MAILBORNE TRANSMISSION OF ANTHRAX: MODELING AND IMPLICATIONS

Glenn F. Webb
Department of Mathematics
Vanderbilt University
Nashville, TN 37240

Martin J. Blaser
Department of Medicine and Microbiology
New York University School of Medicine
New York, NY 10016

THE OBJECTIVES OF THIS TALK

(1) Develop a mathematical model of the fall 2001 anthrax attack on the US Postal System

(2) Use the model to estimate the number of cross contaminated letters produced, the number of anthrax spores on these cross contaminated letters, and the number of resulting infectious cases in recipients of these letters

(3) Extrapolate the model to simulate a larger scale anthrax attack on the US Postal System

(4) Discuss what can be learned from the model about preparedness for a future anthrax attack on our society

THE LETTERS

Four letters laden with anthrax spores were discovered. All were dated as "09-11-01" and sent from Trenton, NJ in the fall of 2001.

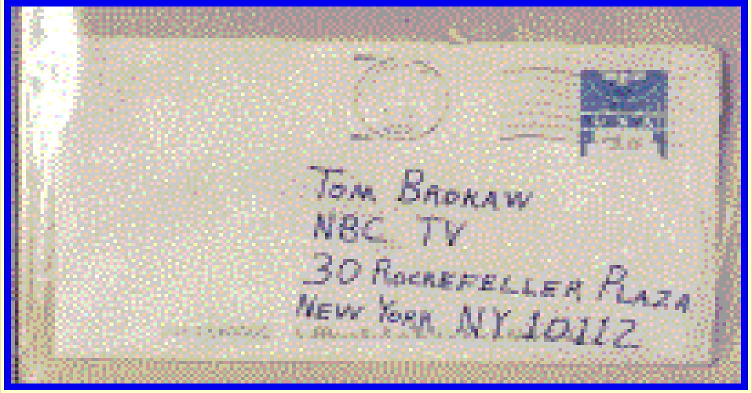
Two of the these letters were postmarked Sept. 18, 2001. One was sent to the *New York Post* where it was handled by several staff members. The other was sent to Tom Brokaw of *NBC*, opened Sept. 19-25 but not found until Oct. 12. The *New York Post* letter, handled but not opened, was found on Oct. 19.

The second two letters were postmarked on Oct. 9, 2001 and mailed to the Washington, DC offices of Senators Tom Daschle and Patrick Leahy. Both letters went though the Washington, DC Brentwood mail processing facility, which handles all incoming federal government mail. The Daschle letter was opened on Oct. 15, 2001.

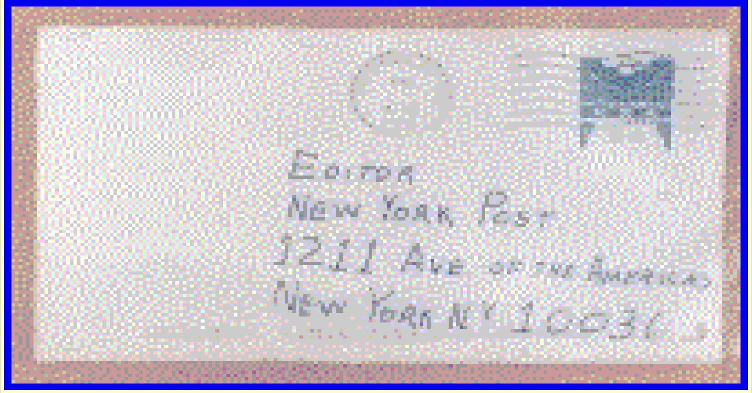
It is believed that there were at least two more anthrax laden letters, one mailed to *American Media* in Florida, and one to *CBS* in New York.

