PANDEMIC IMPACTS TO LIFELINE CRITICAL INFRASTRUCTURE

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SCOPE

The Department of Homeland Security's Office of Cyber and Infrastructure Analysis (DHS/OCIA) produces Critical Infrastructure Security and Resilience Notes in response to changes in the infrastructure protection community's risk environment from terrorist attacks, natural hazards, and other events. This note examines the impact of a pandemic on lifeline critical infrastructure at the local, regional and national level, including the effects of absenteeism on these sectors.[1] This note also reviews the potential economic impacts resulting from a pandemic and procedures for mitigating the impact of a pandemic. This note supports DHS leadership, the DHS Protective Security Advisors, and other Federal, State, and local agencies.

This product was developed in coordination with the DHS Office of Health Affairs, the DHS National Protection and Programs Directorate's Office of Infrastructure Protection, the Department of Health and Human Services (HHS), and the Department of Energy (DOE).

KEY FINDINGS

- **OCIA assesses that the sectors most likely to be affected by a pandemic are: Healthcare and Public Health, Emergency Services, Transportation Systems, Water and Wastewater Systems, and Energy (Electrical Power) Sectors. All other critical infrastructure sectors will be impacted to some degree by the availability of personnel needed to maintain operations.**
- **OCIA assesses that the economic impact of a pandemic will depend upon the severity and duration of the pandemic and mitigation efforts taken by the Federal, State and local governments and the public. Estimates for loss in Gross Domestic Product (GDP) during the first-year of a pandemic range from less than 1 percent in a mild pandemic to up to 4.25 percent during a severe pandemic. Once the pandemic has passed, the longer-term economic losses will be due primarily to the number of deaths caused by the disease.**
- **While a strain-specific vaccine for a pandemic is the most effective mitigation measure available, this will not likely be available until four to six months after the specific strain of a disease has been identified. Second to vaccine development, the most effective and economical mitigation strategy is a rapidly deployed and multilayered approach combining various intervention strategies such as social distancing, school closures, and treatment with antivirals.**

[1] According to the 2013 National Infrastructure Protection Plan, lifeline functions include communications, energy, transportation, and water. For the purposes of this paper, healthcare and emergency services will also be considered lifeline functions because of the health-related effects of a pandemic. Department of Homeland Security, "NIPP 2013: Partnering for Critical Infrastructure Security and Resilience," 2013, p. 17, www.dhs.gov/sites/default/files/publications/National-Infrastructure-Protection-Plan-2013-508.pdf, accessed April 30, 2015.

OVERVIEW

A pandemic is an epidemic occurring globally or over a very wide area that crosses international boundaries and usually affects a very large number of people.[2,3] There is debate over specific pandemic thresholds, however most recognized pandemics have common traits, notably that the disease is infectious and has spread quickly through a large geographic area.[4,5]

The effects of a pandemic on a population and critical infrastructure can vary based on the transmissibility and severity of the disease, with higher rates of sickness (morbidity) and mortality having a greater impact. Pandemics such as influenza and plague vary widely in their characteristics, creating challenges to pandemic planning and mitigation strategies. Even within a disease category, such as influenza, the scenarios can vary dramatically based upon the virulence of the strain.[6] Figure 1 illustrates some of the differences in the severity and transmissibility of previous influenza pandemics and "non-pandemic" influenza seasons.[7] For example, the 1918, 1977-1978, and 2009 influenza pandemics were H1N1 strains of the flu virus, yet these strains varied widely in transmissibility and severity. The 1918 pandemic was far more severe, resulting in 30 and 50 million deaths globally, while the global death toll from the 2009 pandemic has been estimated between 151,700 and 575,400 people.[8,9]

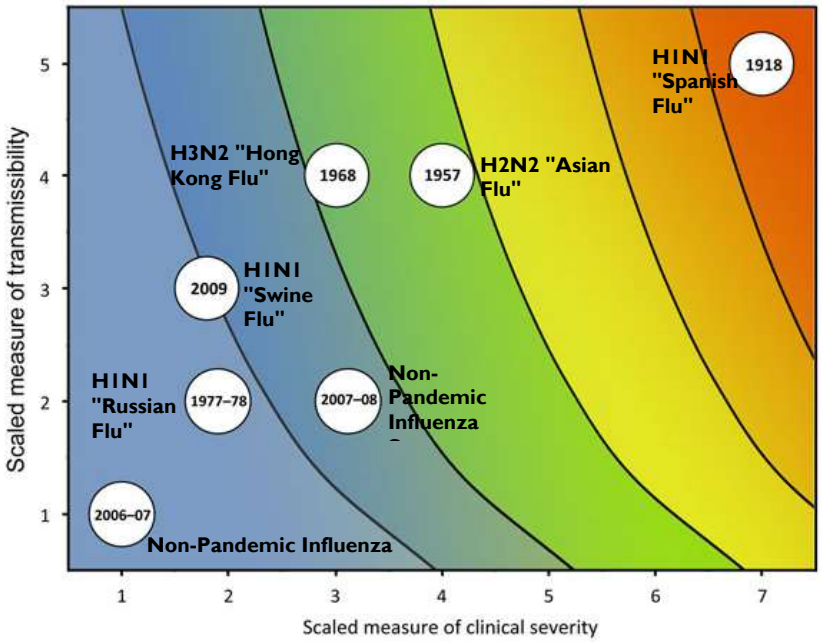

FIGURE 1—ASSESSMENT OF TRANSMISSIBILITY AND SEVERITY OF PAST INFLUENZA PANDEMICS AND INFLUENZA SEASONS[10]

