The *Hague* Centre for Strategic Studies

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EPIDEMICS AND STRATEGIC TIMING

INTEGRATING EPIDEMIC RISK AND INTERVENTION CAPABILITIES IN THE CASE OF THE 2014 WEST-AFRICA EBOLA OUTBREAK

The Hague Centre for Strategic Studies

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KEY FINDINGS

While early medical intervention is a no-regret option during epidemics, the appropriate timing and size of these types of interventions is not always sufficiently recognized or feasible due to the lack of its local capacity. This could lead to the situation where international medical intervention is required. Given the considerable costs of epidemics, both societal and financial, and their exponentially increasing nature when the epidemic is growing in size, timing of such intervention is crucial. From our analysis of the dynamics of epidemics, with the recent Ebola outbreak in West-Africa as the prime case study, we conclude that:

- Developing intervention capabilities for epidemics should be proactive, anticipating both the doubling time of the disease and the delay of building up additional intervention capabilities.
- Deploying intervention capabilities should be done as early as possible in the exponential, first phase of the epidemic.
- Limiting social, political, and economic damage from epidemics is primarily achieved through direct disease control, although late intervention might require additional non-medical intervention measures as well.
- To scale possible international assistance, it is important that a quick but careful assessment is made of the domestic ability to deal with the specific disease at hand. In this assessment, it is important to combine both the risk itself (i.e., the epidemic) and the capabilities needed to control it (e.g., isolation capacity, health workers able to treat the patients, equipment for the health workers, and tracing capacity).

As a rule, international medical interventions must be supported by non-medical measures, such as protective measures, coordination services and logistics. Typically, military organizations play an active role in delivering such support. Regarding the military backup of intervention capabilities, we conclude that:

- The use of the military for quarantining parts of the epidemic area is not effective if geographical spread of an epidemic is too large. Especially in the African situation, closing off an area through roadblocks is often unfeasible.
- Military protection of health workers may impede the ability to build trust with the local population, which in turn decreases the efficiency of the intervention capabilities. It should be anticipated that health care workers may not desire this kind of help.
- Military support units must be prepared to move in very rapidly once it becomes clear that the existing intervention capacity will not be sufficient to bring the epidemic under control.
- Timing and scaling is essential. Military organizations, in their role as international disaster responders, have a shared responsibility for developing quantitative models that help in determining appropriate timing and scaling of international interventions in epidemic crises, including military support and political stability functions.

1 EBOLA OUTBREAK 2014-2015

In 2014, the outbreak of the Ebola virus (EBOV) and the subsequent Ebola virus disease (EVD) caused thousands of victims in Liberia, Sierra Leone, and Guinea.[1] This specific Ebola outbreak took place in highly urbanized rather than rural areas, making it difficult to control. It fully overwhelmed the health care system locally available.[2]

Initially, on 14 September 2014, the expectation was that the number of Ebola victims would exceed 20,000 by 2 November 2014.[3] The estimates for these figures changed over time. In the situation report of 5 November 2014, 13,043 cases were reported, with 4,818 deaths. In one of the most recent Ebola Situation Reports (of 11 March 2015), the total number of cases was reported as 24,247 with 9,961 deaths.

Because of the EVD, the economic situation in the three hardest hit countries significantly worsened, leading to lower economic growth forecasts.[4] For example, GDP growth estimates for 2014 were revised to 2.2 percent in Liberia versus 5.9 percent before the crisis; for Sierra Leone these numbers were 4.0 percent and 11.3 percent respectively. In addition, EVD caused considerable societal impact due to broken families, orphaned children, and social exclusion of survivors.

1 "Ebola Data and Statistics," *WHO*, accessed December 2, 2014, http://apps.who.int/gho/data/view.ebola-sitrep.ebola-summary-latest?lang=en.

2 "Are the Ebola Outbreaks in Nigeria and Senegal Over?," *WHO*, accessed December 2, 2014, http://www.who.int/mediacentre/news/ebola/14-october-2014/en/.

3 WHO Ebola Response Team, "Ebola Virus Disease in West Africa — The First 9 Months of the Epidemic and Forward Projections," *New England Journal of Medicine* 371, no. 16 (September 22, 2014): 1481–95, doi:10.1056/NEJMoa1411100.

4 World Bank, *Update on the Economic Impact of the 2014 Ebola Epidemic on Liberia, Sierra Leone, and Guinea*, December 2, 2014, http://www.worldbank.org/content/dam/Worldbank/document/Economic%20Impact%20Ebola%20Update%202%20Dec%202014.pdf.

The delayed initial response of organizations such as the World Health Organization (WHO) and the U.S. Centers for Disease Control and Prevention (CDC) contributed to a situation that got out of control. It is conceivable that this inadequate response and the resulting lack of isolation capacity increased the transmission speed of EBOV in West Africa.[5] As the epidemic became more uncontrollable, the need for intervention capabilities moved beyond the means of the purely health-care oriented organizations that dealt with the epidemic. This realization led to the sending of military personnel by the United States and other countries to assist in handling and controlling the epidemic.[6]

Additionally, a whole range of 'preventive' and 'protective' measures was taken by various governments around the world to prevent global spreading of the EBOV. For example, multiple countries imposed traveling limitations from and to the affected countries. Morocco declined the organization of the Africa Cup because of fear of the spread of EBOV in the country. Health workers returning from West-Africa to their home countries were quarantined. However, the sometimes disproportionate and ineffective nature of these measures have also led to heated debates.

This paper aims to underscore the broader effects that epidemics have on societies, the importance of early recognition of epidemics, and the ability to assess the progression of the disease in order to determine the most appropriate use of intervention capabilities, potentially with military support. We will use the EBOV epidemic of 2014 as an example throughout the paper.

5 Willem L. Auping et al., "A Quantitative Assessment of Dynamic Intervention-Capacity Effectiveness in the 2014 Ebola Epidemic," *PLoS Currents* Under review (2014).

6 Zeke J. Miller, "U.S. to Commit $500 Million, Deploy 3,000 Troops in Ebola Fight," *Time*, September 16, 2014, http://time.com/3380545/u-s-to-commit-500-million-deploy-3000-troops-in-ebola-fight/; Dan Lamothe, "U.S. Military Force Fighting Ebola Virus Could Grow to 4,000 Troops," *The Washington Post*, October 3, 2014, http://www.washingtonpost.com/news/checkpoint/wp/2014/10/03/u-s-military-force-fighting-ebola-virus-could-grow-to-4000-troops/.

2 IMPACT OF EPIDEMICS ON SOCIETIES

The impact of epidemics on societies can be very profound (Table 1). In the initial stage of the EBOV outbreak in 2014, the United Nations Security Council declared the outbreak as a risk to peace and security.[7] The direct effects of an epidemic have to do with the victims of the disease and their families, and the day-to-day consequences of health-related and non-health-related measures taken.

