Pandemic Influenza, Worker Absenteeism and Impacts on Freight Transportation

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Abstract

A pandemic influenza outbreak could cause serious disruption to operations of several critical infrastructures and concern about the effects of such disruptions is a matter of public concern. This paper focuses on freight transportation services, particularly rail and port operations. It develops models to assess the likely impacts of varying levels of worker absenteeism on the performance of these critical systems. Using current data on performance of specific rail and port facilities, we reach some conclusions about the likelihood of severe operational disruption under varying assumptions about the absentee rate and draw out implications that would be of government concern.

1. Introduction

Influenza viruses have presented a threat to the health of animal and human populations for centuries. Pandemics occur when a new strain of influenza virus emerges, and develops the ability to infect and be passed between humans. Because humans have little immunity to the new virus, a worldwide epidemic, or pandemic, can ensue.

In 1997, the H5N1 influenza virus emerged in chickens in Hong Kong. The virus has shown the ability to infect multiple species, including migratory birds, pigs, cats and humans. While it is impossible to predict whether the H5N1 virus will lead to a pandemic, history suggests that a new influenza virus will emerge at some point and spread quickly through an unprotected human population. The impact of a pandemic is likely to be pervasive, removing essential personnel from the workplace for extended periods. This has significant ramifications for the economy, national security, and the basic functioning of society.

An area of particular concern is the potential effects of worker absenteeism on the functioning of critical infrastructures in our society. In 1997, the report of the U.S. President's Commission on Critical Infrastructure Protection identified eight critical infrastructures "whose incapacity or destruction would have a debilitating impact on our defense and economic security" [13]. In subsequent years, this list of critical infrastructures has been expanded and now includes a set of 17 critical infrastructures / key resources identified in the National Infrastructure Protection Plan created by the Department of Homeland Security [16].

An important part of government planning for the possibility of a pandemic influenza episode is to understand the potential impacts on the functioning of critical infrastructures. This portion of the government's role in creating a pandemic influenza response plan is part of the homeland security mission.

This paper focuses on the transportation infrastructure, and particularly on the effects of large-scale absenteeism in freight transportation. We focus on freight transportation services because the demand for freight movements is unlikely to

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fall very much during a pandemic episode – the basic needs of people for food and a wide variety of other consumer goods will continue, and this drives movements of all types of materials through the transportation system. Some purchases of consumer durables may be postponed, leading to a slowdown in some parts of related supply chains, but on the whole, the demand for freight movement is likely to change relatively little. Thus, the reduction in capacity resulting from workforce absenteeism may create large disruptions.

Within freight transportation, some operations are likely to be more susceptible than others. In this paper, we focus particularly on railroads and container port operations. The effects of insufficient labor that we are analyzing can be illustrated by events at the ports of Los Angeles and Long Beach in 2004. These two ports are operated separately but are physically adjacent. Taken together, they handle about 16 million TEU's (twenty-foot equivalent units) per year, and nearly one-half of all U.S. container imports [11, 12]. About 40% of these container imports leave the LA area on intermodal trains operated by the Union Pacific (UP) and the Burlington Northern Santa Fe (BNSF) railroads.

During the summer of 2004, the UP did not have enough trained workers (largely resulting from a change in federal labor law that triggered increased retirements) to handle the level of container traffic coming through Los Angeles / Long Beach and moving east by rail [5]. The problem was exacerbated by a shortage of longshoremen in the port itself. The rail yards near Los Angeles became clogged; then the congestion reached back into the container storage areas in the port; and eventually ships backed up in the anchorage waiting to unload. By September of that year, truckers were reporting long delays in the terminal to pick up containers [6], and queues of more than 30 ships anchored off the coast waiting for berths were reported [8].

The 2004 situation in LA / Long Beach emphasizes the potential effects of labor shortages on both railroad operations and port operations, as well as how those two types of operations can be interconnected. For the current analysis, we are concerned with labor shortages that may be caused by pandemic influenza. The period of widespread worker absenteeism in a given location is likely to be of modest duration (a few weeks at most), but the reduction in capacity that results in the transportation sector may create ripples that are felt nationally, and over much longer periods. It is these national-level economic impacts that are of primary concern to the federal government.

For the current analysis, an epidemiological model was used to estimate likely rates of worker absenteeism in various economic sectors over time. Depending on the location at which the pandemic influenza enters the U.S., absenteeism at various other locations can be expected to peak at different times. In the current paper, we do not describe the epidemiological modeling directly, but use a series of three scenarios derived from that model, corresponding to different levels of peak absenteeism in the transportation sector (5.8%, 13.6% and 28.2%).