THE ENVELOPES OF 4 OF THE ORIGINAL LETTERS

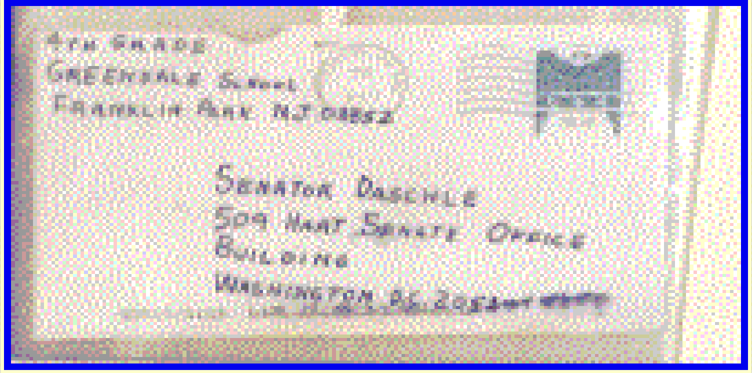
Envelope #1



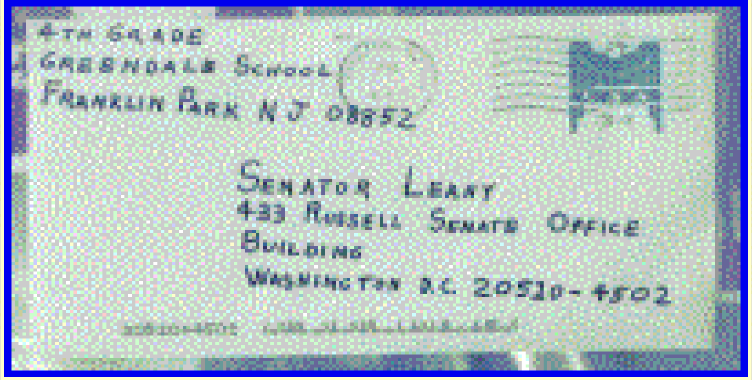
Envelope #2



Envelope #3

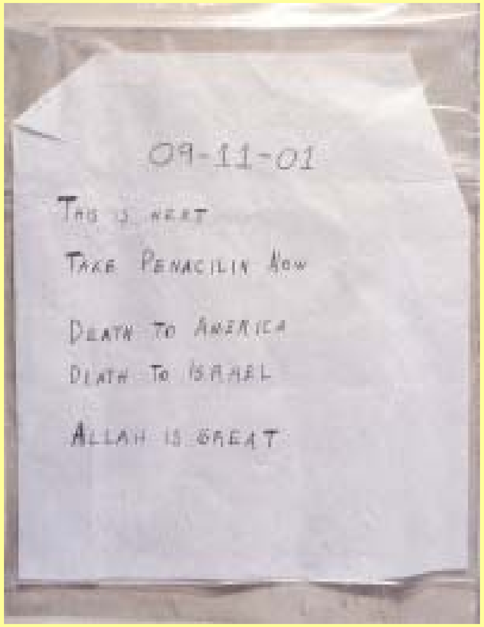


Envelope #4



FOUR OF THE ORIGINAL ANTHRAX LETTERS

Letter 1



09-11-01

THIS IS NEXT

TAKE PENACILIN NOW

DEATH TO AMERICA

DEATH TO ISRAEL

ALLAH IS GREAT

Letter 2

09-11-01

THIS IS NEXT

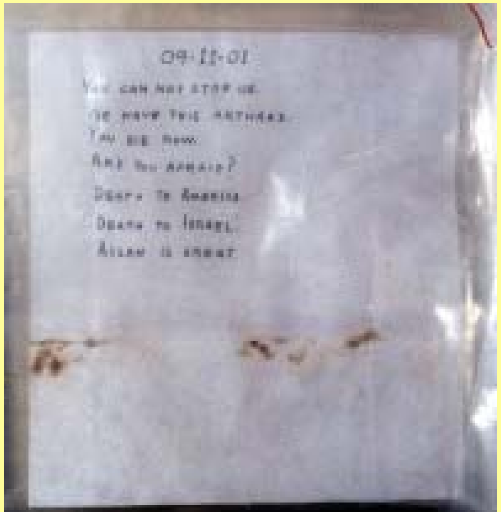
TAKE PENACILIN NOW

DEATH TO AMERICA

DEATH TO ISRAEL

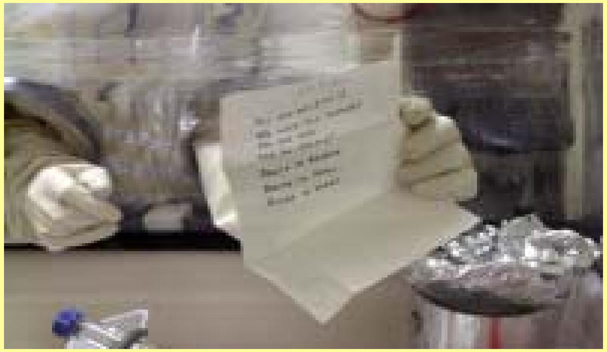
ALLAH IS GREAT

Letter 3



09-11-01

Letter 4

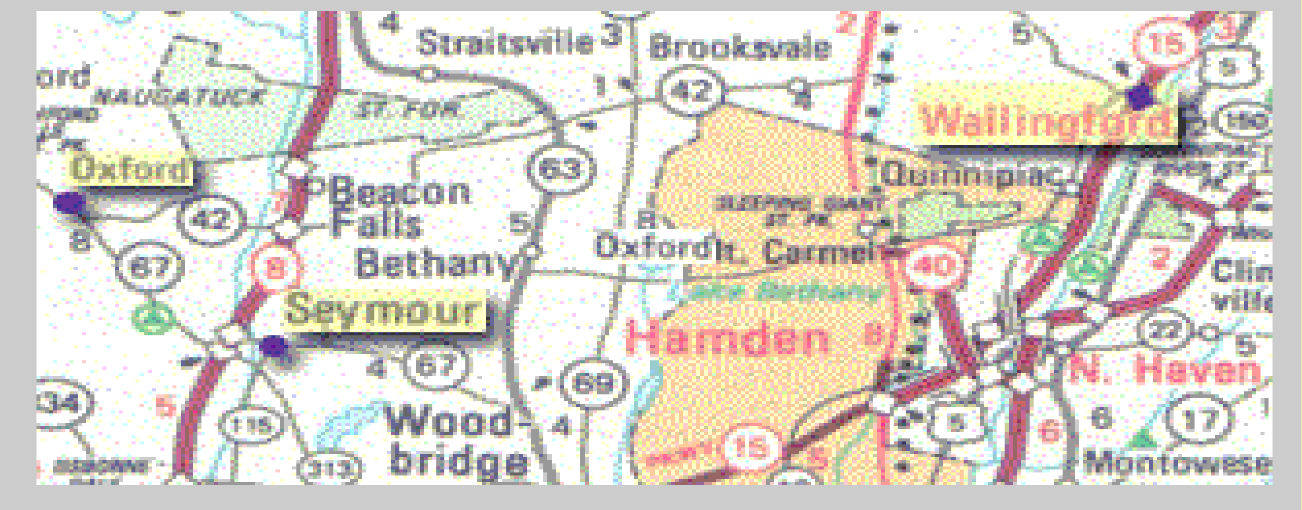


THE CROSS CONTAMINATION OF MAIL

The cross contamination of pieces of mail occurs as the original anthrax laden letters transit through the postal system. Handling of the letters by postal workers and sorting machines results in transfer of the anthrax spores to other letters and to the local postal environments. A possible mechanism for the release of spores from the interior of the envelopes (which in the fall 2001 outbreak were sealed with tape) is the bellows action of the processing machine. The spores, which are several microns in diameter, may be drawn through the envelopes by the actions of these machines.