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[2] Porta, Miquel, "A Dictionary of Epidemiology," Oxford University Press, Sixth Edition (2014), www.irea.ir/files/site1/pages/dictionary.pdf, accessed June 22, 2015.
[3] Kelly, Heath, "The classical definition of a pandemic is not elusive," Bulletin of the World Health Organization (March 2011), www.ncbi.nlm.nih.gov/pmc/articles/PMC3127276/#R2, accessed March 2, 2015.
[4] Morens, David M., Gregory K. Folkers and Anthony S. Fauci, "What is a Pandemic?," The Journal of Infectious Diseases (October 2009), pp. 1018-1021, www.jid.oxfordjournals.org/content/200/7/1018.full.pdf, accessed March 2, 2015.
[5] Doshi, Peter, "The Elusive Definition of Pandemic Influenza," Bulletin of the World Health Organization (March 2011), www.who.int/bulletin/volumes/89/7/11-086173/en/, accessed March 2, 2015.
[6] HHS, "HHS Pandemic Influenza Plan," November 2005, p. 18, www.flu.gov/planning-preparedness/federal/hhspandemicinfluenzaplan.pdf, accessed March 2, 2015.
[7] "Non-pandemic" influenza seasons, as shown in Figure 1, are seasonal influenza outbreaks, which occur annually and usually peak in January or February. For more information, see: HHS, "About Pandemics," www.flu.gov/pandemic/about/, accessed July 23, 2015.
[8] Centers for Disease Control and Prevention, "First Global Estimates of 2009 H1N1 Pandemic Mortality Released by CDC-Led Coalition," June 25, 2012, www.cdc.gov/flu/spotlights/pandemic-global-estimates.htm, accessed March 3, 2015.
[9] HHS, "The Great Pandemic: The United States in 1918-1919," 2012, www.flu.gov/pandemic/history/1918/the_pandemic/legacypendemic/index.html, accessed April 9, 2015.
[10] Reed, Carrie et al., "Novel Framework for Assessing Epidemiologic Effects of Influenza Epidemics and Pandemics," Emerging Infectious Diseases Volume 19, Number 1 (January 2013), wwwnc.cdc.gov/eid/article/19/1/12-0124-f3, accessed March 2, 2015.

The impact to critical infrastructure arises not from the disease itself, but from the effect the pandemic has on personnel required to maintain and operate critical infrastructure and to sustain global supply chains, including medical supplies and food. The impact can vary based not only on the virus' characteristics, but on the demographic details of critical infrastructure personnel, behavior of personnel once a pandemic occurs, and the ability of the public health and healthcare system to provide adequate care to the sick.[11]

KEY ASSUMPTIONS

OCIA assumes that a worst-case scenario pandemic will be similar to the "Spanish Flu" pandemic of 1918, the worst pandemic of the 20th century, resulting in approximately 675,000 American deaths and 30-50 million deaths worldwide.[12] A severe influenza pandemic, like the one in 1918, shares similar characteristics with what could be a worst-case scenario pandemic, including a severe level of both transmissibility and severity.[13,14] In addition, such a pandemic may affect a community for weeks, with the potential for the disease to occur in "waves." Table 1 illustrates the projected numbers of illness, hospitalizations, and ventilation demand associated with different pandemic influenza scenarios.

TABLE 1— PROJECTED NUMBERS OF ILLNESS, HOSPITALIZATIONS, AND VENTILATION DEMAND ASSOCIATED WITH PANDEMIC INFLUENZA SCENARIOS[15,16]

Characteristic	2009-like (mild)	1968-like (moderate)	1957-like (moderate)	1918-like (severe)
2010 US Population	309 million	309 million	309 million	309 million
Clinically Ill	61,935,529	92,903,294	96,000,070	92,903,924
Hospitalizations	279,427	929,033	1,920,001	6,503,231
ICU Care	25,404	148,645	460,800	2,341,163
Mechanical Ventilation	15,242	89,187	276,480	1,404,698
Maximum Ventilation Demand	1,976	11,562	35,843	182,106

The level of absenteeism—those who miss work due to being ill, taking care of someone who is ill or a child dismissed from school, or attempting to avoid illness—created by such a pandemic is highly susceptible to several factors, including the severity of the pandemic and perceived media and government reactions to a pandemic. The 2006 National Strategy for Pandemic Influenza Implementation Plan recommends that government entities and private sector partners make plans with the assumption that up to 40 percent of staff will be absent for up to two weeks.[17,18,19] Since any disease is highly unlikely to impact the entire United States at a given time, the actual absenteeism rate will be more representative of potential regional impacts.

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[11] National Infrastructure Simulation & Analysis Center, "National Population, Infrastructure, and Economic Impacts of Pandemic Influenza with Strategic Recommendations," Department of Homeland Security, Office of Infrastructure Protection, October 2007, p. 87, www.sandia.gov/nisac/wp/wp-content/uploads/Pandemic-Influenza_2007.pdf, accessed April 9, 2015.

[12] HHS, "The Great Pandemic: The United States in 1918-1919," 2012, www.flu.gov/pandemic/history/1918/index.html, accessed April 9, 2015.

[13] For the purposes of this paper, a "severe" pandemic will be one similar to the 1918 pandemic, a "moderate" pandemic similar to the 1958 and 1968 pandemics, and a "mild" pandemic similar to the 2009 and 1977-1978 pandemics. See figure 1 and Table 1 for differences between the individual pandemics.

[14] The judgment of a severe level of transmissibility and severity is based upon comparison to other 20th and 21st century pandemic influenza seasons (see Table 1). Judgment of a severe level of transmissibility and severity also based upon assessment framework used in: Reed, Carrie et al., "Novel Framework for Assessing Epidemiologic Effects of Influenza Epidemics and Pandemics," Emerging Infectious Diseases Volume 19, Number 1 (January 2013), wwwnc.cdc.gov/eid/article/19/1/12-0124_article, accessed March 2, 2015 (see Figure 1).