The following sections describe our analyses of rail and port operations under the various absenteeism scenarios from the epidemiological model and the final section of the paper offers some general conclusions.

2. Railroads

Significant portions of the national rail system are operating quite near capacity, and substantial absenteeism would be likely to disrupt freight movements in some important corridors. The major areas where congestion occurs are the large classification yards in the rail network. At these locations, trains are assembled and disassembled, and individual freight cars are sorted as they move through the network. Data in [4], based on tracing more than 35,000 individual car movement records in 2004, indicate the percentage of total in-transit time that freight cars spend in classification yards. These data are summarized in Figure 1.

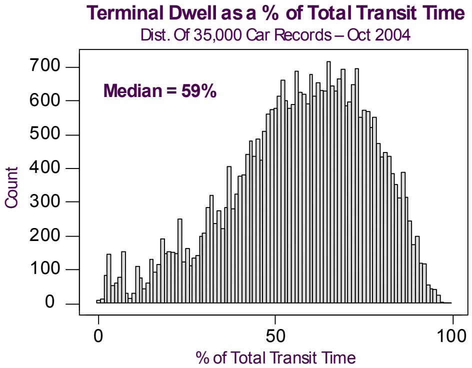

Figure 1. Percentage of total in-transit time spent in rail yards (source: [4]).

Our analysis of the potential effects of absenteeism in the national rail network focuses on 18 of the largest classification yards operated by the four largest Class I railroads. Each of these yards classifies more than 1200 freight cars daily.

Average dwell time statistics for individual yards are reported by the railroads to the Association of American Railroads (AAR) each week, and published online [3]. We have used average dwell times published for the month of February, 2007, as the basis for our assessment of yards that are of greatest importance in the analysis.

At each of these major yards, delay functions represent the effects of congestion, and these functions are sensitive to the level of labor present in the yard. A major influenza outbreak and associated absenteeism could cause some of these facilities to be completely overloaded, and some freight traffic normally carried by the railroads could no longer be moved. Identifying when such situations might occur is one of the important elements of the analysis.

Modeling Delay in Rail Classification Yards

The data in [4] show that freight cars spend an average of 28.2 hours each yard they pass through, and that 71% of that time (or about 20 hours) is delay waiting for a subsequent operational step. The three largest portions of this delay (comprising about 97% of the total) are waiting for inbound inspection on arrival, waiting to be classified at the "hump" and waiting to be assembled into an outbound train.

In the model developed here, the expected dwell time in a yard for a given car is the sum of three parts: a term (T_1) representing processing time, a delay (T_2) prior to classification (representing waiting for inbound inspection and the hump), and a delay (T_3) waiting for outbound connection. For model calibration, we have used estimated averages of 7 hours, 4 hours and 14 hours, for these three parts, respectively. The sum of these three values is 25 hours, which is consistent with the current reported average yard time values from the railroads [3], and their relative values are consistent with the data collected in [4].

In addition to being dependent on car volume passing through the yard, the elements of dwell time are also sensitive to labor availability. The actual processing steps in car classification within the yard are most directly related to labor availability, so to estimate the effects of absenteeism, we inflate the estimate of 7 hours in direct proportion to the absentee rate. Thus, for example, if the projected absentee rate is 15%, the estimated activity time is (7) 1.15 = 8.05 hours. In general:

$$E(T_1) = 7(1+\beta) \tag{1}$$

where β is the proportion of workers absent in a given scenario being analyzed.

The expected delay prior to classification is modeled using a queuing approach, based on previous work in [15]. Using a bulk-arrival queue, bounds on the expected waiting time for classification can be derived. The difference between these bounds is a factor of two in average waiting time, and as a plausible approximate model, we use a delay time that is halfway between the bounds. This leads to the following expression:

$$E(T_2) = \frac{3(L-1+\rho)}{4\mu(1-\rho)} \tag{2}$$

where: L = average inbound train length (# cars)
μ = average classification rate (cars/hour)
$\rho = \lambda L/\mu$ (traffic intensity)
λ = average arrival rate of trains (trains/hour).

The quantity λL represents the average flow rate of cars through the yard (measured in cars/hour).