TABLE 1. OVERVIEW OF HISTORIC EPIDEMICS WITH THEIR DEATH TOLLS AND ECONOMIC COSTS

EPIDEMIC[8]	AREA	PERIOD	DEATH TOLL	ECONOMIC COSTS	SOURCE
Ebola Virus Disease	Africa	2014-2015 -	10.000	$1,6 billion for 3 countries	WHO, 2015; WB, 2014
DoC Measles	Congo	2010 -2013	5.045	-	WHO, 2013
H1N1 Swine Flu	Global	2009 -	123.000 - 400.000	$37,5 billion	CDC, 2012
H5N1 Avian Flu	Asia	2007 -	379	-	-
Q-Fever	Netherlands	2007 - 2010	19	€161M - 336M (just NL)	Tempelman ea, 2011
SARS Coronavirus	Asia	2002 - 2003	774	2% of East Asian GDP	WHO, 2004
Hiv/Aids	Global	1981 -	37.000.000	-	UNAIDS, 2014
H3N2 Hong Kong Flu	Global	1968 - 1969	1.000.000	-	CDC, 2006 (Taubenberger)
H2N2 Asian Flu	Global	1957 - 1958	2.000.000	-	-
H1N1 Spanish Flu	Global	1918 - 1920	20.000.000	-	-
6th Cholera Pandemic	Global	1899 - 1923	1.500.000	-	-

7 United Nations News Service Section, "UN News - UN Announces Mission to Combat Ebola, Declares Outbreak 'threat to Peace and Security,'" *UN News Service Section*, September 18, 2014, http://www.un.org/apps/news/story.asp?NewsID=48746#.VH3V1HsqWuq.

8 If an epidemic spreads faster and across various regions across the world, WHO uses the term pandemic.

Beyond that, societies as a whole may suffer from more long-term economic damage and, potentially, from societal disruption. Apart from the short-term economic impact caused by the direct productivity loss of people falling prey to the epidemic, the disruptive consequences on supply chains may magnify the effect, especially in severe epidemics when many are ill at the same time and professional substitution is not readily available. A large number of patients, unable to fulfill their normal professional responsibilities, may cause limited availability of food, water and energy, also impacting those that are not ill.[9] This in turn may lead to serious population discontent regarding the functioning of governments. This third-order effect may be profound. Among other examples, this is illustrated by the severe labor scarcity after the European plague pandemics in the late Middle Ages, shaking the feudal order and thereby constituting one of the prime causes of the 'glorious revolution' in England.[10] It should be noted that interventions to stop an epidemic, such as social distancing and the quarantining of sick people, could also lead to similar second- and third-order effects, causing damage to both economy and society.

9 *Scenario's Nationale Risicobeoordeling 2008/2009*.

10 Daron Acemoglu and James A. Robinson, *Why Nations Fail: The Origins of Power, Prosperity and Povery*, 1st ed. (New York: Crown, 2012).

3 THE DYNAMICS OF EPIDEMICS

Epidemics are caused by communicable diseases. To be able to assess important indicators of an epidemic and the effects it might cause, so-called transmission models are used.[11] These models provide indications on the way and the extent that epidemics might develop. As a consequence, they could inform decision makers on the scale and timeliness of the intervention required. Even in situations with much data available, current quantitative transmission models often have difficulty taking into account the unpredictable nature of local circumstances to provide precise estimates of numbers of future cases, as became clear in the 2014 West-Africa Ebola epidemic.[12] However, given the complexity of epidemics, relying on qualitative assessments only is undesirable.

The following section describes some of the driving elements of an epidemic, such as the reproduction number, incubation time, and the case fatality rate. An introduction about epidemiology and communicable diseases can be found in the appendix. Some concepts, including the Basic Reproduction Number (R_0), the Case Fatality Rate (CFR), and the Incubation Time, are of crucial importance for understanding the severity of an epidemic and are defined in Table 2 below.

11 E.g., G. Chowell et al., "The Basic Reproductive Number of Ebola and the Effects of Public Health Measures: The Cases of Congo and Uganda," *Journal of Theoretical Biology* 229, no. 1 (July 7, 2004): 119–26, doi:10.1016/j.jtbi.2004.03.006; Gerardo Chowell and Hiroshi Nishiura, "Transmission Dynamics and Control of Ebola Virus Disease (EVD): A Review," *BMC Medicine* 12, no. 1 (October 10, 2014): 196, doi:10.1186/s12916-014-0196-0; WHO Ebola Response Team, "Ebola Virus Disease in West Africa — The First 9 Months of the Epidemic and Forward Projections."

12 Declan Butler, "Models Overestimate Ebola Cases," *Nature* 515 (November 6, 2014): 18, doi:10.1038/515018a.

TABLE 2. IMPORTANT CONCEPTS IN EPIDEMIOLOGY

CONCEPT	DEFINITION
Basic Reproduction Number (R_0)	"The number of secondary cases that arise when one primary case is introduced into an uninfected population."[13] The basic reproduction number is, therefore, defined as the reproduction before interventions are introduced to limit the disease.
Case Fatality Rate (CFR)	The relative number of diseased that dies.
Incubation Time	The time between being exposed to the agent (e.g., virus or bacterium) and becoming diseased.
Herd Immunity	An effective reproduction number (R) of a disease below 1 by a reduction in the susceptible part of the population. This may be caused by vaccination campaigns or immunization by the disease itself.

The Basic Reproduction Number (R_0) and the Case Fatality Rate (CFR) allow comparing different epidemic diseases (see Figure 1). This shows that both extremely deadly diseases (high CFR) and highly contagious diseases (high R_0) have caused very deadly epidemics and pandemics, but only one disease – Tuberculosis – has both a high CFR and a high R_0. This is an explanation for the extreme caution, under the Siracusa principles,[14] to be taken with cases of extensively drug-resistant tuberculosis, or XDR-TB.[15] These extreme conditions only apply if no or very little treatment is available for the particular disease. Ebola Virus Disease, XDR-TB, and a previously unknown strain of influenza are examples of such diseases.

13 WHO Ebola Response Team, "Ebola Virus Disease in West Africa — The First 9 Months of the Epidemic and Forward Projections," *New England Journal of Medicine* 371, no. 16 (September 22, 2014): 1481–95, doi:10.1056/NEJMoa1411100.

14 United Nations Commission on Human Rights, "The Siracusa Principles on the Limitation and Derogation Provisions in the International Covenant on Civil and Political Rights," September 28, 1984, http://www.refworld.org/docid/4672bc122.html.

