tools that must be assigned;

$$\sum_{j=1}^t x_{ij} \geq \underline{W}_i, \quad \text{for selected } i = 1, 2, \dots, a.$$

The number of assigned agents must be within the minimum required and maximum allowed levels and any target segment may adopt multiple agents;

$$\underline{T}_j \leq \sum_{i=1}^w x_{ij} \leq \overline{T}_j, \quad \forall j = 1, 2, \dots, t.$$

For any selected pair of tool i and target segment j , there must be some required number of agents to exposure to the related target segment; eg, there may be a certain amount of vaccine dose that health care workers must get;

$$x_{ij} \geq \underline{\underline{T}}_j, \quad \text{for any appropriate pair of } i \text{ and } j,$$

The decision variables must not exceed the populations of target segments;

$$x_{ij} \leq P_j, \forall j = 1, 2, \dots, t.$$

The decision variables for *a priori* tools (*a priori* decision variables) must equal to the related population shares (target segment distribution) of population of *a priori* tools P_i where the target segment distribution is $\{ P_1/P, P_2/P, \dots, P_T/P \}$;

$$x_{ij} \leq \frac{P_j}{P} P_i, \quad \forall i = a + 1, \dots, w, \quad \forall j = 1, 2, \dots, w.$$

$$x_{ij} \geq \frac{P_j}{P} P_i, \quad \forall i = a + 1, \dots, w, \quad \forall j = 1, 2, \dots, t.$$

All decision variables must be nonnegative and integer;

$$x_{ij} \geq 0 \text{ and integer, } \quad \forall i = 1, 2, \dots, w, \quad \forall j = 1, 2, \dots, t.$$

As the WTA problem is an NP-complete problem[9], from which the nonlinear integer programming model stemming is also in the class of NP-complete.

3. Applications of the Models for COVID-19 Combat in the United States

The proposed mathematical models are implemented for COVID-19 combat of a person and the United States as real-world illustrative examples, respectively. The data that inputs the models is collected in the following way.

3.1. Data Collection

The data that the models fed are taken from open reliable sources and published works. There is a wide uncertainty about the novel coronavirus, its behavior and response, and its interaction with protection and fighting tools, and hence there is lack of published data for the novel coronavirus.

As we specify the planning horizon is 6 weeks for the model implementation, we set the units of the agents fired from the tools for as follows. The unit for vaccine is a single dose, the unit of antivirals is the required drug dose regimen (ie, for 10 capsules, required 75 mg twice daily 5 days). The unit for surgical mask is a box of 50 Pcs, and for N95 respirator is is 2 boxes of 3M7185 respirator particulate N95 10/Box (20 items). A unit of hand hygiene product is 1000 ml hand sanitizer (70% alcohol hand sanitizer fluid-1 liter bottle). The units for the remaining nonpharmaceutical and *a priori* agents are per person.

The population of the United States for 2020 is estimated as 331,002,647[27]. The age distribution of population is also considered[32] and re-arranged with respect to the population of risk factors to obtain target segment distribution. The numbers of risk factors are obtained as follows. By 2020, it is projected that 157 million Americans will have chronic diseases, with 81 million having multiple conditions[24]. This means that 47% of the US population have at least one chronic illness, which is in compatible with other published estimations. We take the number of health care workers which is another risk factor is 16,866,020 from the 2018 statistics[33]. We consider the number of pregnancies is 6,155,000 from 2010 statistics[28] (published in 2019) which seems stable over years. The number of infants is taken as 3,791,712 which is registered number of births in 2018, down 2% from 2017[6].

Regarding *a priori* tools, we arbitrarily specify the population of a hypothetical quarantined city #1 in US which is 4,150,000. We also assume the number of people affecting from border shutdown and canceling sailings are 1,250,000 and 2,100,000, respectively.

The US cancels all travel from/to continental Europe as of 13 March 2020 for the next 30 days except UK, Turkey and US citizens. We only take this concrete mass airline canceling in the model implementation. The number of passengers from US to Europe was 7,687,718 and 2,360,804 from UK to US in June 2019- a supposition equal to from US to UK in size[34]. Thus, we take the number of people affected by Europe airline canceling, the difference, is 5,326,914 as an estimation with the presumption that a traveler from US would not fly to Europe and be protected from the novel coronavirus. We distribute the numbers to target segments using target segment distribution that is acquired by normalizing the segment populations to the US population in 2020.