We will assume that the average classification rate depends on the labor available, through a multiplier $\theta(\beta)$ whose value is defined by the relationship shown in Figure 2. Small proportions of absent workers in a yard create a very modest reduction in the service rate, but as the proportion increases the effect is magnified. The function $\theta(\beta)$ is defined for absentee rates up to 0.3 only, because this covers the range to be studied in this analysis. Thus, in equation (2), the average classification rate, μ, is replaced by

$$\mu = \mu_0\ \theta(\beta) \tag{3}$$

where μ_0 is the nominal classification rate of a given yard. This change in μ also affects the computation of ρ for a given arrival rate of trains.

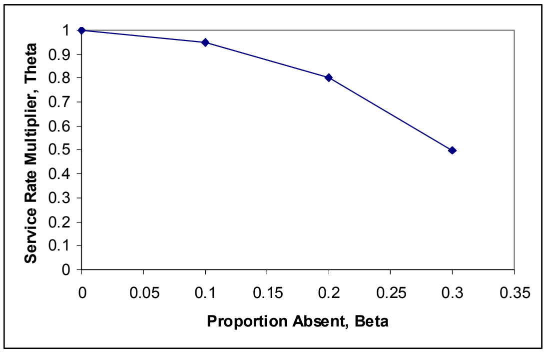

Figure 2. Relation of service rate multiplier to absentee rate.

A second effect of absenteeism on the classification process is that the average train length is likely to increase. If crews are in short supply, some trains will be cancelled and the ones that run are likely to move more cars, in an effort to maintain overall capacity. We represent the change in average train length as being proportional to the absentee rate, so that L is given by the following expression:

$$L = L_0\,(1+\beta) \tag{4}$$

L_0 is the nominal average train length. For this analysis, we assume L_0 = 69 cars, the average train length for the industry as a whole in 2005 [2]. In the network model computations, the input rate to each yard is computed as number of cars per day (the product λL in equation (2)), so the effect of the change in L does not directly affect the computation of ρ.

The expected connection delay while cars wait for their outbound connections is determined by the "effective headway" (i.e., time between potential departures) distribution of the outbound connection. We assume a simple discrete distribution that assumes that a "normal" connection is to an outbound train that operates once a day. There is a probability, p, that the "effective headway" for a given outbound connection is 48 hours, either because of cancellation of an outbound train, or because of capacity limits that preclude a car from making the first available connection. The remaining probability, 1-p, is that there is a "normal" 24-hour headway between outbound connections.

When headways between outbound departures are uncertain, the expected waiting time for a car that arrives at a random point in time can be expressed as:

$$E(T_3) = \frac{E(H)}{2} + \frac{V(H)}{2E(H)} \tag{5}$$

where $E(H)$ and $V(H)$ are the mean and variance of the headway distribution, respectively. This result was first shown in the context of waiting times of passengers at bus stops [19], but the same mathematics can be applied to freight cars in a classification yard.

For the headway distribution used here, we can write the expected connection delay as:

$$E(T_3) = 12\left(\frac{1+3p}{1+p}\right) \tag{6}$$

With increasing absenteeism, more outbound trains are likely to be cancelled and the probability that an inbound car makes its first scheduled connection decreases (i.e., p increases). A simple reflection of that is the following relationship:

$$p = 0.09 + \beta \tag{7}$$

The base value of p (0.09) when substituted into (6) results $E(T_3)$ = 14 hours. This is the target value based on current observed data. At values of β = 0.1, 0.2 and 0.3, the values of $E(T_3)$ increase to 15.8 hours, 17.4 hours, and 18.7 hours, respectively.

Substituting (7) into (6), we can rewrite the expression for $E(T_3)$ as:

$$E(T_3) = 12\left(\frac{1.27+3\beta}{1.09+\beta}\right) \tag{8}$$

Equations (1), (2) and (8) have been used to calibrate overall delay functions for each of the 18 major classification yards at nominal conditions (β = 0). This calibration has been based on reported average terminal dwell times for February 2007 and reported typical daily classification volumes. The results of this calibration are summarized in Table 1.

Scenario Analysis

In the lowest impact scenario, absenteeism peaks at 5.8% in the third month after the onset of the pandemic outbreak. Using this 5.8% value as β in equations (1), (3), (4) and (8), we estimate that the effective capacity of the rail yards under consideration will be reduced approximately 3%. Absenteeism also results in additional train cancellations and a modest increase in average train length to 73 cars. If the traffic volume on the rail system is unchanged, the effect of the reduction in yard capacity is to increase the utilization levels of the yards, and hence to increase the delays. In most of the 18 yards analyzed, the increases in average dwell times are between 4 and 17 hours. We could expect origin-destination times for most shipments to increase by 1-3 days, depending on how many yards a specific shipment must pass through. The system-wide average in 2004 was 2.8 reclassifications per shipment [4], so a typical shipment might see an increase in overall travel time of about two days.