15 "WHO Guidance on Human Rights and Involuntary Detention for XDR-TB Control," *WHO*, accessed February 12, 2015, http://www.who.int/tb/features_archive/involuntary_treatment/en/.

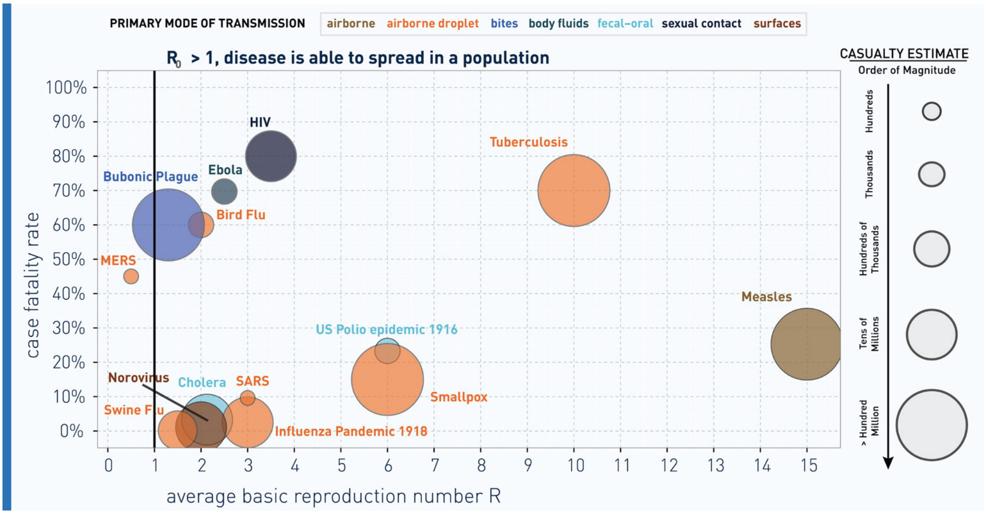

FIGURE 1. DIFFERENT EPIDEMIC DISEASES COMPARED BY R_0, CFR, AND THE NUMBER OF CASUALTIES. ADAPTED FROM MCCANDLESS[16]

For very deadly diseases of the past, like the bubonic plague or HIV, there are known treatments that either cure patients or reduce the CFR to a value close to zero. On the other hand, vaccination campaigns mostly influence the effective reproduction number via herd immunity. These turn out to be particularly effective in outbreak prevention of, for example, measles and smallpox. Therefore, in the case of diseases with high CFR, treatment of patients is most important in avoiding casualties, while vaccination campaigns are needed for diseases with high R_0. If neither treatment nor vaccines are available, isolation of the diseased and quarantining the possible infected are the only remaining options for containing the disease.

16 David McCandless, "The MicrobeScope - Infectious Diseases in Context," *Information Is Beautiful*, accessed February 9, 2015, http://www.informationisbeautiful.net/visualizations/the-microbescope/.

4 CONTROLLING EPIDEMICS AND ITS CONSEQUENCES

Controlling the effects of epidemics is often aimed at first order effects, limiting the dynamics of an epidemic itself. However, these medical interventions often need to be supported by additional measures, ranging from information campaigns to logistical support and the protection of health care workers. In addition, policy makers will have to consider controlling the higher order effects as well.

Epidemics and pandemics are known risk factors to national and international security.[17] They can have considerable consequences for society, both directly and indirectly.[18] Still, limiting the social and economic effects of the epidemic is generally not possible without limiting the epidemic, but might require dedicated attention in any case.

While for any known disease the 'what to do' in medical intervention is clear (Table 3), determining the appropriate size and timeliness of the intervention might be problematic (as was the case in the 2014 EBOV outbreak) as well as the need and effectiveness of other types of measures in uncertain conditions. Traditional transmission models might provide assessments of the development of diseases in known or stable circumstances. However, they cannot always adjust to uncertain situations nor do they incorporate the potential effects of intervention measures.

17 *Scenario's Nationale Risicobeoordeling 2008/2009*, Nationale Veiligheid (Ministerie van Binnenlandse Zaken en Koninkrijksrelaties, 2009), http://www.rijksoverheid.nl/documenten-en-publicaties/rapporten/2009/10/21/scenario-s-nationale-risicobeoordeling-2008-2009.html; CDC, *Interim Pre-Pandemic Planning Guidance: Community Strategy for Pandemic Influenza Mitigation in the United States—Early, Targeted, Layered Use of Nonpharmaceutical Interventions* (Atlanta: Centers for Disease Control and Prevention, 2007), -, http://stacks.cdc.gov/view/cdc/11425.

18 *Scenario's Nationale Risicobeoordeling 2008/2009*.

TABLE 3. EXAMPLE OF STRATEGIC INTERVENTION TOOLS RELATED TO EPIDEMICS

ORDER	TYPE	OPERATIONALIZATION
1st	Medical intervention	Tracing Vaccination Treatment Isolation Quarantine
1st	Health-support	Information campaign (causes and effects, prevention) Logistics (trans, infra) Protection of health care workers
2nd	Economic intervention	Financial aid and Investment Provisional services delivery
3th	Social & Political Intervention	Re-integration Protection and control Strengthening rule of law Health programs

This is where quantitative system dynamics modeling can help in assessing the uncertain elements related to the development of diseases and in integrating the effect of capabilities, either available or to be developed. As an example, we modeled (see Figure 2) various possible developments paths (i.e., scenarios in which size of the population affected or the R0 is varied) of an epidemic, taking into consideration a number of intervention measures:

- isolation capacity (i.e., beds in treatment centers),
- tracing officer capacity,
- medical personnel capacity, and
- vaccination capacity (i.e., number of vaccines available).

In this model, the population in a society confronted with an epidemic is divided in Susceptible, Exposed, Infectious, and Recovered (SEIR) parts (see Appendix for further explication). The infectious population is split up in an 'isolated' part and a 'non-isolated' (i.e., in community) part. During the exponential first phase of an epidemic (see Appendix for explanations of the four phases of an epidemic), existing intervention capabilities such as hospital capacity, available treatments, and health care personnel perform a buffer capacity. In an ideal situation, this capacity should be sufficient to prevent an epidemic from taking place. To correctly calculate the isolation capacity in use (i.e., the number of beds in treatment centers occupied by patients at a given moment), the isolated population in a critical phase is further split up into two categories, in which 1) part of the diseased will die, and 2) the recovering survivors, also in need of medical attention, will remain in isolation while still contagious.