THE CROSS CONTAMINATED LETTER IN CONNECTICUT

On Oct. 9, 2001 anthrax laden letters addressed to two US Senators were processed through the Hamilton Township sorting center near Trenton, NJ. In < 1 minute, 300 letters passed through the same sorting machines as each of these two original contaminated letters. These 600 letters (and more) were most likely cross contaminated letters. All were identifiable by postal bar code data and traceable to their destinations. A small number of these letters went to the Southern Connecticut Processing and Distribution Center in Wallingford, CT on Oct. 11. Anthrax spores were found on mail-sorting equipment in Wallingford. One of the Wallingford letters went to a recipient in Seymour, CT, who lived near a 94-year old woman in Oxford, CT. The woman died of inhalational anthrax on Nov. 21. The Seymour letter was found to contain small numbers of spores, and was probably a cross contaminated letter. No spores were found in the home of the woman in Oxford.



THE CASES

The 22 cases of anthrax in the outbreak, 18 confirmed by the CDC and 4 deemed suspicious. Case 10 was removed due to lack of confirmatory testing.

Case	Age	Gender	Onset Date	Location	Type	Status	Source	Disp.	DOD
1	30	F	09/22/01	NYC	Cutaneous	Suspected	Sept. 18 letter	Alive	
2	38	F	09/25/01	NYC	Cutaneous	Confirmed	Sept. 18 letter	Alive	
3	39	M	09/26/01	NJ	Cutaneous	Suspected	Sept. 18 letter	Alive	
4	45	F	09/27/01	NJ	Cutaneous	Confirmed	Sept. 18 letter	Alive	
5	63	M	09/27/01	FL	Inhalational	Confirmed	Unfound mail	Dead	10/05/01
6	23	F	09/28/01	NYC	Cutaneous	Suspected	Sept. 18 letter	Alive	
7	73	M	09/28/01	FL	Inhalational	Confirmed	Unfound mail	Alive	
8	0.6	M	09/29/01	NYC	Cutaneous	Confirmed	Sept. 18 letter	Alive	
9	27	F	10/01/01	NYC	Cutaneous	Confirmed	Unfound mail	Alive	
10	54	M	10/13/01	NJ	Cutaneous	Removed	Oct. 9 letter	Alive	
11	56	F	10/14/01	NJ	Inhalational	Confirmed	Oct. 9 letter	Alive	
12	35	M	10/14/01	NJ	Cutaneous	Confirmed	Oct. 9 letter	Alive	
13	43	F	10/15/01	NJ	Inhalational	Confirmed	Oct. 9 letter	Alive	
14	56	M	10/16/01	DC	Inhalational	Confirmed	Oct. 9 letter	Alive	
15	55	M	10/16/01	DC	Inhalational	Confirmed	Oct. 9 letter	Dead	10/21/01
16	47	M	10/16/01	DC	Inhalational	Confirmed	Oct. 9 letter	Dead	10/22/01
17	56	M	10/16/01	DC	Inhalational	Confirmed	Oct. 9 letter	Alive	
18	51	F	10/17/01	NJ	Cutaneous	Confirmed	Oct. 9 letter	Alive	
19	34	M	10/19/01	NYC	Cutaneous	Suspected	Sept. 18 letter	Alive	
20	59	M	10/22/01	DC	Inhalational	Confirmed	Oct. 9 letter	Alive	
21	38	M	10/23/01	NYC	Cutaneous	Confirmed	Sept. 18 letter	Alive	
22	61	F	10/25/01	NYC	Inhalational	Confirmed	Unknown	Dead	10/31/01
23	94	F	11/14/01	CT	Inhalational	Confirmed	Oct. 9 letter	Dead	11/21/01

DATE OF ANTHRAX ONSET BY LOCATION OF THE CASES

The outbreak started on Friday, Sept. 21, 2001 in New York City (NYC), then extended to New Jersey (NJ), followed by Florida (FL), Washington DC (DC) and much later on Nov. 14, Connecticut (CT). There appear to be two waves of infection and one outlier.

QuickTime™ and a
Photo - JPEG decompressor
are needed to see this picture.