The effects represented in this scenario are significant changes in delays for shipments, and the

Table 1. Estimated characteristics of major rail yards for model calibration.

Railyard	Railroad	Reported Average Daily Volume (cars)	Reported Average Dwell Time (hours)	Estimated Base Capacity (cars/day)	Capacity Utilization	Estimated Average Dwell Time (hours)
Argentine-Kansas City, KS	BNSF	1795	29.5	1950	0.92	29.0
Barstow, CA	BNSF	1384	33.5	1480	0.94	33.9
Galesburg, IL	BNSF	1653	40	1720	0.96	39.5
Cincinnati, OH	CSX	1557	32.8	1700	0.92	29.7
Indianapolis, IN	CSX	1494	35.7	1600	0.93	32.7
Nashville, TN	CSX	1695	31	1850	0.92	29.0
Selkirk, NY	CSX	1627	34.4	1750	0.93	31.1
Waycross, GA	CSX	2276	26.8	2500	0.91	26.5
Willard, OH	CSX	1557	36.4	1650	0.94	34.3
Bellevue, OH	NS	N/A	40.4	1500	0.95	38.7
Conway, PA	NS	N/A	28.1	2000	0.91	27.9
Englewood- Houston TX	UP	1500	32.7	1600	0.94	33.4
Fort Worth, TX	UP	1300	37	1380	0.94	36.5
North Platte, NE	UP	2900	30.7	3040	0.95	29.8
North Little Rock, AR	UP	1800	27.6	2000	0.90	27.2
Proviso, Chicago, IL	UP	1600	35.4	1700	0.94	33.4
Roseville, CA	UP	1450	31.1	1600	0.91	29.3
W. Colton, CA	UP	1300	31.1	1450	0.90	29.2

terminals across the rail system would experience a noticeable increase in congestion levels, but since the overall duration of the event is limited, this scenario does not create an intolerable level of disruption for the system as a whole.

In the mid-level scenario, absenteeism peaks at 13.6%. The estimated reduction in effective capacity for the major rail yards is approximately 10%, and we might expect the effect of train cancellations to increase the average train length to about 78 cars. If the total volume of shipments is unaffected by absenteeism in other industries, the 10% reduction in effective yard capacity is likely to push all 18 of these major yards to a critical situation, as shown in Table 2.

Table 2. Summary of changes for mid-level absenteeism scenario.

Railyard	Railroad	Reported Average Daily Volume (cars)	Nominal Capacity Utilization	Scenario Capacity Utilization
Argentine-Kansas City, KS	BNSF	1795	0.92	1.03
Barstow, CA	BNSF	1384	0.94	1.04
Galesburg, IL	BNSF	1653	0.96	1.07
Cincinnati, OH	CSX	1557	0.92	1.02
Indianapolis, IN	CSX	1494	0.93	1.04
Nashville, TN	CSX	1695	0.92	1.02
Selkirk, NY	CSX	1627	0.93	1.04
Waycross, GA	CSX	2276	0.91	1.02
Willard, OH	CSX	1557	0.94	1.05
Bellevue, OH	NS	N/A	0.95	1.06
Conway, PA	NS	N/A	0.91	1.02
Englewood- Houston TX	UP	1500	0.94	1.05
Fort Worth, TX	UP	1300	0.94	1.05
North Platte, NE	UP	2900	0.95	1.06
North Little Rock, AR	UP	1800	0.90	1.00
Proviso, Chicago, IL	UP	1600	0.94	1.05
Roseville, CA	UP	1450	0.91	1.01
W. Colton, CA	UP	1300	0.90	1.00

When the capacity utilization exceeds 1.0, it means that the input rate of cars to be processed every day exceeds the capacity of the yard to handle them, and the delays simply get worse and worse as the days progress. In the terms of the models used here for analysis, there is no "steady-state" solution at that level of traffic input to the system, and the longer the situation persists, the worse conditions become.

At the level of absenteeism projected in this scenario, it is very likely that shipping and receiving industries that use rail transportation will also be affected, and the level of overall volume being shipped is likely to drop. This may keep the situation in the rail system from becoming as critical as reflected in Table 2, but in this scenario we should expect to see reasonably widespread problems as specific locations are unable to handle volumes coming into them over a 6-8 week period. There are likely to be persistent "waves" of congestion and disruption across the system as various yards become overly congested and adjustments are made, only to move the problem somewhere else. It is also likely that the railroads will embargo shipments to or from areas that are experiencing the worst problems at specific times during the overall event.