In the same model the size of intervention capabilities is also represented, where delays in the system determine when the capability expansion becomes available (this part of the model is not depicted in Figure 2). Thus, it is possible to assess whether the approach chosen for expanding intervention capabilities is robust, given the uncertainties in the case of an epidemic. The exact intervention capabilities used depends on the characteristics of the epidemic, often distinguished by combining outcomes from quantitative transmission models and characteristics of the disease itself. These intervention capabilities may include behavioral change like social distancing, quarantining healthy but potentially infected people, tracing, treatment and isolation of infected patients, vaccination of the still susceptible population, and eradication of vectors in the case of vector-borne diseases (such as rat control with the plague).

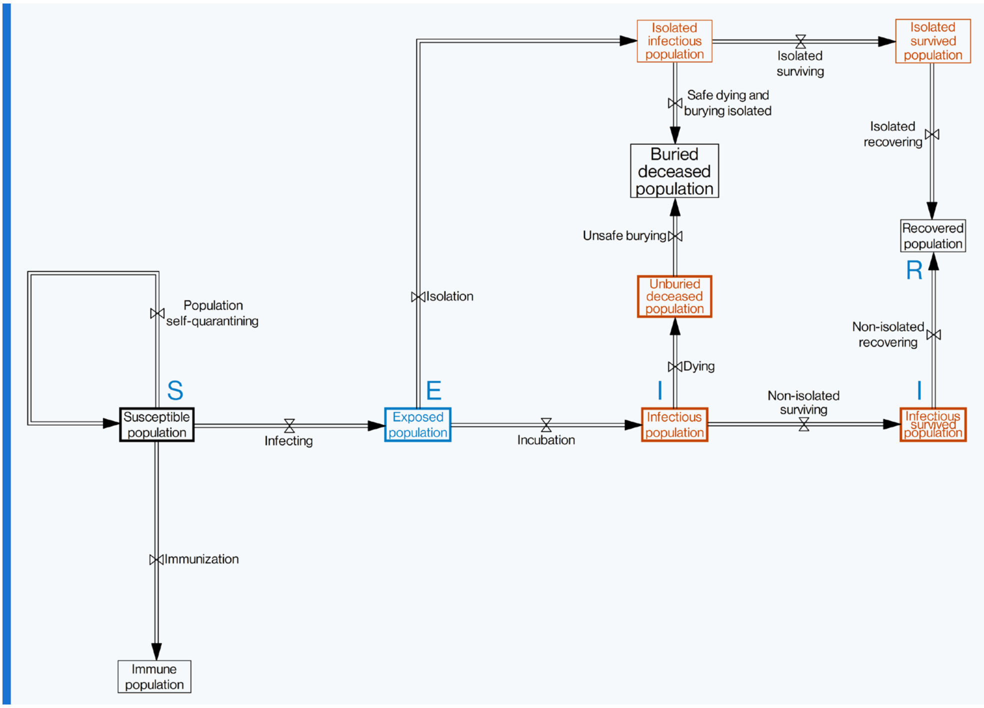

FIGURE 2. TRANSMISSION STRUCTURE OF AN EPIDEMIC MODEL WHERE THE RISK (I.E., THE EPIDEMIC) IS INTEGRATED WITH THE INTERVENTION CAPABILITIES (E.G., ISOLATION CAPACITY)

If the buffer capacity – i.e., beds in treatment centers, tracing officer capacity, medical personnel capacity, and vaccination capacity – is exhausted, expansion and development of new intervention capabilities will be necessary. The exhaustion of the intervention capabilities may also affect the speed of transmission of the disease, which became exemplary in the EVD. Here, because of the delayed intervention, buffer capacity was absorbed quite rapidly, leading to an acceleration of EBOV transmission. Development of new capabilities required a buildup time that was too long to halt the acceleration.

This situation is illustrated in Figure 3. The figure shows the development of the number of EBOV cases over time given the availability and exhaustion of intervention capabilities under various circumstances. The different lines in Figure 3 indicate different model runs. Thus, the blue line in the graph, which is closest to the actual course of events in the 2014 Liberian situation for the EBOV outbreak, shows a situation in which the buffer capacity is too small to effectively reduce the reproduction number of the EVD, and therefore insufficient in nipping the epidemic in the bud (which would be represented by a line that is declining over time).

These types of scenarios, in which the initially existing isolation is effective in limiting transmission and stopping the epidemic, are not represented in the graph. In circumstances in which the growth in number of cases accelerates over time (visible in the graph around day 80 and represented by orange and brown lines), exhaustion of intervention capabilities (i.e., buffer capacity) has taken place. In the 2014 situation, the initial limited effectiveness of the isolation was caused by a lack of understanding about the disease at hand, as health workers initially thought they were dealing with Lassa fever. It is possible to imagine a situation with similar case measurement over the first period of time, but with an effective reduction of reproduction in the treatment centers (the orange and brown scenario in Figure 3). A further increase in the number of cases beyond the limits of the isolation capacity would then have a very different effect. Having relatively less people in treatment centers would in that case increase the average reproduction rate in the population. Consequentially, reaching the limits of the isolation capacity would cause situations with far more people infected and far more people dying.

This happens if transmission of diseases is indeed lower 'in isolation' compared to 'in communities'. After all, in these situations the average transmission rate will increase when the isolated part of the infectious population decreases. In contrast to this, if the transmission rate in isolation is similar or higher compared to the transmission in communities, this increase in virus spreading will not take place. In other words, if people in isolation infect at least as many susceptible people as people outside isolation, the limits of existing isolation capacity will lead to an increased transmission speed. In these scenarios, exceeding the available bed capacity in isolation will not further deteriorate the epidemic situation.

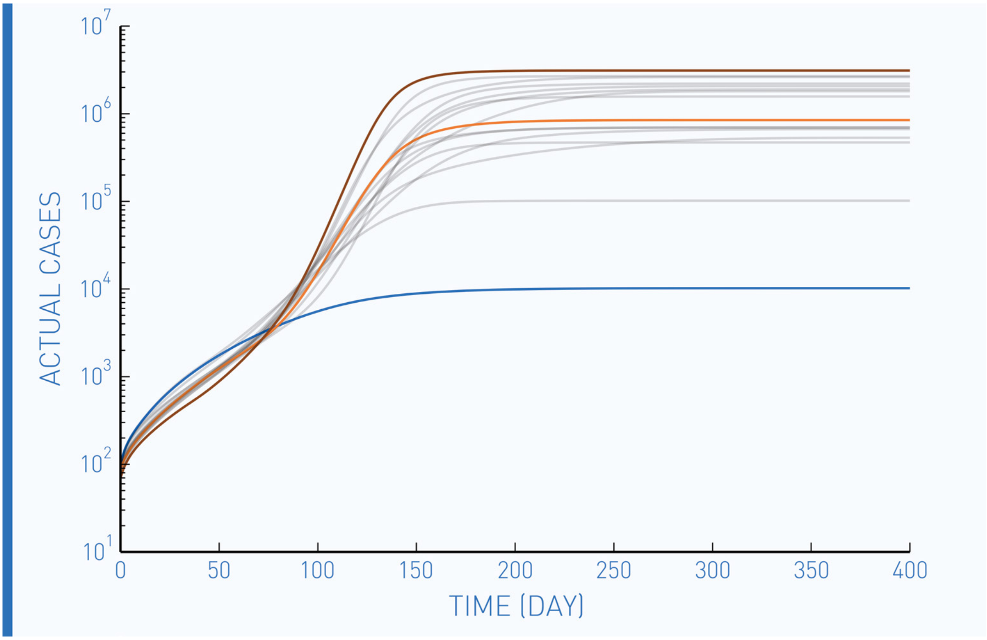

FIGURE 3. THE INCREASE IN THE NUMBER OF EBV CASES IN SCENARIOS WITH INITIAL CONDITIONS SIMILAR TO THE 2014 LIBERIA SITUATION