At present, there are no approved vaccines and antiviral drugs for the novel coronavirus. Thus, there is no information about their protection probabilities. We substitute -as estimators- the protection probabilities of vaccines and antivirals against pandemic A(H1N1), which are used in Yurt[43] based on published scientific data. Immune response at 21 days, seroprotection ratio for single dose is 80% as it is 92-96% for pregnant women[43]. We take protection probability of vaccine for pregnant women is 0.94, and 0.80 for the other target segments, except infants (zero probability) since they cannot get vaccine[43]. Similarly, we substitute two antivirals for novel coronavirus by Oseltamivir and Relenza (Zanamivir) and efficient for A(H1N1) as estimators on the protection probability base. The use of Tamiflu and Oseltamivir protects with the ratio of 70%-80%[21]. As estimators, we adopt the protection probabilities of Antiviral #1 and Antiviral #2 as 0.79 and assume Antiviral #2 must not be used for infants, so its protection probability is 0.00 for infants.

The use of face mask and hand hygiene reduces influenza-like illness within 35%-51% for 4-6 weeks[1]. Since there is no published data for the novel coronavirus on the matter, in this study, we assume the protection probability of the use of surgical mask is 0.51 with the implicit assumption a person uses surgical mask and hand hygiene products together. The use of N95 respirators may protect with 95% when the use of hand hygiene products protects with 89.2% and school closure provides a protection between 30%-50%, and lifestyle education such as avoiding close contact and cover coughs and sneezes does 77% (except infants)[43]. We take the protection probabilities of school closure is from 0.15 to 0.40 alongside with the target segments. 50% social distancing provide 40.9% protection compared to no intervention[30]. As there is no published data for the novel coronavirus in the regards following, we also assume the protection probabilities of voluntary self-quarantine and compulsory quarantine are 0.95 and that of border shutdown, airlines canceling and canceling sailings are 0.90 equally for all target segment.

Regarding costs, as there are not vaccines and antivirals at present, we substitute available vaccine and medicine costs as estimators for COVID-19. For the vaccines, we consider Pediatric Influenza Vaccine Price List published by the CDC for infants, the median price of the pediatric influenza vaccine state prices (not private sector price) is \$13.55 per single dose for infants when the median price is \$13.25 per single dose for all remaining target segments from Adult Influenza Vaccine Price List[4]. We assume two antivirals for COVID-19; as cost estimators, we take Oseltamivir prices for Antiviral #1, the price of 75 mg Oseltamivir oral capsule \$39.50 (for 10 capsules, required 75 mg

twice daily 5 days) for adults whereas the price of 6 mg/mL Oseltamivir oral powder reconstitution (60 milliliters) is \$71.30 for babies[25]. We substitute Relenza (zanamivir) price as a substitute price for Antiviral #2 which is \$71.10 for 5 mg Relenza inhalation powder a quantity of 20 (5x4 each) for all segments except infants[29].

We consider the unit of surgical mask agent is a box of 50 disposable surgical face mask to be used for 6 weeks. The unit variable cost of 50 disposable surgical mask is \$22.19[2]. We take the unit of N95 respirator agent is 2 boxes of 3M7185 respirator particulate N95 10/Box (20 items) to be used for 6 weeks. The unit variable cost of that product was \$189.96 at Amazon on 15 March 2020. We also consider 1000 ml hand sanitizer (70% alcohol hand sanitizer fluid- 1 liter bottle) as the unit of our hand hygiene product agent for use during 6 weeks. The unit variable cost was \$42.15 at eBay on 15 March 2020 (the products and links are currently not available). We assume lifestyle education to public and adaptation is \$1.5 per person. The cost of school closures is estimated in a US study in 2009 as a pandemic mitigation strategy in terms of GDPs. For 6 weeks closure, low cost estimate measures 0.1%, base estimate calculates 0.4% and high cost estimate quantifies 0.5% of GDP, respectively[20].