In the highest-impact scenario, the peak absentee rate is 28.2%. This absentee rate reduces the effective capacity of the major rail yards by approximately 45%. In the absence of shipment volume reductions, this capacity reduction, combined with train cancellations, reduced maintenance, etc., would likely cause the system to be completely clogged with shipments that are not moving. In this scenario, the demand on the major rail yards is 60-70% above their effective capacity.

Of course, the shipping industries are very likely to be feeling similar absentee rates, and as a result, shipment volumes will be substantially decreased. Nevertheless, at the absentee rates projected in this scenario, there is likely to be an enormous disruption in the rail system over a period of two months or more.

Because the major rail yards considered here are all high-volume facilities that are the focal points in the network, these facilities are likely to experience the congestion worst, but at such a high rate of absenteeism over an extended period, the effects will move beyond these major facilities and be felt system-wide.

3. Container Ports

Our approach to analyzing the impact of substantial levels of absenteeism at container ports is to develop a queuing model to represent the process of loading and unloading containers from ships at specific ports. This is an approximation to the true impact of absenteeism because it is limited to dockside activities and therefore does not consider the effects of reductions in capacity caused by absenteeism in the container yards, absenteeism that reduces the ability to transfer containers to and from rail facilities or the impact of reductions in the speed with which truck drivers can pickup and deliver containers to the port. However, dockside operations are generally a limiting factor in port throughput and therefore represent a critical predictor of port performance.

The three largest U.S. ports (Los Angeles, Long Beach and New York-New Jersey) handle about 50% of total container traffic (imports and exports) coming through all ports. In 2005, the Port of Los Angeles handled about 7.4 million TEUs [12] and the Port of Long Beach handled about 6.7 million TEUs [11]. A TEU is a nominal unit of measure equivalent to a 20'x8'x8' shipping container, and is the standard unit of traffic measurement in container freight shipments. We focus on the Port of Los Angeles to analyze the impacts of substantial absenteeism caused by pandemic influenza on port performance because it is the largest of the seaports and has the best available data. The Port of Los Angeles has 8 terminals operated by various terminal companies. Each terminal has vessel berths, gantry cranes for loading/unloading ships, container yard facilities for staging and storing containers, etc. Different sets of ocean carriers have agreements with each terminal operator for use of their facilities. Table 3 summarizes important characteristics of the LA terminals.

The port of Long Beach is adjacent to the Port of Los Angeles and has 6 terminals. In total, it has the same number of gantry cranes – 71 – as Los Angeles [11]. Given the similarities in the traffic and terminal capabilities at these two adjacent seaports, we focus on the Port of Los Angeles, with the understanding that similar conclusions are valid for the Port of Long Beach.

Table 3. Description of the terminals at the Port of Los Angeles.

Terminal Number	Terminal	Shipping Lines	Number of Cranes	Approximate Number of Vessel Calls in 2005
1	West Basin Container Terminal	China Shipping, Yang Ming, K-Line, Cosco, Hanjin, Sinotrans, Zim	4	*
2	West Basin Container Terminal	China Shipping, Yang Ming, K-Line, Cosco, Hanjin, Sinotrans, Zim	8	*
3	Trans Pacific Container Service Corp.	Mitsui, China Shipping, Norasia, Compania Sudamerica de Vapores, Zim, Wan Hai, APL, Hyundai Merchant Marine Co., CMA-CGM	11	*
4	Port of Los Angeles Container Terminal	N/A	4	75
5	Yusen Terminal	NYK, OOCL, Hapag-Lloyd	10	111
6	Seaside Terminal	Evergreen, Hatsu Marine Ltd., Italia Marittima	8	217
7	APL Terminal/Global Gateway South	APL, Hyundai, MOL, ANZDL, Fresco, HamburgSud, Maersk	12	*
8	APM Terminals/Pier 400	Maersk, Horizon	14	*

* There were 933 total vessel calls among terminals 1, 2, 3, 7 and 8 but because of overlapping usage, data on how many occurred at each terminal individually are unavailable. (Source: [12])

In general, the rate-limiting step in handling containers at ports is the rate at which the gantry cranes can unload and then reload the vessels. The key measure of capacity for a crane is the number of lifts per hour (LPH) that it can accomplish. Labor absenteeism reduces the effective capacity of the cranes at dockside. The consequence of reduced effective capacity is increased delay to the vessels, both because unloading and reloading takes longer, and because they must wait longer for an available berth. A reasonable way to represent the impact of absenteeism is to reducee the LPH by the fraction of the workforce that is absent. For example, suppose that a crane under normal operating conditions can lift 25 TEUs per hour but the absentee rate is 20%. The modified LPH is then 25*(0.8), which equals 20 LPH.