To avoid epidemic situations with increased speeds of transmission after exhausting available intervention capabilities, it is of utmost importance to correctly assess the desired scale of the interventions. After all, not having enough capacity will lead to continued and/or increased transmission, while developing superfluous capacity will waste effort and investment.

Furthermore, the development of additional capabilities depends on the speed of the development of the disease, in essence represented by the reproduction number R_0 and the doubling time of the disease, which is the period of time wherein the number of cases doubles. For example, when the UN had its first meeting on the public health crisis evoked by the Ebola outbreak,[19] the number of cases was doubling every two weeks.[20] The shorter the doubling time, the more limited the time available to expand intervention capabilities, and thus the greater the need for anticipation of capabilities.

The doubling time is also sensitive to exhaustion of the available intervention capabilities (Figure 4), when it may strongly shorten as the result of the increased transmission rates. On the other hand, when the spreading of a disease slows down, the doubling time will rapidly rise, until at some moment the number of cases does not double anymore (the doubling time becomes infinite). This is often indicative of the fourth and final phase of an epidemic.

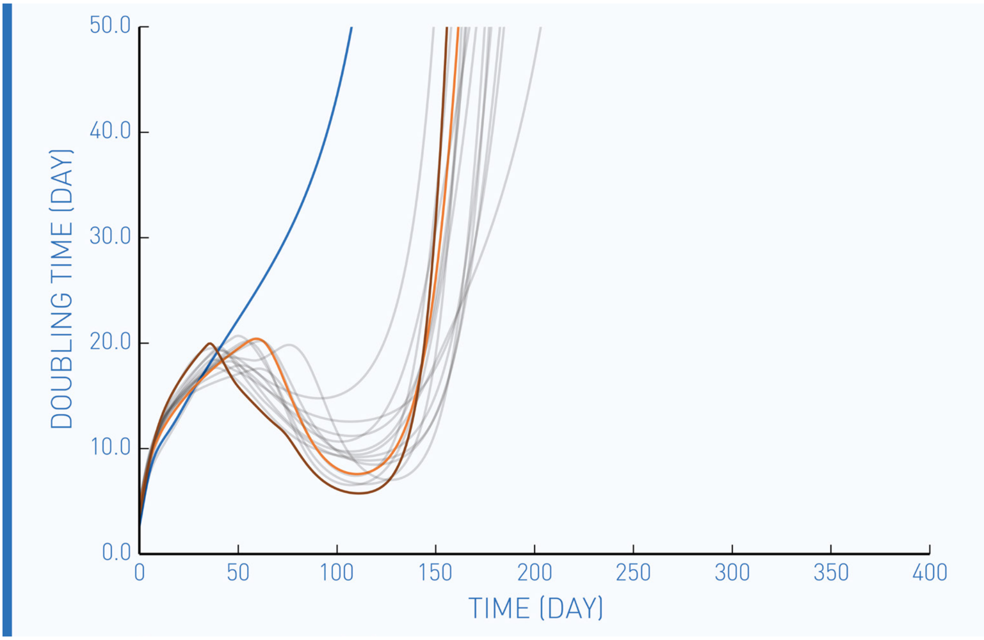

FIGURE 4. SCENARIOS FOR THE DOUBLING TIME

19 Section, "UN News - UN Announces Mission to Combat Ebola, Declares Outbreak 'threat to Peace and Security.'"

20 "Ebola 'Threat to World Security,'" BBC News, accessed March 13, 2015, http://www.bbc.com/news/world-africa-29262968.

The blue scenario shows a situation in which reaching the limit of the intervention capacities makes no difference, as the intervention capacities were not effective in reducing the infectivity. However, in the orange and brown scenario, the doubling time drastically decreases after approximately day 50. These indicate the start of the intensified transmission that leads to the high numbers of EBOV cases also seen in Figure 3.

To anticipate the availability of intervention capacities and the doubling time, the most robust approach during an epidemic is a proactive approach which takes the relation between capability development time and doubling time into account. For example, at a specific moment 1000 beds are needed as isolation capacity, while at that moment only 100 beds are available. We know that it would take 3 weeks to develop this capacity. The doubling time of the disease is also 3 weeks. Consequentially, we will need 2000 beds in three weeks. This requires the development of a capacity of 1900 beds – 2000 minus the existing 100 – and ensuring that the health workers required for this bed capacity are also available. In addition, if it appears that the number of cases reported by the authorities might be underestimated, for example by a factor 2, we will need to multiply the number of beds under development with this factor as well. Therefore, in a proactive approach of this hypothetical situation, 3900 beds would need to be developed in the span of 3 weeks. This example also makes clear how important it is to be as fast as possible, and minimize the delay time for capability expansion.

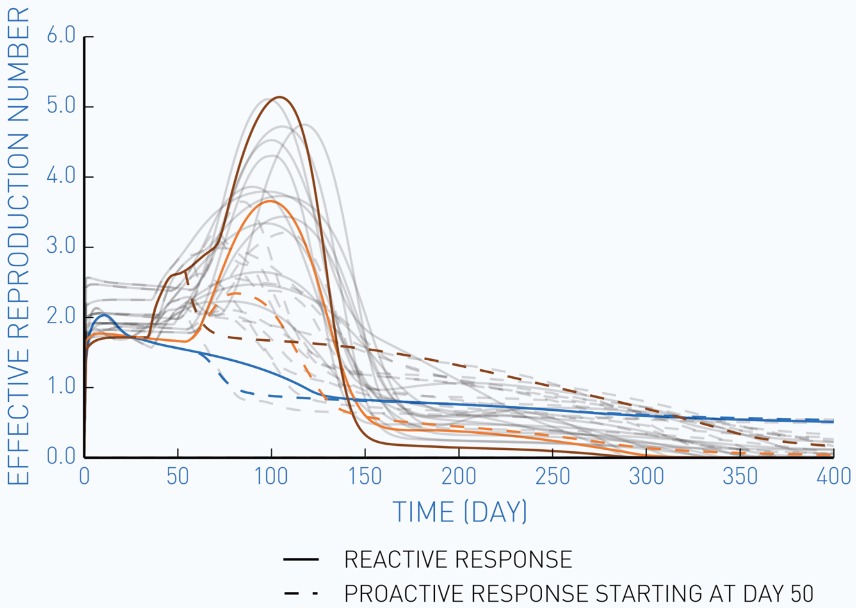

FIGURE 5. THE EFFECTIVE REPRODUCTIVE NUMBER WITH THE START OF A PROACTIVE APPROACH AT DAY 50 OF THE EPIDEMIC. THE DOTTED LINES SHOW THE EFFECT OF THE PROACTIVE APPROACH, WHILE THE NORMAL LINES SHOW THE REACTIVE RESPONSE