We also assume that school closure does not lead to a reduction in key HCWs. As we deal with persons in target segments and as agent units for the related tools, we can easily estimate this cost using GDP per capita. The GDP per capita forecast of the US for 2020 is \$ 67,426.8[12]. We consider the base estimate scenario, which is 0.4% of the GDP (per capita), then we estimate the school closure cost for 6 weeks per person is \$269.7072. As school closure estimations include absenteeism, it would be a good measure to estimate the followings. We also assume that the cost of 50% social distancing per person for 6 weeks is 0.4% of the GDP (per capita) which is \$269.7072. We assume the costs of voluntary self-quarantine and compulsory quarantine per person for 6 weeks is 0.5% of the GDP (per capita), ie. \$337.134. We suppose that people are able to work from home while they are in voluntary or compulsory quarantine. We assume the costs of the tools of border shutdown, airlines canceling and canceling sailings again per person are in terms of GDP per capita; we arbitrarily suppose those costs equally per person for 6 weeks as 0.01% of the GDP (per capita) which is \$67.4268.

We assume the budget for the personal protection model is \$500 and \$ 600 billion for the mass protection model which is sum of \$500 billion that the government must meet and \$100 billion which the nongovernment resources must meet. We specify the available amounts of agents fired from the tools (in their related units) as shown on the spreadsheets that the models implemented.

3.2. Achieving the Personal Protection Protocol

We also implement the model with real-world data for a person living in USA in order to obtain optimal protection strategies from COVID-19. The person is an adult aged between 18 and 59, and can work from home. Although the model can handle any finite number of tools, we consider a vaccine and two antiviral medicines as pharmaceutical tools and using surgical mask, N95 respirator, hand hygiene products, lifestyle adaptation, 50%

social distancing and self-quarantine as nonpharmaceutical interventions for the adoption of the person for 6 weeks. We employ either-or constraints for the model so that the person cannot adopt vaccine and any antiviral or both antivirals at the same time. The data acquisition for this one-person model is also presented in Data Collection section. The model is easily optimized by MS Excel Solver as a powerful spreadsheet tool within a few seconds, and the optimal solution which may also result in other optimal combination of decision variables- *alterna optima* is given in Figure 1.

	A	B	C	D	E	F	G	H	I
1	Personal Protection Model								
2									
3	Fail matrix			Success matrix - Protection probabilities					
4									
5	Vaccine	0,1000		Vaccine	0,9000				
6	Antiviral #1	0,2100		Antiviral #1	0,7900		# of assigned tools		# of required tools
7	Antiviral #2	0,2169		Antiviral #2	0,7831	pharmaceutical	1	>=	1
8	Surgical mask	0,6500		Surgical mask	0,3500	nonpharmaceutical	4	>=	1
9	N95 respirator	0,0583		N95 respirator	0,9417	# of total assigned tools	5	>=	4
10	Hand hygiene	0,1158		Hand hygiene	0,8842				
11	Lifestyle education	0,2367		Lifestyle education	0,7633				
12	50% Social distancing	0,5910	50% Social distancing	0,4090		Protection ratio	max		
13	Self-quarantine	0,0500	Self-quarantine	0,9500			99,99109%		
14						Total cost	\$416,224	<=	Budget
15	Cost Matrix			Assignment matrix					
16									
17	Vaccine	\$13,250		Vaccine	1		% cost of used tools		
18	Antiviral #1	\$39,500		Antiviral #1	0		3,18%		
19	Antiviral #2	\$71,100		Antiviral #2	0		0,00%		
20	Surgical mask	\$22,190		Surgical mask	1		5,33%		
21	N95 respirator	\$189,960		N95 respirator	0		0,00%		
22	Hand hygiene	\$42,150		Hand hygiene	1		10,13%		
23	Lifestyle education	\$1,500		Lifestyle education	1		0,36%		
24	50% Social distancing	\$269,707		50% Social distancing	0		0,00%		
25	Self-quarantine	\$337,134		Self-quarantine	1		81,00%		
26									

Figure 1: Optimal personal protection strategies

According to our personal protection model, the person should adopt vaccine, surgical mask, hand hygiene, lifestyle education and self-quarantine strategies for 6 weeks within his/her \$500 budget. S/he should stay home and work from home for 6 weeks after getting vaccine and use hand hygiene products and surgical mask-when needed although the Centers for Disease Control and Prevention (CDC) does not currently suggest for Americans, but it seems a policy shift is forthcoming- with careful lifestyle like avoiding close contact and cover coughs and sneezes. This optimal protection strategy provides 99.991% protection of the person with a cost of \$416.224. That is, the protection probability of the person from the coronavirus is 0.99991. As it is seen in Figure 1, the costliest strategy is self-quarantine with 81%.