[15] Data provided to OCIA by HHS. HHS calculated totals with the help of the following sources: Shrestha SS et al., "Estimating the burden of 2009 pandemic influenza A (H1N1) in the United States (April 2009-April 2010)," Clinical Infectious Diseases, Volume 52, Supplement 1 (2011), p. S75-S82, http://www.ncbi.nlm.nih.gov/pubmed/21342903, accessed May 15, 2015. Meltzer, Martin et al., "The Economic Impact of Pandemic Influenza in the United States: Priorities for Intervention," Emerging Infectious Diseases, Vol. 5 No. 5 (September-October 1999), pp. 659-671, www.who.int/influenza_vaccines_plan/resources/ARTICLE_Economic_Impact_of_Pandemic_Influenza_in_the_US.pdf, accessed March 4, 2015. Reed, Carrie et al., "Novel Framework for Assessing Epidemiologic Effects of Influenza Epidemics and Pandemics," Emerging Infectious Diseases, Volume 19, Number 1 (January 2013), wwwnc.cdc.gov/eid/article/19/1/12-0124_article, accessed March 2, 2015.

[16] Peak ventilation demand is the number of patients that require ventilation at the peak of the pandemic. Mechanical ventilators are a re-usable resource, thus the maximum number of ventilators needed is when the peak of the pandemic occurs. Data provided by HHS is based on CDC models, assuming that peak demand is equal to approximately 13 percent of all patients that will need mechanical ventilation during the pandemic.

[17] Homeland Security Council, "Implementation Plan for the National Strategy for Pandemic Influenza," May 2006, p. 13, www.flu.gov/planning-preparedness/federal/pandemic-influenza-implementation.pdf, accessed March 18, 2015.

IMPACTS TO CRITICAL INFRASTRUCTURE

OCIA assesses that the sectors most likely to be affected by a pandemic are: Healthcare and Public Health, Emergency Services, Transportation Systems, Water and Wastewater Systems, and Energy (Electrical Power) Sectors. All other critical infrastructure sectors will be impacted to some degree by the availability of personnel needed to maintain operations.

HEALTHCARE AND PUBLIC HEALTH

The Healthcare and Public Health and Emergency Services Sectors will likely experience the greatest and most immediate impact and face the significant prospect of being overwhelmed due to a simultaneous increase in demand for services and staff absenteeism.

- Data provided by HHS found that during a severe influenza pandemic, up to 6.5 million people may need to be hospitalized in the United States over the course of the pandemic, with up to 2.3 million needing intensive care unit (ICU) treatment.[20] Without government intervention, a severe influenza pandemic could overwhelm the Healthcare and Public Health Sector in as little as 3-6 weeks.[21] Healthcare facilities in metropolitan areas are at greater risk of being overwhelmed due to population size and density.
- The National Infrastructure Advisory Council surveyed critical infrastructure sectors and found that 51.8 percent of Healthcare and Public Health Sector workers were deemed "Tier 1" critical workers that were essential to maintaining operations during a pandemic, including 100 percent of doctors, surgeons, dentists and nurses.[22] Due to direct contact with infected patients, these critical personnel are at an increased risk of becoming ill, resulting in a greater strain upon the Sector. Surge capacity—the ability to bring additional healthcare personnel into an area to assist with the increase in the number of patients—and mutual aid agreements may be limited due to the geographical expanse of a pandemic.
- In addition to personnel shortages, the Healthcare and Public Health Sector will have to prioritize limited resources to treat pandemic victims in addition to their usual patient load. The New York City Department of Health and Mental Hygiene suggested that during an influenza pandemic, 67 percent of ICU beds would be filled by flu patients, but these beds are usually occupied by other patients needing medical care.[23] The Sector may also experience significant shortages in vaccines, antivirals, pharmaceuticals needed to treat secondary infections and complications, personal protective equipment (PPE), and medical

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[18] National Infrastructure Simulation & Analysis Center, "National Population, Infrastructure, and Economic Impacts of Pandemic Influenza with Strategic Recommendations," Department of Homeland Security, Office of Infrastructure Protection, October 2007, p. 87, www.sandia.gov/nisac/wp/wp-content/uploads/Pandemic-Influenza_2007.pdf, accessed April 9, 2015.

[19] National Infrastructure Advisory Council, "The Prioritization of Critical Infrastructure for a Pandemic Outbreak in the United States Working Group," DHS, January 16, 2007, p. 18, www.dhs.gov/xlibrary/assets/niac/niac-pandemic-wg_v8-011707.pdf, accessed March 4, 2015.

[20] Data provided to OCIA by HHS. HHS calculated totals with the help of the following sources: Shrestha SS et al., "Estimating the burden of 2009 pandemic influenza A (H1N1) in the United States (April 2009-April 2010)," Clinical Infectious Diseases, Volume 52, Supplement 1 (2011), p. S75-S82, http://www.ncbi.nlm.nih.gov/pubmed/21342903, accessed May 15, 2015. Meltzer, Martin et al., "The Economic Impact of Pandemic Influenza in the United States: Priorities for Intervention," Emerging Infectious Diseases, Vol. 5 No. 5 (September-October 1999), pp. 659-671, www.who.int/influenza_vaccines_plan/resources/ARTICLE_Economic_Impact_of_Pandemic_Influenza_in_the_US.pdf, accessed March 4, 2015. Reed, Carrie et al., "Novel Framework for Assessing Epidemiologic Effects of Influenza Epidemics and Pandemics," Emerging Infectious Diseases, Volume 19, Number 1 (January 2013), wwwnc.cdc.gov/eid/article/19/1/12-0124_article, accessed March 2, 2015.