DATE OF ANTHRAX ONSET BY SOURCE OF EXPOSURE

No source letter was found for three persons in the first wave, but likely came via a Sept. 18th mailing. Two persons who appear in the second wave had contact with a Sept. 18 letter during Oct. 12-15. The second wave most likely had contact with the Daschle or Leahy letters, postmarked Oct. 9. Case 23 was most likely infected through cross contamination with a letter that had been processed Oct. 9 in Trenton, NJ. There is no definite link to explain Case 22, although possibly there was contact with disposed Sept. 18th letters or with mail cross contaminated by contact with the Oct. 9th letters.

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are needed to see this picture.

DATE OF ANTHRAX ONSET BY DISEASE TYPE

Cutaneous anthrax and inhalational anthrax each accounted for half of the 22 cases. Most of the inhalational anthrax occurred in the second wave, following exposure to the October 9th letters containing smaller, more refined spores.

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are needed to see this picture.

AGE AT ANTHRAX ONSET

Most of the 22 anthrax cases were aged 30-59 years, with three being less than 29 years and four being 60 or older. The persons in the second wave tended to be aged 30-59, reflective of the postal workers who came in contact with the October 9 letters.

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Photo - JPEG decompressor
are needed to see this picture.

SUMMARY OF THE MAILBORNE TRANSMISSION

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are needed to see this picture.

ROUTING OF THE LETTERS AND LOCATIONS OF CASES

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A MATHEMATICAL MODEL OF MAILBORNE TRANSMISSION OF ANTHRAX

(1) The model counts the number of contaminated letters at a series of postal nodes. As the contaminated letters travel through the nodes, there is a probability that they transfer spores to other letters, and thus proliferate the number of contaminated letters in successive generations. At each node the letters are classified according to spore count and generation level of cross-contamination.

(2) The model counts the recipients of contaminated letters at the last node. These recipients are classified by their age, which determines their probability of becoming infected as a function of the spore count of the letter they received.

COUNTING THE NUMBER OF CONTAMINATED LETTERS

The mail stream involves collection, handling, sorting, and distribution. A logical view of this process is sequential travel through 5 Nodes:

Node 1 - mailboxes or other points of entry into the postal system

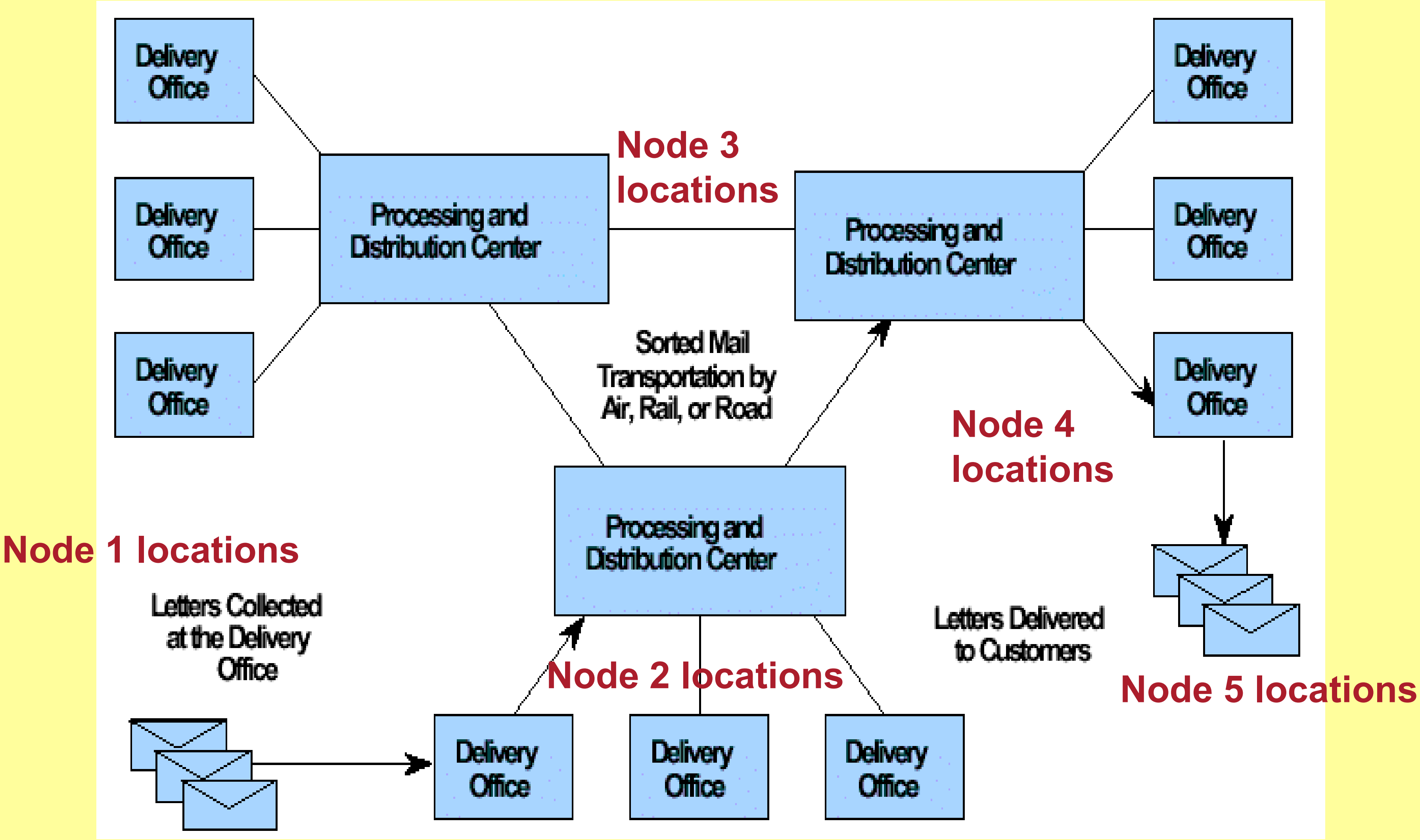
Node 2 - local postal delivery units

Node 3 - intra plant processing and distribution centers

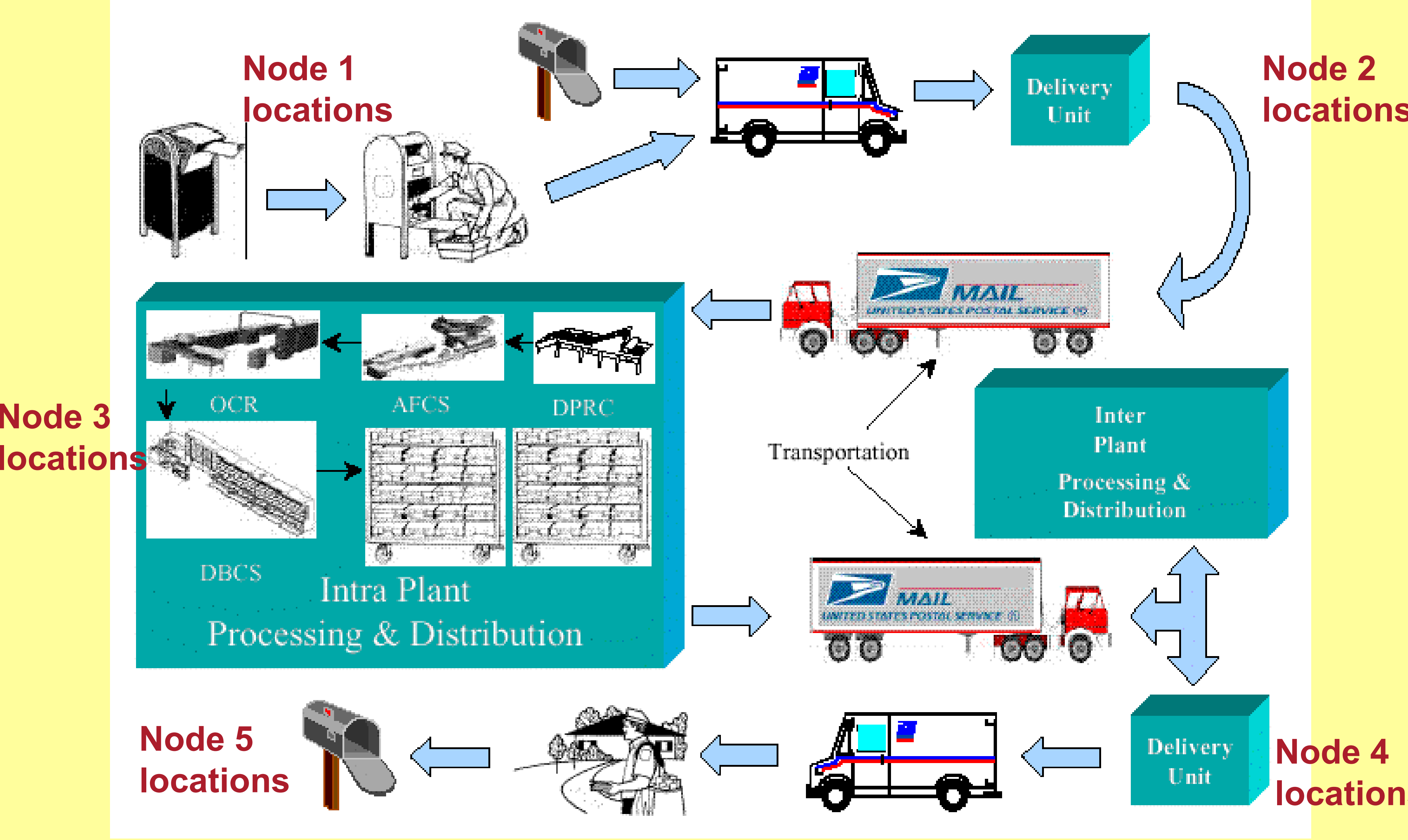
Node 4 - local postal delivery units

Node 5 - final destinations, such as households, businesses, or offices.

MAIL FLOW BLOCK DIAGRAM OF THE US POSTAL SYSTEM



MAIL HANDLING OVERVIEW



In the mathematical model the number of contaminated letters that travel through each of the nodes is represented by a vector

$$\vec{L}[m] = \begin{bmatrix} L[m]_1 \\ L[m]_2 \\ L[m]_3 \\ L[m]_4 \end{bmatrix}$$

The first component $L[m]_1$ **corresponds to the number of original contaminated letters at node** ***m = 1,2,3,4,5*****, each having > 10^{10} spores.**

The second component $L[m]_2$ **corresponds to the number of cross contaminated letters at node** ***m = 1,2,3,4,5*****, each having between 10^3 and 10^4 spores.**