There are no approved vaccine and antivirals for COVID-19 at present. Thus, based on the current practice, we easily re-run the model without pharmaceutical tools by just relaxing the number of pharmaceutical required tools constraint and giving the zero protection probabilities to vaccine and antivirals on the same spreadsheet, we get an optimal solution again under new conditions covering only some nonpharmaceutical interventions. In this case, the optimal protection rate reduces to 99.910% with the surgical mask, hand

hygiene, lifestyle education and self-quarantine strategies. The protection gap is 0.08% which is the opportunity cost of vaccine or antivirals.

3.3. Mass Protection Policy for Fighting COVID-19 in the United States

We run the mass protection model with real data of USA to protect the whole country from COVID-19. Even though the model can handle thousands of target segments and therapeutic/nontherapeutic and pharmaceutical/non pharmaceutical tools; any finite numbers of tools and targets (wxt), we consider 14 tools and 9 target segments of USA population. The planning time horizon is 6 weeks.

The pharmaceutical tools are a vaccine and two antiviral medicines when nonpharmaceutical instruments are use of surgical masks, N95 respirators and hand hygiene products, lifestyle adaptation, school closures, 50% social distancing, voluntary self-quarantine and a set of *a priori* tools. The CDC does not currently recommend the use of surgical masks for healthy citizens in the US; however, the agency may recommend due to that about 25% of infected people may be asymptomatic[22]. *A priori* decisions are as follows: We assume that there is already a decision that a city with a population of 4,150,000 must be on lockdown. The US has made a real decision to ban the travel from/to Europe (except UK and Turkey) effecting 5,326,914 people for a month. We also take border shutdown and cancelling sailings influencing, by assumption, 1,250,000 and 2,100,000 people, respectively. The real US data acquisition is also discussed for the mass protection model in Data Collection section.

We set the target segments of the US population as chronic patients, pregnant women, health care workers, infants (0-6 month), and people aged 6 month-14 years, 15-24 years, 25-54 years, 55-64 years and 65+ years. Possible risk factors for COVID-19 may include, but are not limited to, older age, and underlying chronic medical conditions such as lung disease, cancer, heart failure, cerebrovascular disease, renal disease, liver disease, diabetes, immunocompromising conditions, and pregnancy[5]. Also, coronaviruses and enteroviruses/ rhinoviruses affect chronically ill, older patients than healthy, young adults[13]. Besides, healthcare workers (HCWs) taking care of MERS-CoV patients are at an increased risk of acquiring the infection[14], and those dealing with novel coronavirus, too. Thus, in this study, we consider chronic patients, pregnant women, health care workers and older people (65+) as risk factors that is why we set them as risk factors target segments. The estimated protection probabilities (success probabilities) over target segments are tabulated in Figure 2

Unit variable costs of tools or agents with respect to their units along the target segments are also presented (in USD) in Figure 3. We assume that people are volunteer to adopt self-quarantine can work from home. The huge unit costs in the HCWs and Infants columns are for avoiding assignments to related cells.

The mass protection model is fed by real US data on MS Excel which is a robust spreadsheet instrument. The availability of tools, required agents to exposure target segments, priority weights and budgets are given in Figure 4, 5 and 6. We give relative importance weights to target segments between 1 and 10, the higher weight means more preemptive