[21] National Infrastructure Simulation & Analysis Center, "National Population, Infrastructure, and Economic Impacts of Pandemic Influenza with Strategic Recommendations," Department of Homeland Security, Office of Infrastructure Protection, October 2007, p. 4, www.sandia.gov/nisac/wp/wp-content/uploads/Pandemic-Influenza_2007.pdf, accessed April 9, 2015.

[22] In the NIAC Survey, critical infrastructure sectors divided their critical workforce into Tiers 1, 2, and 3, with Tier 1 being the most critical to maintaining operations. Each critical infrastructure sector provided its own rationale as to who is a critical worker and the reasoning behind their tiering strategy. National Infrastructure Advisory Council, "The Prioritization of Critical Infrastructure for a Pandemic Outbreak in the United States Working Group," DHS, January 16, 2007, p. 29, 94, www.dhs.gov/xlibrary/assets/niac/niac-pandemic-wg_v8-011707.pdf, accessed March 4, 2015.

[23] Peter J. Levin, Eric N. Gebbie and Kristine Qureshi, "Can the Health-Care System Meet the Challenge of Pandemic Flu? Planning, Ethical, and Workforce Considerations," Public Health Reports, Volume 122, Issue 5 (Sep-Oct 2007), pp. 573–578, www.ncbi.nlm.nih.gov/pmc/articles/PMC1936949/pdf/phr122000573.pdf, accessed March 3, 2015.

equipment, including ventilators.[24] For example, the 2009 H1N1 pandemic saw shortages in vaccines, PPE, and antivirals as demand outpaced supplies.[25,26]

EMERGENCY SERVICES

The risk to Emergency Services Sector personnel is increased during a pandemic, with the potential for regions to be overwhelmed due to increased demand and absentee personnel.

- Much like the Healthcare and Public Health Sector, the workers in the Emergency Services Sector, and especially those in the Emergency Medical Services Subsector, are at an increased risk due to the likelihood of contact with infected people.
- Absenteeism also presents a significant risk to the operations of the Sector during a pandemic. The 2007 National Infrastructure Advisory Council survey on critical infrastructure stated that the Emergency Services Sector considered over 87 percent of workers "Tier 1" critical, and it is likely that many emergency services agencies have a rate of Tier 1 workers above 87 percent.[27] With such a high percentage of workers deemed critical, even a small number of absent workers can have an impact on the Emergency Services Sector and the sectors that rely on them, especially the Healthcare and Public Health Sector.[28] A review of previous surveys by the Pacific Northwest National Laboratory (PNNL) found that up to 40-50 percent of healthcare workers and emergency responders may not report to work during a pandemic.[29] PNNL did not find consistent historical precedent for this level of absenteeism, however, and officials in the Emergency Services and Healthcare and Public Health Sectors interviewed by PNNL were split between those expecting high levels and those expecting much lower levels of absenteeism.[30]
- Supply chain disruptions could also significantly hamper the effectiveness of the Sector's workforce during a pandemic. Emergency Services agencies are dependent on "just-in-time" delivery of healthcare supplies and are often not large consumers of those products. The Emergency Services Sector is dependent upon suppliers to maintain an adequate stockpile of equipment and supplies needed during a pandemic event (i.e. fuel, oxygen, basic medical supplies). When a spike in demand occurs, Emergency Services Sector entities are often less able to obtain high demand products than customers with more established vendor relationships.[31,32]

TRANSPORTATION SYSTEMS

OCIA assesses that a significant risk to the Transportation Systems Sector during a pandemic is in the movement of freight by rail. The loss of critical employees to illness or absenteeism could create significant delays moving cargo in and out of rail yards. In addition, there is the possibility for congestion at ports and delays in the delivery of goods by truck. Congestion caused by a disruption in the movement of freight by rail, truck, or ships could have significant cascading impacts on other critical infrastructure sectors.

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[24] Peter J. Levin, Eric N. Gebbie and Kristine Qureshi, "Can the Health-Care System Meet the Challenge of Pandemic Flu? Planning, Ethical, and Workforce Considerations," Public Health Reports, Volume 122, Issue 5 (Sep-Oct 2007), pp. 573–578, www.ncbi.nlm.nih.gov/pmc/articles/PMC1936949/pdf/phr122000573.pdf, accessed March 3, 2015.
[25] Center for Infectious Disease Research and Policy, "CDC Says Vaccine Shortage Likely to Outlast Current H1N1 Wave," November 4, 2009, www.cidrap.umn.edu/news-perspective/2009/11/cdc-says-vaccine-shortage-likely-outlast-current-h1n1-wave, accessed February 25, 2015.
[26] National Public Radio, "Will Tamiflu Shortage Drive U.S. to India's Version?" November 10, 2009, www.npr.org/templates/story/story.php?storyId=120254536, accessed February 25, 2015.
[27] National Infrastructure Advisory Council, "The Prioritization of Critical Infrastructure for a Pandemic Outbreak in the United States Working Group," DHS, January 16, 2007, p. 76-77, www.dhs.gov/xlibrary/assets/niac/niac-pandemic-wg_v8-011707.pdf, accessed June 22, 2015.
[28] National Infrastructure Simulation & Analysis Center, "National Population, Infrastructure, and Economic Impacts of Pandemic Influenza with Strategic Recommendations," Department of Homeland Security, Office of Infrastructure Protection, October 2007, p. 47, www.sandia.gov/nisac/wp/wp-content/uploads/Pandemic-Influenza_2007.pdf, accessed April 9, 2015.
[29] Lesperance, AM, and JS Miller, "Preventing Absenteeism and Promoting Resilience Among Health Care Workers in Biological Emergencies," Pacific Northwest National Laboratory, p. 2.1, August www.pnl.gov/main/publications/external/technical_reports/PNNL-18405.pdf, accessed on 22 June, 2015.
[30] Lesperance, AM, and JS Miller, "Preventing Absenteeism and Promoting Resilience Among Health Care Workers in Biological Emergencies," Pacific Northwest National Laboratory, p. 2.5, August www.pnl.gov/main/publications/external/technical_reports/PNNL-18405.pdf, accessed on 22 June, 2015.
[31] National Infrastructure Advisory Council, "The Prioritization of Critical Infrastructure for a Pandemic Outbreak in the United States Working Group," DHS, January 16, 2007, p. 74, www.dhs.gov/xlibrary/assets/niac/niac-pandemic-wg_v8-011707.pdf, accessed March 4, 2015.
[32] Information obtained from HHS feedback.