The expected time required to process a ship (i.e., berth the ship, unload the inbound containers, load the outbound containers and have the ship leave the berth) can be estimated based on the total number of inbound and outbound containers, the total number of cranes assigned, the LPH of the cranes, the fraction of the containers that are 40 foot containers versus 20 foot containers and the amount of time needed to position the ship at the berth and to move the ship from the berth. This relationship is given in equation (9) and is similar to formulae used in other studies [10, 14].

*Service Time = [(TEUs to lift)/(1+fraction of 40 foot containers)]/(# cranes assigned*LPH) + ship positioning time* (9)

Data for the Port of Los Angeles indicates that about 70% of their containers are 40-foot containers and 30% are 20-foot containers [1]. This statistic is important because it takes about the same amount of time to lift one 20-foot container as to lift one 40-foot container. We assume that the time required to position the ship at the berth and to move it from the berth afterwards is a total of 3 hours. This is consistent with estimates in [14].

The actual service time for a ship may vary from the value given in equation (9) for a variety of reasons (crane breakdowns, crews not ready on time, other equipment problems, etc.), but the largest source of variation in service times across processing of many vessels is the variation in the number of TEUs to lift for different ships. We have estimated this variation using data on vessel calls at the Port of Los Angeles for 2005 [17].

Using size information for the individual vessels in the Vessel Call data [17] and the aggregate number of TEUs handled each month (as reported by the Port), we have estimated the variation in TEUs to lift per ship, and from this, the probability distribution for the service times, using equation (9).

Several previous authors (e.g. [10, 14]) conclude that the arrival process of ships at seaports can be effectively modeled as a Poisson process where the mean varies by month. We have used this approach, focusing on analysis reflecting both an average month (with approximately 111 vessel arrivals) and a peak month (October).

For a given arrival rate, λ, expressed in vessels/hour, the queuing model formula for the expected vessel time in port is as follows [7]:

$$\frac{\lambda^k E[S^2](E[S])^{k-1}}{2(k-1)!(k-\lambda E[S])^2\left[\sum_{n=0}^{k-1}\frac{(\lambda E[S])^n}{n!}+\frac{(\lambda E[S])^k}{(k-1)!(k-\lambda E[S])}\right]}+E[S] \tag{10}$$

where k is the number of servers, $E[S]$ is the expected service time and $E[S^2]$ is the second moment of the service time.

To use equation (10) effectively, we must specify the number of servers, k, available to a given stream of arrivals. For the Port of Los Angeles, this means that we need to segregate vessel arrivals by shipping company (or groups of shipping companies), because the ships of a specific company can only use certain terminals, as indicated in Table 3. We note in Table 3 that terminals 4, 5 and 6 can be considered individually, because the set of shipping lines using each terminal is different. However, terminals 1, 2, 3, 7 and 8 must be considered together because there is overlap in the shipping lines using those terminals and the shipping lines can generally use more than one of those terminals.

In order to calibrate our queuing models of the Port of Los Angeles, we use the Vessel Movement files available from the Maritime Administration [18]. That dataset records the day of entrance and exit for each vessel call at every U.S. port. The latest year for which that data is available is 2005. However, we also know that TEUs handled at the Port of Los Angeles rose 13% from 2005 to 2006. If we assume that the same growth rate continues into 2007, the total number of TEU's handled at the port will rise to 9.6 million in 2007. In addition, all terminals at the Port of Los Angeles now operate 24 hours per day. For analysis of the scenarios, we have increased the overall demand level to 9.6 million TEUs and based the terminal service times on 24-hour operation.

Figure 3 summarizes the predicted average vessel times in port for the varying absentee rates represented in the three scenarios of interest – 5.8%, 13.6% and 28.2%. The average time in port with the current volumes and an absentee rate of 0% is also shown for comparison. Terminals other than Terminal 6 could absorb much of the absenteeism associated with the pandemic influenza scenarios. Delays would certainly increase, especially in the 28.3% scenario, where total time in port increases by about 40-50%, but if the duration of the events is not excessive, this may be tolerable.