	V	W	X	Y	Z	AA	AB	AC	AD	AE
2	Success matrix - Estimated protection probabilities									
3										
4		Chronic patients	Pregnants	Health care workers	Infants (0-6M)	Aged 6M-14	Aged 15-24	Aged 25-54	Aged 55-64	Aged 65+
5	Vaccine	0,80	0,94	0,80	0,00	0,80	0,80	0,80	0,80	0,80
6	Antiviral #1	0,79	0,79	0,79	0,79	0,79	0,79	0,79	0,79	0,79
7	Antiviral #2	0,79	0,79	0,79	0,00	0,79	0,79	0,79	0,79	0,00
8	Surgical mask	0,51	0,51	0,51	0,00	0,51	0,51	0,51	0,51	0,51
9	N95	0,95	0,95	0,95	0,00	0,95	0,95	0,95	0,95	0,95
10	Hand Hygiene	0,89	0,89	0,89	0,00	0,89	0,89	0,89	0,89	0,89
11	Lifestyle education	0,77	0,77	0,77	0,00	0,77	0,77	0,77	0,77	0,77
12	School closure	0,40	0,15	0,40	0,00	0,40	0,35	0,25	0,25	0,15
13	50% Social distancing	0,41	0,41	0,41	0,41	0,41	0,41	0,41	0,41	0,41
14	Self-quarantine	0,95	0,95	0,95	0,95	0,95	0,95	0,95	0,95	0,95
15	Quarantined city #1	0,95	0,95	0,95	0,95	0,95	0,95	0,95	0,95	0,95
16	Border shutdown	0,90	0,90	0,90	0,90	0,90	0,90	0,90	0,90	0,90
17	Airlines canceling	0,90	0,90	0,90	0,90	0,90	0,90	0,90	0,90	0,90
18	Canceling sailings	0,90	0,90	0,90	0,90	0,90	0,90	0,90	0,90	0,90
19										
20	Population of target segments	157.000.000	6.155.000	16.866.020	3.791.712	52.456.395	14.771.568	45.932.752	10.979.704	23.049.496
21	Target segment distribution	0,4743	0,0186	0,0510	0,0115	0,1585	0,0446	0,1388	0,0332	0,0696
22										
23	Estimated US 2020 population	331.002.647								
24										

Figure 2: Estimated protection probabilities of tools over target segments.

	A	B	C	D	E	F	G	H	I	J	K
20	Cost Matrix										
21		Chronic patients	Pregnants	Health care workers	Infants (0-6M)	Aged 6M-14	Aged 15-24	Aged 25-54	Aged 55-64	Aged 65+	
22	Vaccine	\$13,250	\$13,250	\$13,250	\$999,999	\$13,550	\$13,250	\$13,250	\$13,250	\$13,250	
23	Antiviral #1	\$39,500	\$39,500	\$39,500	\$71,300	\$39,500	\$39,500	\$39,500	\$39,500	\$39,500	
24	Antiviral #2	\$71,100	\$71,100	\$71,100	\$999,999	\$71,100	\$71,100	\$71,100	\$71,100	\$71,100	
25	Surgical mask	\$22,190	\$22,190	\$22,190	\$999,999	\$22,190	\$22,190	\$22,190	\$22,190	\$22,190	
26	N95	\$189,960	\$189,960	\$189,960	\$999,999	\$189,960	\$189,960	\$189,960	\$189,960	\$189,960	
27	Hand Hygiene	\$42,150	\$42,150	\$42,150	\$999,999	\$42,150	\$42,150	\$42,150	\$42,150	\$42,150	
28	Lifestyle education	\$1,500	\$1,500	\$1,500	\$999,999	\$1,500	\$1,500	\$1,500	\$1,500	\$1,500	
29	School closure	\$269,707	\$269,707	\$269,707	\$999,999	\$269,707	\$269,707	\$269,707	\$269,707	\$269,707	
30	50% Social distancing	\$269,707	\$269,707	\$269,707	\$21,810	\$269,707	\$269,707	\$269,707	\$269,707	\$269,707	
31	Self-quarantine	\$337,134	\$337,134	\$999,999	\$337,134	\$337,134	\$337,134	\$337,134	\$337,134	\$337,134	
32	Quarantined city #1	\$337,134	\$337,134	\$337,134	\$337,134	\$337,134	\$337,134	\$337,134	\$337,134	\$337,134	
33	Border shutdown	\$67,427	\$67,427	\$67,427	\$67,427	\$67,427	\$67,427	\$67,427	\$67,427	\$67,427	
34	Airlines canceling	\$67,427	\$67,427	\$67,427	\$67,427	\$67,427	\$67,427	\$67,427	\$67,427	\$67,427	
35	Canceling sailings	\$67,427	\$67,427	\$67,427	\$67,427	\$67,427	\$67,427	\$67,427	\$67,427	\$67,427	
36											