- In analyzing the potential impacts to the Transportation Systems Sector, NISAC found that a pandemic could cause critical problems at most major rail yards in the United States. NISAC found that even at a mid-level peak absenteeism rate of 14 percent, incoming rail traffic could exceed outgoing rail traffic at some of the largest rail yards in the United States.[33] The resulting delays at rail yards could continue to worsen until normal operations resume, with the backlog taking additional time to clear.
- Truck drivers, due to their consistent contact with persons at warehouses, ports, rest stops, and other locations, face a significant risk of becoming ill. The trucking industry is highly decentralized, with over one million companies, over 97 percent of which have fewer than 20 trucks.[34] The locations and organizations that could face delays due to a shortage of drivers are highly dependent upon which companies are affected and what they carry. Smaller companies may be forced to halt operations entirely, while others may experience limited or no operational hurdles due to the pandemic.
- While there is the possibility for a pandemic to negatively impact ports, there is not enough information at this time to support modeling of the probability and depth of impact. Numerous factors could affect the impact at individual ports during a pandemic, including the effects on different segments of port personnel, changes in international and domestic shipping demand and supply, the delivery of essential services and supplies to ports, and the ability of supplies and cargo to be shipped to and from other locations.
- NISAC analysis found that the demand for passenger transportation services would decline at a rate similar to or greater than the absenteeism rate amongst employees. Companies that provide passenger services will most likely see a drop in revenue, though these short-term negative effects to companies may be partially mitigated by a reduction in service during the pandemic.[35]

A number of critical infrastructure sectors, including the Energy, Chemical, and Food and Agriculture Sectors, are heavily reliant upon the Rail Subsector for the movement of goods and commodities. In 2014, Class I Railroads moved over 1.8 billion tons of freight. Coal, chemicals, non-metallic minerals, farm products, food, and kindred products accounted for over 70 percent of tonnage carried by Class I Railroads.[36] Any loss in rail capacity could result in cascading impacts on critical infrastructure sectors, leading to lengthy delays in the delivery of goods and potential increases in cost due to the need to use other transportation modes.

Trucks moved 9.2 billion tons of freight in 2011, 67 percent of total domestic tonnage shipped.[37] Nearly every industry is reliant upon trucks to carry cargo at some point in the shipping chain. In addition, many firms, including those in the Healthcare and Public Health and Emergency Services Sectors, have decreased inventories and have become increasing reliant on "just-in-time" deliveries. Any delays caused in these two sectors due to a shortage of drivers could impact their ability to care for the sick. Other sectors, including but not limited to the Chemical, Food and Agriculture, and Commercial Facilities Sectors, could experience economic losses due to the lost production resulting from shipping delays.

WATER AND WASTEWATER SYSTEMS

The greatest risk to the Water and Wastewater Systems Sector comes from the loss of available operators and support staff due to illness or absenteeism. The effect of the pandemic on water and wastewater systems will primarily be felt on the local level depending on the number of critical personnel in each locality who are ill or absent.

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[33] National Infrastructure Simulation & Analysis Center, "National Population, Infrastructure, and Economic Impacts of Pandemic Influenza with Strategic Recommendations," Department of Homeland Security, Office of Infrastructure Protection, October 2007, p. 49, www.sandia.gov/nisac/wp/wp-content/uploads/Pandemic-Influenza_2007.pdf, accessed April 9, 2015.
[34] American Trucking Associations, "Reports, Trends, and Statistics," http://www.trucking.org/News_and_Information_Reports_Industry_Data.aspx, accessed May 20, 2015.
[35] National Infrastructure Simulation & Analysis Center, "National Population, Infrastructure, and Economic Impacts of Pandemic Influenza with Strategic Recommendations," Department of Homeland Security, Office of Infrastructure Protection, October 2007, p. 47, www.sandia.gov/nisac/wp/wp-content/uploads/Pandemic-Influenza_2007.pdf, accessed April 9, 2015.
[36] Association of American Railroads, "Class I Railroad Statistics," May 16, 2015, www.aar.org/Documents/Railroad-Statistics.pdf, accessed June 24, 2015.
[37] American Trucking Associations, "Reports, Trends, and Statistics," http://www.trucking.org/News_and_Information_Reports_Industry_Data.aspx, accessed May 20, 2015.

- Highly specialized personnel, such as plant operators, may be difficult to replace and their absence could result in disruptions of water and wastewater systems during the pandemic. The effect of the pandemic will vary locally, depending on the number of critical personnel in each locality who are ill or absent. Smaller water systems, which generally have smaller staffs and a smaller number of external personnel that could be called up in an emergency, are at greater risk than larger systems.[38]
- Demand for water could be reduced due to the closure of commercial or industrial facilities, which in turn could increase the amount of time water remains in the system. NISAC found that the risk resulting from demand changes in the Water and Wastewater Systems Sector will be minimal.[39]
- A 2006 survey by the Association of Metropolitan Water and the Water Information Sharing and Analysis Center found that the Sector deemed roughly 41 percent of Sector workers critical to maintaining water and wastewater systems.[40]

ENERGY (ELECTRIC POWER)

A pandemic alone is unlikely to cause disruptions to the electric grid, but the greatest risk to the electric power subsector is a significant incident occurring at the same time as a pandemic, which can potentially result in longer-lasting power outages that could have cascading effects on other critical infrastructure in the area.