Terminal 6 (the Seaside Terminal, used by Evergreen, Hatsu and Italia Marittima), however, does not have enough capacity to accommodate the high level of absenteeism associated with the 28.3% absentee scenario. At the average monthly volume, the average delay increases to 152 hours (approximately 6.3 days). This would create delays comparable to the situation that existed in the fall of 2004. If the influenza event were to occur in the peak month of October, the delays would be intolerable. The model actually computes a value of nearly 1500 hours (about 63 days), but this value is not shown in Figure 3 because no ship owner would tolerate such a wait. What is important is to note that under high absentee rates there is one terminal that will likely be severely congested and some vessels from the lines that normally use that terminal will either have to make temporary arrangements with other terminal operators or be diverted to other ports to unload.

This analysis was done based on projected 2007 container volumes at the Port of Los Angeles. Traffic has grown approximately 43% since 2000 at that port, and is currently growing at about 13% per year. If future investment in port capacity does not keep pace with the traffic growth, these conclusions may significantly under-estimate the impact of pandemic influenza occurring in later years.

The Port of Long Beach is similar in many respects to the Port of Los Angeles. It does have a higher proportion of "shared use" terminals, and thus is somewhat less susceptible to the "single terminal" problem seen in the Los Angeles analysis. The Port of Long Beach is also experiencing rapid traffic growth and is investing to increase capacity. As in Los Angeles, if the capacity investments keep pace with traffic growth, there should be sufficient capacity to weather an influenza outbreak (and associated worker absenteeism) with noticeable, but tolerable increases in delays. However, with such high growth rates for traffic volume, available "buffer" capacity can disappear very rapidly.

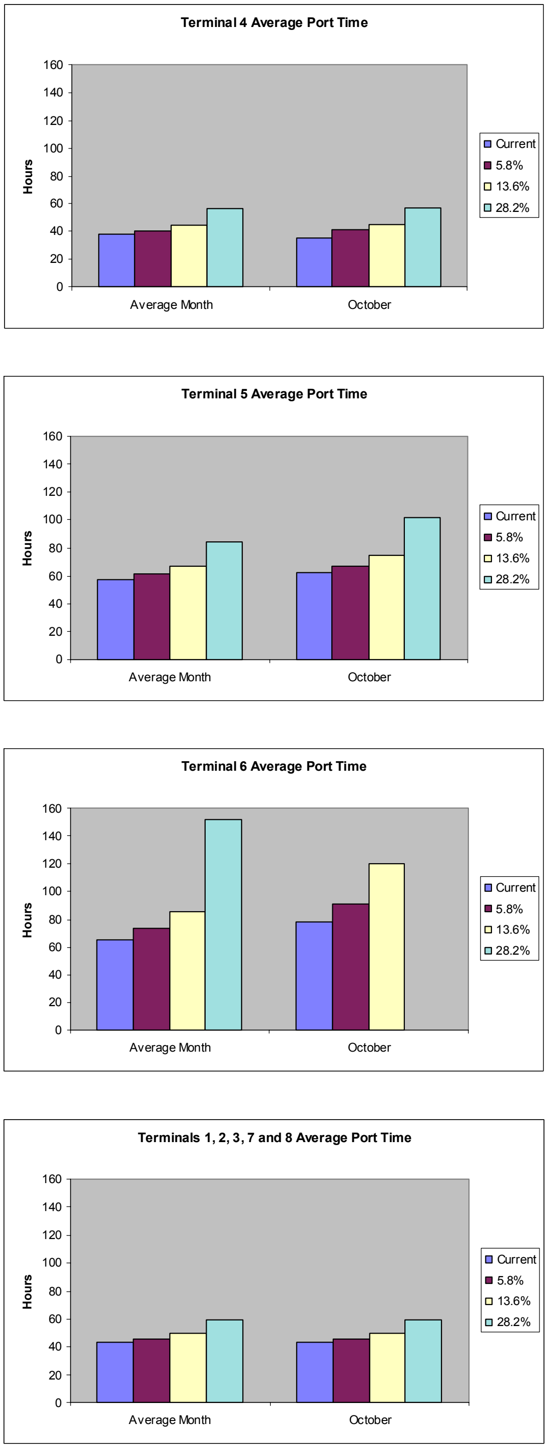

Figure 3. Summary of average time in port for the LA terminals under various absentee rate scenarios.