Figure 3: Unit variable costs of tools over target segments.

target since the objective function is in maximization form. As the most important risk factors are HCWs, chronic patients and 65+, we give them 10, and 8 to pregnant women. Also, we designate that HCWs must get vaccine at least 12,000,000 doses (one dose each), in the model context, we impose the constraint $x_{ij} \geq \underline{T}_j$, $x_{13} \geq 12,000,000$. There are also other regulations. As examples, HCWs must not adopt voluntary self-quarantine strategy, and infants must not get vaccine or cannot wear masks, or they cannot get Antiviral #2 when they are able to get Antiviral #1. In order to impose those limitations, we just give a huge amount of cost to their related costs to guarantee not to assign agents. This procedure is called the big-M-method which is common in optimization. We assume that the government budget is \$500 Billion and nongovernment budget is \$100 billion which sums to \$ 600 billion as total budget of assignment. We also specify that 40% of the cost of assigned agents of Antiviral #1, Antiviral #2, surgical mask, N95 respirators, hand hygiene products, 50% social distancing and self-quarantine would be met by people and private sector ($\rho = 0.40$).

The model is solved by MS Excel Solver. The CPU time for the solution of the model with $wxt = 14 \times 9 = 126$ integer decision variables is 97 seconds on a computer. The solution is very practical even for such an NP-complete model with 126 decision variables. Since the model is NP-complete, we consider the solution as near-optimal assignments. The near-optimal protection for the US as public health policy against novel coronavirus is given in Figure 4. It shapes the general framework of protecting people from COVID-19. The key point is that all target segments should adopt and be exposed appropriately the assigned number of agents to themselves for 6 weeks. The re-run of the model may also generate *alterna optima* solutions.

According to the mass protection model, 99.431% of HCWs, 94.707% of chronic patients, 99.741% of pregnant women, 99.223% of aged 65+ and, etc. are protected from COVID-19 if the near-optimal policies are adopted. The average protection ratio or average protection probability of all target segments, given in Figure 4, is 96.961% which is very high.

	A	B	C	D	E	F	G	H	I	J
38	Assignment matrix									
39		Chronic patients	Pregnants	Health care workers	Infants (0-6M)	Aged 6M-14	Aged 15-24	Aged 25-54	Aged 55-64	Aged 65+
40	Vaccine	42.579.294	6.155.000	16.824.750	0	7.668.508	7.577.611	12.381.742	8.609.802	18.203.289
41	Antiviral #1	11.790.796	3.647.089	5.901.650	3.791.712	2.024.784	3.150.988	6.675.316	3.258.419	9.759.243
42	Antiviral #2	30.238.262	1.559.968	5.426.304	0	2.527.332	2.479.252	6.130.867	1.638.011	0
43	Surgical mask	24.593.290	6.085.530	16.839.808	0	10.834.469	6.950.383	12.208.857	9.352.210	13.135.449
44	N95	7.587.894	5.883.122	14.749.732	0	7.031.962	7.059.347	12.604.272	8.173.614	16.910.052
45	Hand Hygiene	17.011.625	6.152.018	16.822.603	0	8.038.507	7.937.738	13.713.976	10.810.909	19.512.620
46	Lifestyle education	132.289.595	4.836.200	16.824.940	0	52.456.025	14.735.324	45.089.495	10.821.322	22.947.096
47	School closure	157.000.000	1.980.955	16.866.020	0	52.456.394	14.771.568	45.932.751	10.979.704	12.605
48	50% Social distancing	126.571.259	6.154.992	16.853.007	3.791.712	52.456.198	14.765.866	45.540.534	10.896.596	22.969.832
49	Self-quarantine	144.341.026	6.151.244	0	3.791.712	52.455.939	14.677.843	44.973.680	10.794.563	22.813.990
50	Quarantined city #1	1.968.413	77.169	211.460	47.539	657.680	185.200	575.889	137.659	288.991
51	Border shutdown	592.895	23.243	63.692	14.319	198.096	55.783	173.460	41.463	87.049
52	Airlines canceling	2.526.642	99.054	271.429	61.021	844.194	237.722	739.208	176.699	370.945
53	Canceling sailings	996.064	39.049	107.004	24.055	332.802	93.716	291.413	69.659	146.238
54										
55	# of assigned agents	700.087.055	48.844.633	127.762.399	11.522.070	249.982.890	94.678.341	247.031.460	85.760.630	147.157.399
56		>=	>=	>=	>=	>=	>=	>=	>=	>=
57	# of required agents	300.000.000	35.000.000	100.000.000	2.500.000	40.000.000	10.000.000	27.000.000	6.000.000	17.000.000
58										
59	protection ratios of targets	94,70780%	99,74159%	99,43135%	88,75789%	95,58458%	98,76136%	96,90661%	99,54052%	99,22368%