- NISAC analysis found that even in its most severe pandemic scenario, disruptions to the power grid were unlikely. Negative effects on the electric grid were only predicted when absenteeism levels were so extreme that the loss of a single operator caused a power plant to be idled.[41] The electric grid is also designed to meet N-1 reliability standards, so the loss of a generation plant or transmission line at any given time will not result in cascading outages.[42]
- The greatest risk to the electric power subsector is a significant incident, such as a severe storm, occurring at the same time as a pandemic, which can potentially result in longer-lasting power outages that could have cascading effects on other critical infrastructure in the area. Electric utilities often rely on mutual aid agreements in order to provide surge capacity following a storm or other incident that causes large numbers of outages.[43] This mutual assistance may not be available due to personnel being unavailable during a pandemic, leading to longer outages that can in turn have a significant effect on other regionally-based critical infrastructure.
- In extreme circumstances, the electricity subsector could face a significant risk if a pandemic disrupts supply of fuel for power generation plants for an extended period of time.[44] In 2014, coal provided 39 percent of electric power generation in the United States, and approximately two-thirds of coal was shipped entirely or in part by rail.[45,46] Coal-fired plants maintain stockpiles in reserve, which vary in size.[47]

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[38] Mary Van Beusekom, "Will the Water Still Run During a Pandemic?" Center for Infectious Disease Research and Policy, University of Minnesota, Dec. 20 2006, www.cidrap.umn.edu/news-perspective/2006/12/will-water-still-run-during-pandemic, accessed March 4, 2015.
[39] National Infrastructure Simulation & Analysis Center, "National Population, Infrastructure, and Economic Impacts of Pandemic Influenza with Strategic Recommendations," Department of Homeland Security, Office of Infrastructure Protection, October 2007, p. 38, www.sandia.gov/nisac/wp/wp-content/uploads/Pandemic-Influenza_2007.pdf, accessed April 9, 2015.
[40] National Infrastructure Advisory Council, "The Prioritization of Critical Infrastructure for a Pandemic Outbreak in the United States Working Group," DHS, January 16, 2007, p. 119, www.dhs.gov/xlibrary/assets/niac/niac-pandemic-wg_v8-011707.pdf, accessed June 22, 2015.
[41] National Infrastructure Simulation & Analysis Center, "National Population, Infrastructure, and Economic Impacts of Pandemic Influenza with Strategic Recommendations," Department of Homeland Security, Office of Infrastructure Protection, October 2007, p. 33, www.sandia.gov/nisac/wp/wp-content/uploads/Pandemic-Influenza_2007.pdf, accessed April 9, 2015.
[42] The N-1 reliability standard means that the electric grid can withstand the loss of any single component at a given time and still function normally. Alvarado, F., and S. Oren, "Transmission System Operation and Interconnection," https://certs.lbl.gov/sites/all/files/transmission-system-operation-and-interconnection.pdf, accessed March 3, 2015.
[43] Edison Electric Institute, "Understanding the Electric Power Industry's Response and Restoration Process," Washington, DC (May 2014), www.eei.org/issuesandpolicy/electricreliability/mutualassistance/Documents/MA_101FINAL.pdf, accessed March 4, 2015.
[44] Nicholas Kelly, Michael Osterholm, "Pandemic Influenza, Electricity, and the Coal Supply Chain," Center for Infectious Disease Research and Policy, University of Minnesota (November 2008), www.cidrap.umn.edu/sites/default/files/public/downloads/cidrap_coal_report.pdf, accessed March 25, 2015.
[45] Energy Information Administration, "Frequently Asked Questions: What is U.S. electricity generation by energy source?," last updated March 31, 2015, www.eia.gov/tools/faqs/faq.cfm?id=427&t=3, accessed June 23, 2015.
[46] Energy Information Administration, "Railroad deliveries continue to provide the majority of coal shipments to the power sector," June 11, 2014, www.eia.gov/todayinenergy/detail.cfm?id=16651, accessed June 23, 2015.
[47] Energy Information Administration, "Coal stockpiles at coal-fired power plants smaller than in recent years," November 6, 2014, www.eia.gov/todayinenergy/detail.cfm?id=18711, accessed March 3, 2015.

ECONOMIC IMPACT

OCIA assesses that the economic impact of a pandemic will depend greatly upon the severity of the pandemic and mitigation efforts taken by the Federal, State and local governments and the public. Estimates for loss in GDP during the first year of a pandemic range from less than 1 percent in a mild pandemic to up to 4.25 percent during a severe pandemic.[48,49,50] Once the pandemic has passed, the longer-term economic losses will be due primarily to the number of deaths caused by the disease.