Intermodal Transfers

Beyond the process of unloading and loading containers at the dockside, there is potential concern about the transfer process through which these containers move from the port terminal to truck or rail for delivery across the nation. The severe congestion in Los Angeles / Long Beach that occurred in 2004, for example, had roots in both the rail system and in the port facilities themselves. The inability to move containers through the port and away to their destinations by truck or rail can result from limitations in any step of that overall process.

We have focused on the dockside operations because they are typically rate-limiting. Over the last two years, the change to 24-hour operations at the dockside in LA / Long Beach has been accompanied by expansion to 24-hour gate operations on the land side of the terminals to help move containers more effectively into and out of the terminal area. Both LA and Long Beach have also increased the proportion of dockside rail loading, so that more containers are placed directly on rail cars at the dock and a labor-intensive intermediate handling of the containers is eliminated. These changes help the intermodal transfer process capacity keep pace with the unloading / loading capacity at dockside, and our focus on dockside operations remains appropriate. However, during a potential pandemic influenza outbreak, the rate of worker absenteeism could exhibit strong local fluctuations, and shift the bottleneck in port operations to the container yard or intermodal transfer. In such an event, the delays might be worse than what we've forecast here, but such an event would likely be of short duration. In general, the dockside operations are most likely to be the rate-limiting step in the operations.

4. Conclusions

The first major conclusion from the analysis here is that at the level of absenteeism projected in the mid-level scenario (13.6% peak absentees), it is very likely that there will be reasonably widespread problems in the rail system as specific locations are unable to handle volumes coming into them over a 6-8 week period. There are likely to be persistent "waves" of congestion and disruption across the system as various yards become overly congested and adjustments are made, only to move the problem somewhere else.

In the high-level absentee scenario (28.2% absentees), the effective capacity of the major rail yards is reduced by approximately 45%. In the absence of shipment volume reductions, this capacity reduction, combined with train cancellations, reduced maintenance, etc., would likely cause the system to be completely clogged with shipments that are not moving.

Ortiz, *et al*. [9] describe the whole national freight system as being "brittle" – i.e., small disruptions can produce large consequences. Under such conditions, the likely unevenness of shipment pattern changes as influenza affects different geographic areas and/or different industries to varying degrees, is likely to create substantial disruptions in freight transportation generally, and among railroads in particular, because there is very little excess capacity to "buffer" the variations across the system.

The second key conclusion is that most of the individual terminals in the Port of Los Angeles could withstand the absenteeism associated with the pandemic influenza scenarios. Delays would certainly increase, especially in the 28.2% absentee scenario, where total time in port increases by about 40-50%, but if the duration of the events is not excessive, this may be tolerable.

Terminal 6 (the Seaside Terminal, used by Evergreen, Hatsu and Italia Marittima) is the likely exception. Under high absentee rates this one terminal will likely be severely congested and some vessels from the lines that normally use that terminal will either have to make temporary arrangements with other terminal operators or be diverted to other ports to unload.

The Port of Long Beach is similar in many respects to the Port of Los Angeles. It does have a higher proportion of "shared use" terminals, and thus is somewhat less susceptible to the "single terminal" problem seen in the Los Angeles analysis. Both ports are experiencing rapid traffic growth and are investing to increase capacity. If the capacity investments keep pace with traffic growth, there should be sufficient capacity to weather an influenza outbreak (and associated worker absenteeism) with noticeable, but tolerable increases in delays. However, with such high growth rates for traffic volume, available "buffer" capacity can disappear very rapidly.

These findings are important to government planning for a potential pandemic influenza outbreak for several reasons. The National Infrastructure Protection Plan [16] sets a goal for the federal government that reads, in part, "…to strengthen national preparedness, timely response, and rapid recovery in the event of an attack, natural disaster, or other emergency." The cornerstone of the NIPP is a risk management framework that integrates concerns regarding physical, cyber and human resources. There are many important public concerns surrounding a potential pandemic influenza outbreak – morbidity and mortality risks to the public, the likelihood of overwhelming the health care system, etc. Among these concerns should be placed a concern regarding continued functioning of critical infrastructure systems.

The analysis done here indicates that there is significant likelihood of major breakdowns in the freight transportation sector under the more severe influenza scenarios as a direct result of large-scale worker absenteeism. This may affect distribution and availability of a wide variety of consumer goods as well as availability of raw materials for many other industries. Planning for actions to reduce the rate of infection and to slow the transmission of the disease is very important, and will create benefits via the transportation sector as well as in easing the load on the health care sector.

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