Figure 4: Assignment of tools to target segments and protection ratios of target segments.

The top four weighted protection values are of HCWs, aged 65+, chronic patients and pregnant women which are all risk factors. The costliest segment is chronic patients with a share of 45.06% of total cost when the least costly is infants (0-6 month) with 0.56%. The weighted protection and costs of all target segments are presented in Figure 5.

The costs of tools are also obtained that the costly tool is voluntary self-quarantine with a share of 34.479% of total cost as the pharmaceutical tools are associated with 2.469%. we also observe that all available agents are assigned to target segments. The near-optimal weighted protection of the country, objective function value of the model, is 62.335 unit. The total cost of near-optimal assignment is \$ 293,332,400,284 which is less than half of allocated total budget, and only 14.66% of \$ 2 trillion that has been recently released by the US government and the US Senate to combat and protect from the novel coronavirus pandemic and economic devastation[10]. The details are shown in Figure 6.

	A	B	C	D	E	F	G	H	I	J
38	Assignment matrix									
39		Chronic patients	Pregnants	Health care workers	Infants (0-6M)	Aged 6M-14	Aged 15-24	Aged 25-54	Aged 55-64	Aged 65+
60										
61	priority weights	10,0	8,0	10,0	5,0	4,0	4,0	5,0	8,0	10,0
62										
63	weighted protection of targets	9,47	7,98	9,94	4,44	3,82	3,95	4,85	7,96	9,92
64										
65	cost of targets	132.167.046.830	6.160.697.432	13.947.063.672	1.654.090.238	48.652.102.347	15.256.448.218	44.283.037.380	12.196.573.262	19.015.340.905
66	cost of targets (%)	45,06%	2,10%	4,75%	0,56%	16,59%	5,20%	15,10%	4,16%	6,48%
67										
68										
69										
70										

Figure 5: Weighted protection and costs of target segments.

	A	L	M	N	O	P	Q	R
38	Assignment matrix							
39		# of used agents	<=	agent capacity		cost of tools	cost of tools (%)	
40	Vaccine	119.999.996	<=	120.000.000		1.592.300.499,40	0,54283%	
41	Antiviral #1	49.999.997	<=	50.000.000		2.095.576.323,10	0,71440%	
42	Antiviral #2	49.999.996	<=	50.000.000		3.554.999.715,60	1,21194%	
43	Surgical mask	99.999.996	<=	100.000.000		2.218.999.911,24	0,75648%	
44	N95	79.999.995	<=	80.000.000		15.196.799.050,20	5,18074%	
45	Hand Hygiene	99.999.996	<=	100.000.000		4.214.999.831,40	1,43694%	
46	Lifestyle education	299.999.997	<=	300.000.000		449.999.995,50	0,15341%	
47	School closure	299.999.997	<=	300.000.000		80.912.159.190,88	27,58378%	
48	50% Social distancing	299.999.996	<=	300.000.000		79.972.204.133,16	27,26334%	
49	Self-quarantine	299.999.997	<=	300.000.000		101.140.198.988,60	34,47972%	
50	Quarantined city #1	4.150.000	<=	4.150.000		1.399.106.100,00	0,47697%	
51	Border shutdown	1.250.000	<=	1.250.000		84.283.500,00	0,02873%	
52	Airlines canceling	5.326.914	<=	5.326.914		359.176.764,90	0,12245%	
53	Canceling sailings	2.100.000	<=	2.100.000		141.596.280,00	0,04827%	
54								
55								
56		Total cost		293.332.400.284	<=	600.000.000.000	Total budget	
57								
58		Weighted protection		62.335915001206		max		
59							Budgets	
60				cost to government		209.974.889.102,66	<=	500.000.000.000
61				cost to nongovernment resources		83.357.511.181,32	<=	100.000.000.000

Figure 6: Total weighted protection, costs of tools, costs to government and non-government resources and total cost.