Figure 5 and Figure 6 both show the effect of switching from a reactive approach (i.e., just developing the bed capacity currently needed and not taking delays for new bed capacity development into account) to a proactive approach. Comparing the two Figures makes clear that timing is very important. If the change in approach is implemented around day 50, the spike in infectivity due to exhausting the original available isolation capacity would be avoided. Consequentially, the total number of cases would be far less, also limiting the social and economic damage caused by the epidemic. Further, the total size of required intervention capacities is also lower, resulting in lower costs. If this change in approach is implemented later in the epidemic, for example starting at day 110 (Figure 6), the effect is relatively limited, as the reproduction number is already on the decline in all these scenarios. The crucial moment for adequate intervention was thus missed, as the intervention only took place in the second phase of the epidemic. The exponential first phase is thus the only appropriate moment to intervene in an epidemic in order to control it.

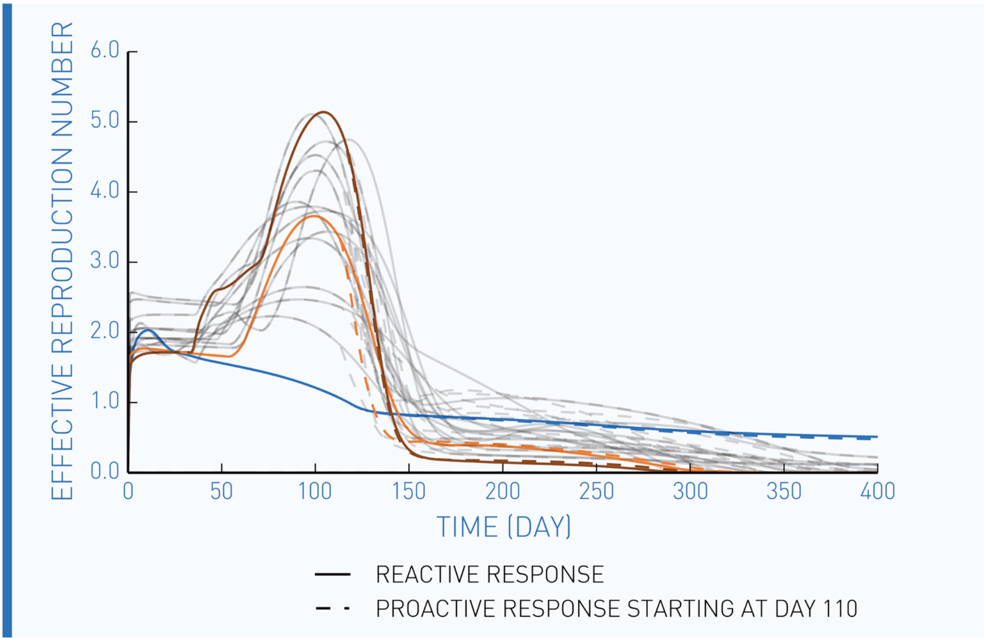

FIGURE 6. THE EFFECTIVE REPRODUCTIVE NUMBER WITH THE START OF A PROACTIVE APPROACH AT DAY 110 OF THE EPIDEMIC. THE DOTTED LINES SHOW THE EFFECT OF THE PROACTIVE APPROACH, WHILE THE CONTINUOUS LINES SHOW THE REACTIVE RESPONSE

5 THE ROLE OF MILITARY ORGANIZATIONS IN EPIDEMICS

The challenges that epidemics impose on health systems are extensive. These challenges may be further magnified by large second and third order effects on the economy and society. To manage these challenges and contain the associated risks, both timing and scale of interventions are crucial. Disease transmission must be limited as early and as much as possible. Apart from health-related measures, this typically requires a host of supporting activities.

When the 2014 EBOV outbreak in West-Africa grew out of control, military logistics support was needed to back up the purely health-care oriented organizations. Concrete tasks might have included setting up roadblocks to limit the geographic spread of the disease and protecting health care workers. This, however, was not the most appropriate response in the case of the EBOV epidemic. The geographic spread of the disease was already so expanded that trying to limit the spread by setting up roadblocks would have needed more military personnel than could possibly be allocated. The African situation, with very few formal roads and very many informal paths made this a unfeasible approach. And while protecting health care workers may seem like an important task, especially in the face of accounts of health care workers being attacked and even killed by people trying to keep Ebola away from their villages, the health care workers themselves often did not want military protection. They felt it hindered them in building trust in the communities to facilitate their work. As a result, the military role in the Ebola crisis concentrated on implementing health-related measures, such as isolating and quarantining people, but even more so on logistics support functions.

The assistance of military organizations in their disaster response role is seen as a major contribution, especially if it is related to epidemics with considerable societal impact. Military organizations are accustomed to the execution of tasks under difficult conditions, have a wide variety of crisis management capabilities, are capable of deploying these capabilities in an timely, effective and efficient manner, and can cater for basic resources such as fuel, food and water, using their own logistic infrastructure.

An obvious follow-up question is the issue of timing. When do healthcare organizations that perform the initial international response in epidemic interventions call in the assistance of international military forces for support? The most logical answer is at that moment when it becomes clear that the healthcare organizations themselves will be unable to quickly bring the situation back under control. In practical terms, the most appropriate moment to intervene for the military is immediately when the existing intervention capabilities reach their limit and are at the verge of being overwhelmed by the number of cases. The moment when the number of diseased starts to exhaust the isolation capacity or other intervention capabilities is thus the most important indicator for the necessity of international military backup in epidemics. The premise, of course, is that military forces in question have their contingency plans ready and political backup for their deployment organized, so they can move in quickly and decisively. Models like the ones presented in the previous Chapters are crucial to grasping the resource planning and timing issues involved. Further elaboration of such models could well be seen as a responsibility, or at least a co-responsibility, for military organizations in the context of their international disaster response role.