- The Congressional Budget Office (CBO) found in 2005, and revised in 2006, that a mild pandemic would result in an approximately one percent drop in GDP and a severe pandemic resulting in a 4.25 percent drop in GDP.[51] A 2006 study by the Lowy Institute for International Policy, the Australian National University, and the Brookings Institution suggested roughly similar economic impacts, with a 0.6 percent drop in GDP during a mild pandemic and a 3.0 percent drop in GDP during a severe pandemic.[52] Using United States GDP following the fourth quarter of 2014, the percentages produced by the CBO and the Lowy Institute and Brookings Institution studies would suggest a loss of between $531.04 billion and $752.31 billion during a severe pandemic.[53]
- The estimated economic loss to the Healthcare and Public Health Sector from a pandemic would be limited when compared to the size of the Sector. A 2007 study found that U.S. hospitals would incur a net loss of $3.9 billion, or an average of $784,000 per hospital, during a 1918-like influenza pandemic.[54]
- Mitigation efforts, such as cancellation of public events and school closures, as well as voluntary social distancing by the public, will have negative short-term economic consequences. The Transportation Systems and Commercial Facilities Sectors should expect to see a drop in revenues as citizens attempt to distance themselves socially during a pandemic through avoidance of such things as air travel, tourism, and nonessential retail shopping.[55,56] A 2008 World Bank study suggests that over half the loss in GDP in high income countries would result from efforts to avoid infection.[57]
- Once a pandemic has run its course, economic activity should rebound due to people returning to work and resuming pre-pandemic routines.[58] Long-term economic impacts will mostly result from the number of deaths caused by the pandemic.[59,60]
- Since the last severe pandemic in 1918 and more moderate pandemics in 1957 and 1968, the world economy has become more globalized and dependent upon international trade and "just-in-time" supply chains. Supply chain interruptions could cause disruptions in the manufacturing and distribution of affected goods and in turn cause potential shortages.

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[48] Loss in GDP is based upon U.S. GDP relative to what it would have been over the subsequent year had no pandemic been experienced.
[49] Congressional Budget Office, "A Potential Influenza Pandemic: Possible Macroeconomic Effects and Policy Issues," July 27, 2006, pp. 12-13, www.cbo.gov/sites/default/files/12-08-birdflu.pdf, accessed March 3, 2015.
[50] McKibbin, Warwick, "Global Macroeconomic Consequences of Pandemic Influenza," Lowy Institute for International Policy, February 2006, p. 60, www.brookings.edu/~/media/research/files/papers/2006/2/development-mckibbin/200602.pdf, accessed March 4, 2015.
[51] Congressional Budget Office, "A Potential Influenza Pandemic: Possible Macroeconomic Effects and Policy Issues," December 8, 2005, pp. 12-13, www.cbo.gov/sites/default/files/12-08-birdflu.pdf, accessed March 3, 2015.
[52] McKibbin, Warwick, "Global Macroeconomic Consequences of Pandemic Influenza," Lowy Institute for International Policy, February 2006, p. 60. www.brookings.edu/~/media/research/files/papers/2006/2/development-mckibbin/200602.pdf, accessed March 4, 2015.
[53] GDP information obtained from: Bureau of Economic Analysis, "Gross Domestic Product: Fourth Quarter and Annual 2014 (Second Estimate)," U.S. Department of Commerce, February 27, 2015, www.bea.gov/newsreleases/national/gdp/gdpnewsrelease.htm, accessed March 3, 2015.
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[56] Congressional Budget Office, "A Potential Influenza Pandemic: Possible Macroeconomic Effects and Policy Issues," July 27, 2006, pp. 12, www.cbo.gov/sites/default/files/12-08-birdflu.pdf, accessed March 3, 2015.
[57] Burns, Andrew, Dominique van der Mensbrugghe and Hans Timmer, ""Evaluating the Consequences of Avian Influenza," The World Bank, September 2008, p. 4, http://siteresources.worldbank.org/EXTAVIANFLU/Resources/EvaluatingAHIeconomics_2008.pdf, accessed March 4, 2015.
[58] The International Monetary Fund, Avian Flu Working Group, "The Global Economic and Financial Impact of an Avian Flu Pandemic and the Role of the IMF," February 28, 2006, www.imf.org/external/pubs/ft/afp/2006/eng/022806.pdf, accessed March 4, 2015.
[59] Loose, Verne W. et al., "Economic and Policy Implications of Pandemic Influenza," Sandia National Laboratories, 2010, www.sandia.gov/nisac/wp/wp-content/uploads/downloads/2012/04/economic-and-policy-implications.pdf, accessed June 23, 2010.
[60] Martin Meltzer, Nancy Cox and Keiji Fukuda, "The Economic Impact of Pandemic Influenza in the United States: Priorities for Intervention," Emerging Infectious Diseases, Vol. 5 No. 5 (September-October 1999), pp. 659-671, www.who.int/influenza_vaccines_plan/resources/ARTICLE_Economic_Impact_of_Pandemic_Influenza_in_the_US.pdf, accessed March 4, 2015.

MITIGATION MEASURES

While a strain-specific vaccine for a pandemic is the most effective mitigation measure available, this will not likely be available until 4-6 months after the specific strain of a disease has been identified.[61] Second to vaccine development, the most effective and economical mitigation strategy is a rapidly deployed and multilayered approach combining various intervention strategies such as social distancing, school closures, and treatment with antivirals.[62,63]

- Specific vaccine development can only begin once the strain has been clearly identified.[64] There are two critical components that define the potential impact of an influenza pandemic vaccination program: the start date of such a program and the number of persons vaccinated per week.[65]
- In the interim, a combination of intervention measures is the most effective means of delaying and lowering the number of infected people until a strain-specific vaccine is available and can also lower the burden on the Healthcare and Public Health and Emergency Services Sectors.[66,67] Figure 2 illustrates how the use of mitigation measures can lower and delay the peak burden of daily cases.