Mind the Gap: Opportunity Cost of Vaccines and Antiviral Medicines

There are no approved vaccines and antiviral medicines against novel coronavirus at present. Thus, for the present-day situation, we also run the mass protection model without pharmaceutical tools, only with the nonpharmaceutical tools by just easily giving zero protection probabilities to the vaccine and antivirals or adding new constraints imposing them to zeros on the spreadsheet, which is indeed another advantage of spreadsheet modeling.

We get the total weighted protection of 60.845 unit based on the near-optimal policy. The average of protection probabilities of all target segments reduces from 96.961% to 94.198% as the total cost decreases by about \$7,25 billion. The protection ratio gap between the models with and without vaccine and antivirals is 2.763% which corresponds the failure of protecting 8,292,109 people as much as population of the State of Virginia or

New York City – opportunity cost of vaccines and antiviral drugs. If the available number of nonpharmaceutical agents would decrease or be in shortage in the nonpharmaceutical case, the number of expected unprotected people would increase dramatically.

4. Concluding Remarks

Some properties of the personal protection protocol and the mass protection model are discussed and several recommendations on fighting COVID-19 are drawn using analogy and metaphor as concluding comments.

Unus pro omnibus, omnes pro uno: Relation Between the Models

It could be asserted that “protecting yourself means protecting people” is an extremely important principle in epidemiology to combat the outbreaks. Our two proposed models for fighting all epidemics, pandemics or bioterror attacks in this work are in favor of the fact *unus pro omnibus, omnes pro uno* – one for all, all for one. From a standpoint, the mass protection model with integer decision variables is a mathematical generalization of the personal protection model with binary decision variables, and conversely, a special case of the mass protection model is the personal protection model. If you join the mass protection policy, you will have personal protection strategy in a somewhat and if you adopt personal protection protocol, you will contribute to the mass protection policy to fight epidemics, which leads us to *unus pro omnibus, omnes pro uno* - one for all, all for one.

Triple Corona of Protection and Fighting

We remark that both personal and mass protection models have some crowns of surviving epidemic diseases. In other words, in our approach, there are hallmarks of protection and hence fighting against invisible enemy which can be asserted as “triple corona”.

The first crown may be protection probability which is a brilliant parameter for our procedures. The second corona would be cost which is also vitally important for fighting pandemics even when it is also thought pandemics are global health concerns as well as economic issues. The third corona, the coronation of the models, is optimal policy. The models yield us maximum protection policies in micro and macro planning dimensions. The first two crowns bloom the third corona to shine the proposed models and the “triple corona” on the top.

Our personal protection model can treat a finite number of tools (w) when the mass protection model can handle any finite numbers of tools and target segments (wxt) and can be applied to any region at the levels from county to city, to state and across country as well as in the global scale. Once the models are built on spreadsheet, their data and parameters may be easily updated and re-run due to the benefits and elasticity of spreadsheet modeling, which makes the implementation of the models user-friendly. The developed optimization models that are quite efficient may be incorporated into dynamic frames as future research.

Love in the Time of Corona

As the moving enemy, novel coronavirus, is double invisible due to its viral nature and the availability of the high level of symptom-free cases of infected people which is guessed 1 in 4 in the US and 2 in 4 in Ireland, the seriousness and difficulty of fighting coronavirus pandemic should be internalized altogether.

Recognize the enemy, love yourself, love the personal protection protocol and the mass protection synergy to give lovely gifts of life to yourself first, your family and the people that you love, to society, to people and your country, and to the rest of the world. Love life, follow the measure rules and stay at home! That is the greatest ever social impact. Global health policy makers and governments would join the circle of love in the time of corona!

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