6 CONCLUSIONS

During the 2014 EBOV epidemic, it became painfully clear that the international response was far worse than what it could and should have been, due to inadequate effectiveness and issues of timeliness. Only after a considerable delay were the intervention capabilities in West-Africa sufficiently scaled up, with aid from international organizations specialized in health care, supported by international military assistance. It is more likely the disease was controlled as a function of the natural evolution of the virus, in which it became less virulent after entering a new host, than due to the timing and adequacy of the international intervention.

In most epidemic situations, the sort of capabilities required for barring the spread of the disease are clear. However, the timing and desired scale of the response are more difficult to determine. In this paper, we illustrated how modeling can help to determine these variables. We concluded the following regarding the timing and scale of the response:

- Developing intervention capabilities for epidemics should be proactive, taking into account the doubling time of the disease and the development delay for the intervention capabilities.
- Deploying intervention capabilities should be done as early as possible in the exponential, first phase of the epidemic.
- Limiting social, political, and economic damage from epidemics is primarily achieved through direct disease control, although late intervention might require additional non-medical intervention measures as well.
- To scale possible international assistance, it is important that a quick but careful assessment is made of the domestic ability to deal with the specific disease at hand. In this assessment, it is important to combine both the risk itself (i.e., the epidemic) and the capabilities needed to control it (e.g., isolation capacity, health workers able to treat the patients, equipment for the health workers, and tracing capacity).

As a rule, international medical interventions require supporting non-medical measures, such as protective measures, coordination services and logistics. The environment in which such support must be delivered can be challenging. Typically, military organizations are trained and equipped to perform under difficult conditions and are therefore the designated party for delivering such support. Based on the 2014 Ebola outbreak, we draw the following general conclusions for the use of military capabilities during epidemics:

- The use of the military for quarantining parts of the epidemic area is not effective if geographical spread of an epidemic is too large. Especially in West Africa (as demonstrated by the Ebola case), closing off an area through roadblocks is often unfeasible.
- Military protection of health workers may impede the ability to build trust with the local population, which in turn decreases the efficiency of the intervention capabilities. It should be anticipated that health care workers may not desire this kind of help.
- Military support units must be prepared to move in very rapidly once it becomes clear that the existing intervention capacity will not be sufficient to bring the epidemic under control.
- Timing and scaling are essential. Military organizations, in their role as international disaster responders, have a shared responsibility for developing quantitative models that help in determining appropriate timing and scaling of international interventions in epidemic crises, including military support and political stability functions.

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APPENDIX: INTRODUCTION TO EPIDEMIOLOGY

Epidemics are caused by communicable diseases. In this appendix, we provide a description of the characteristics of communicable diseases, followed by an explanation of the circumstances under which these disease may lead to epidemics.

COMMUNICABLE DISEASES

Infectious diseases, or communicable diseases, are caused by "a specific infectious agent or its toxic products."[21] These infectious agents can be classified into microorganisms such as viruses, bacteria, and fungi, or parasites such as protozoa and helminths (i.e., worms).[22] Transmission of infectious diseases may happen directly or indirectly. In the case of direct transmission, there is an immediate transfer of the infectious agent to a human or an animal. With indirect transmission, an extra step exists between the infectious agent and a susceptible host.[23] Direct transmission may happen by physical contact, but also by droplet spread, exposure to susceptible tissue in soil, the bite of a rabid animal, or trans-placental transmission. Indirect transmission, on the other hand, may be via a vehicle, vector, or be airborne. A vehicle may be any inanimate material or object, water or food, or a biological product like blood and serum. A vector may be any non-vertebrate host or carrier transmitting a disease. Finally, indirect airborne transmission may happen if droplets are created by, for example, abattoirs or plants, or dust in the case of fungus spores. Influenza viruses and EBOV are examples of directly transmitted agents, while the plague is a vector disease and hence indirectly transmitted.

21 Miquel Porta, ed., *A Dictionary of Epidemiology*, 5th ed. (New York: Oxford University Press, 2008), https://www-oxfordreference-com.acces-distant.sciences-po.fr/view/10.1093/acref/9780195314496.001.0001/acref-9780195314496.

22 Charles A Jr. Janeway. et al., *Immunobiology: The Immune System in Health and Disease*, 5th ed. (New York: Garland Science, 2001), http://www.ncbi.nlm.nih.gov/books/NBK27114/.

23 Miquel Porta, *A Dictionary of Epidemiology*.

Knowing the agent of the epidemic disease and the mode of transmission is vital to the intervention capabilities needed to prevent or stop an epidemic. For example, viral epidemics like influenza can be prevented by vaccination, whereas the plague can be prevented by eradication of the rats that host the vectors (i.e., the fleas). Treatment may constitute of the administration of anti-viral medication for viruses, or antibiotics for bacteria. In the case of EBOV, during the outbreak no treatment existed to eliminate the symptoms of the disease, leaving isolation of patients as most important, next to safe burials of Ebola victims. Before we elaborate more on these interventions, we first explain what epidemics are and how they may evolve, and what societal impacts these dynamics may have.

DYNAMICS OF EPIDEMICS: TRANSMISSION OF THE DISEASE

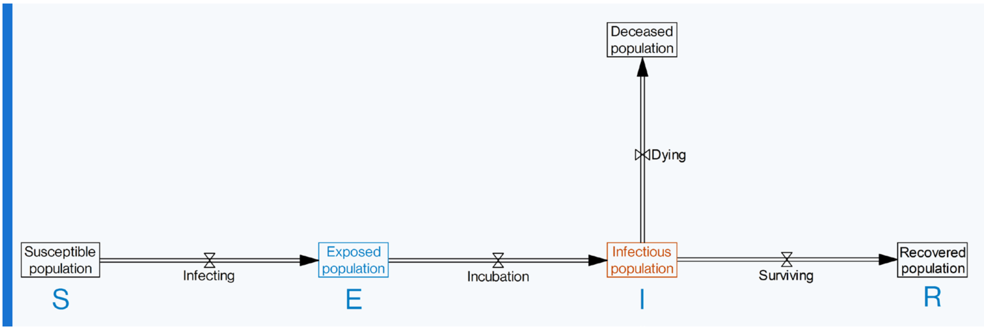

FIGURE 7. RELATIONS BETWEEN THE DIFFERENT SUBDIVISIONS OF A POPULATION DURING AN EPIDEMIC

Epidemics are the occurrence of illnesses "clearly in excess of normal quantities."[24] An epidemic may also be called an outbreak when it is localized in for example a village or an institution, or when no previous occurrence of the disease took place in the area of the epidemic. An epidemic may be called a pandemic in situations with extensive transmission in multiple countries and in multiple regions in the world.