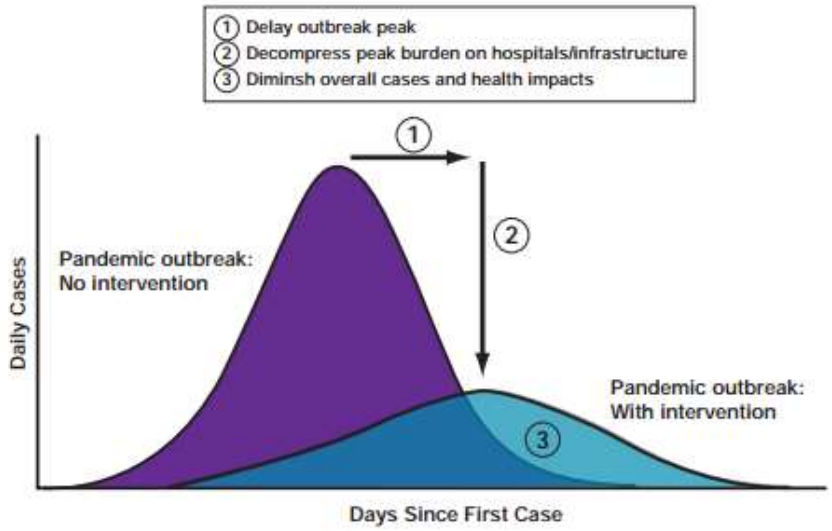

FIGURE 2—ILLUSTRATION OF COMMUNITY MITIGATION POLICY GOALS DURING A PANDEMIC OUTBREAK[68]

- Intervention policies that can help minimize the effect of a pandemic include: school closures, antivirals to be used for treatment and prophylaxis, and social distancing measures—i.e., limiting physical contact with others, voluntary household quarantining of the ill, and wearing gloves and appropriates protective masks such as N95 respirators.[69] Using a single intervention policy, however, is generally not as effective as using

[61] HHS, "HHS Pandemic Influenza Plan," November 2005, p. S6-5, www.flu.gov/planning-preparedness/federal/hhspandemicinfluenzaplan.pdf, accessed June 23, 2015.
[62] Daniella J. Perlroth et al., "Health Outcomes and Costs of Community Mitigation Strategies for an Influenza Pandemic in the United States," Clinical Infectious Diseases, Volume 50, Issue 2 (2010), p. 171, http://cid.oxfordjournals.org/content/50/2/165.full.pdf+html, accessed March 4, 2015.
[63] Milne, George J., Nilimesh Halder and Joel K. Kelso, "The Cost Effectiveness of Pandemic Influenza Interventions: A Pandemic Severity Based Analysis," PLoS ONE, Volume 8, Issue 4 (April 2013), www.plosone.org/article/fetchObject.action?uri=info:doi/10.1371/journal.pone.0061504&representation=PDF, accessed March 4, 2015.
[64] HHS, "HHS Pandemic Influenza Plan," November 2005, p. S6-5, www.flu.gov/planning-preparedness/federal/hhspandemicinfluenzaplan.pdf, accessed June 23, 2015.
[65] Biggerstaff, Mattew et al., " Estimating the Potential Effects of a Vaccine Program Against an Emerging Influenza Pandemic—United States," Clinical Infectious Diseases, Volume 60, Supplement 1 (2015), p. S20-S29, http://cid.oxfordjournals.org/content/60/suppl_1/S20.abstract, accessed May 15, 2015.
[66] Daniella J. Perlroth et al., "Health Outcomes and Costs of Community Mitigation Strategies for an Influenza Pandemic in the United States," Clinical Infectious Diseases, Volume 50, Issue 2 (2010), p. 171, http://cid.oxfordjournals.org/content/50/2/165.full.pdf+html, accessed March 4, 2015.
[67] Milne, George J., Nilimesh Halder and Joel K. Kelso, "The Cost Effectiveness of Pandemic Influenza Interventions: A Pandemic Severity Based Analysis," PLoS ONE, Volume 8, Issue 4 (April 2013), www.plosone.org/article/fetchObject.action?uri=info:doi/10.1371/journal.pone.0061504&representation=PDF, accessed March 4, 2015.
[68] U.S. Department of Transportation, Emergency Medical Services Pandemic Influenza Guidelines for Statewide Adoption. May 3, 2007, p. 21, http://icsw.nhtsa.gov/people/injury/ems/PandemicInfluenzaGuidelines/Task61136Web/PDFs/Task%206.1.13.6Lo.pdf, accessed March 25, 2015.
[69] Prophylaxis is a measure or measures designed to preserve health and prevent the spread of disease. Merriam-Webster, "Prophylaxis," www.merriam-webster.com/dictionary/prophylaxis, accessed July 15, 2015.

a multilayered mitigation strategy.[70] In a moderate or severe pandemic, using multiple strategies at once can be more cost-effective than no intervention or a single intervention due to the number of infections, hospitalizations and fatalities prevented by the mitigation strategy.[71,72]

- Rapid implementation of intervention strategies is also important to effective mitigation. For example, NISAC found that school closures are most effective if such action occurs before 0.1 percent of the local population becomes infected.[73] A 2015 model of the effects of school closures during a pandemic found that for every week of school closures starting at day five of an outbreak, the peak of the outbreak can be delayed by up to five days.[74] The effectiveness of school closures depends on the ability to identify the disease and respond quickly to it, as well as the public's willingness to comply.

Critical infrastructure owners can take several continuity measures in order to mitigate the effects of a pandemic, including increased teleworking, staggered shifts, social distancing within the workplace, and cross-training employees.[75] The effectiveness of these measures depends on the ability of critical infrastructure owners to implement these actions and at the same time maintain operations.

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[70] Daniella J. Perlroth et al., "Health Outcomes and Costs of Community Mitigation Strategies for an Influenza Pandemic in the United States," Clinical Infectious Diseases, Volume 50, Issue 2 (2010), p. 165-174, http://cid.oxfordjournals.org/content/50/2/165.full.pdf+html, accessed March 4, 2015.
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[75] The International Monetary Fund, Avian Flu Working Group, "The Global Economic and Financial Impact of an Avian Flu Pandemic and the Role of the IMF," February 28, 2006, p. 24-25, www.imf.org/external/pubs/ft/afp/2006/eng/022806.pdf, accessed March 4, 2015.

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