In the case of an epidemic, the population can be subdivided in four major groups: the Susceptible, Exposed, Infectious, and the Recovered (or Deceased)

24 Ibid.

(Figure 7). Generally speaking, the infectious cause the susceptible to be exposed. After the incubation period, the exposed will become infectious.

The average number of exposed by each infectious is called the reproduction number of the epidemic. More precisely, the reproduction number is "the number of secondary cases that arise when one primary case is introduced into an uninfected population."[25] Simply put, the epidemic grows when it is larger than 1, and declines in size when it is smaller than 1. In endemic situations, the reproduction number is around 1, resulting in a relatively constant number of diseased within the population. The goal of epidemic interventions is, therefore, always to get the reproduction number below 1 as soon as possible.

Another characteristic that affects the dynamics of an epidemic disease is the Case Fatality Rate (CFR). This is the relative number of diseased that dies. In the first 9 months of the EBOV epidemic in West-Africa, the CFR was around 70%.[26] This meant that 70% of the diseased died.

DYNAMICS OF EPIDEMICS: DEVELOPMENT OF STAGES

In most epidemics, roughly four different stages can be observed (Figure 8). In the initial stage, the exposed population grows exponentially. That is, there is a more a less constant 'doubling time' in which the cumulative number of infectious doubles.

This phase is followed by a period in which the spread of the disease declines and the number of cases per day. This may be due to several reasons. First, the susceptible population becomes relatively small compared to the rest of the population. Generally, this is caused by increased immunity, either by vaccination or by disease survivors becoming immune. Second, when interventions to halt the spread of the disease start to become effective, the reproduction number start declining. Third, if the population changes behavior limiting the transmission, the same may happen. In the case of Ebola, this may be due to more careful treatment of diseased, or limiting the number of traditional burials where, due to ceremonial burial practices, people may become infected.

25 WHO Ebola Response Team, "Ebola Virus Disease in West Africa — The First 9 Months of the Epidemic and Forward Projections."

26 Ibid.

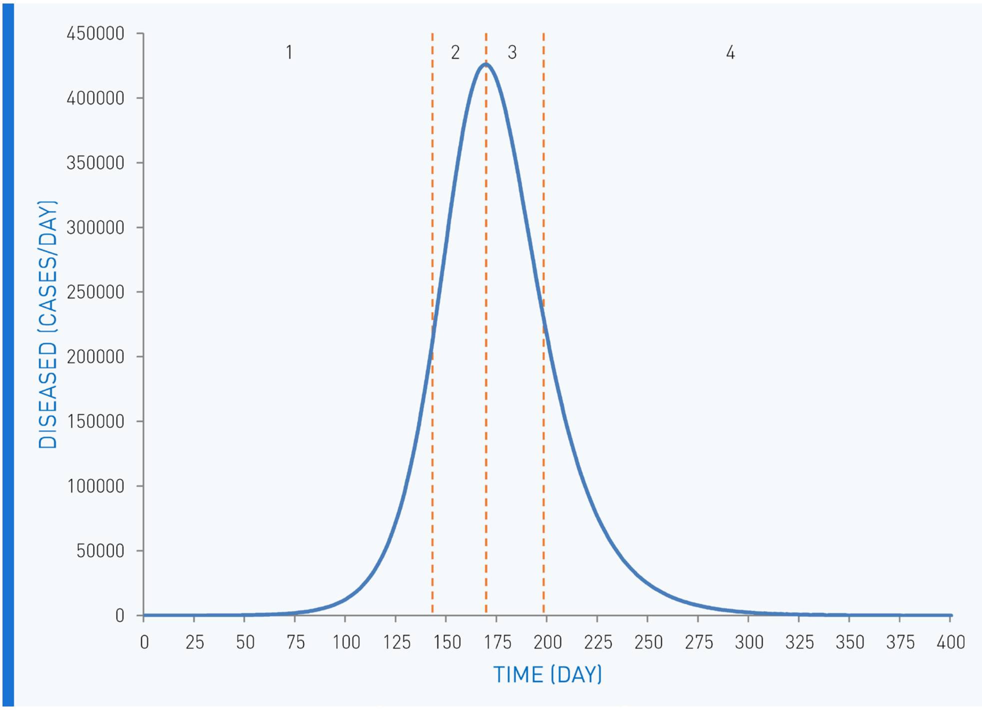

FIGURE 8. THE DIFFERENT PHASES OF AN EPIDEMIC[27]

As soon as the reproduction number becomes below 1, the third phase starts. From that moment on, the number of new cases per day starts to decline. This phase is followed by the fourth phase, in which the decline slows down, but the number of new cases will be very small. This phase may take most time, however. An example of a very long fourth phase can be found in the fourth – sometimes also referred to as the third – plague pandemic, which started in 1855 and is, considering to some, still active.[28] Most large outbreaks in this pandemic took place between 1882 and 1912, but a recent small outbreak in Madagascar in November 2014[29] illustrates the very long tail of this pandemic.

27 The numbers 1, 2, 3, and 4 indicate the different phases. The red dashed lines indicate the transition moments between the phases

28 Iqbar Akhtar Kahn, "Plague: The Dreadful Visitation Occupying the Human Mind for Centuries," *Transactions of the Royal Society on Tropical Medicine and Hygiene* 98, no. 5 (2004): 270–77, doi:10.1016/S0035-9203(03)00059-2.

29 "WHO | Plague – Madagascar," *WHO*, accessed January 9, 2015, http://www.who.int/csr/don/21-november-2014-plague/en/.

In order to be able to identify important indicators of an epidemic, like the reproduction number, incubation time, or the case fatality rate, so-called transmission models are frequently used.[30] These models often follow the SEIR structure visible in Figure 7. These quantitative, mathematical models are fit to data from health workers and institutions monitoring the epidemic, like local health ministries, the CDC, and the WHO, to find the appropriate values of the aforementioned variables. These values inform decision makers regarding the scale and timeliness of the intervention needed. Even in situations with much data available, the capricious nature of local circumstances make that quantitative models often overestimate the future numbers of cases, which became painfully clear in the 2014 West-Africa Ebola epidemic.[31] However, the non-linearity of the epidemic dynamics makes relying on qualitative assessment or mental simulation of the speed of transmission undesirable.

30 E.g., Chowell et al., "The Basic Reproductive Number of Ebola and the Effects of Public Health Measures"; Chowell and Nishiura, "Transmission Dynamics and Control of Ebola Virus Disease (EVD)"; WHO Ebola Response Team, "Ebola Virus Disease in West Africa — The First 9 Months of the Epidemic and Forward Projections."

31 Butler, "Models Overestimate Ebola Cases."

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