The third component $L[m]_3$ **corresponds to the number of cross contaminated letters at node** ***m = 1,2,3,4,5*****, each having between 10^2 and 10^3 spores.**

The fourth component $L[m]_4$ **corresponds to the number of cross contaminated letters at node** ***m = 1,2,3,4,5*****, each having between 1 and 10^2 spores.**

NODE 1	NODE 2	NODE 3	NODE 4	NODE 5
$L[1]_1$ = number of letters with $> 10^{10}$ spores at node 1 = N	$L[2]_1$ = number of letters with $> 10^{10}$ spores at node 2 = N	$L[3]_1$ = number of letters with $> 10^{10}$ spores at node 3 = N	$L[4]_1$ = number of letters with $> 10^{10}$ spores at node 4 = N	$L[5]_1$ = number of letters with $> 10^{10}$ spores at node 5 = N
	$L[2]_2$ = number of letters with 10^3 to 10^4 spores at node 2	$L[3]_2$ = number of letters with 10^3 to 10^4 spores at node 3	$L[4]_2$ = number of letters with 10^3 to 10^4 spores at node 4	$L[5]_2$ = number of letters with 10^3 to 10^4 spores at node 5
	$L[2]_3$ = number of letters with 10^2 to 10^3 spores at node 2	$L[3]_3$ = number of letters with 10^2 to 10^3 spores at node 3	$L[4]_3$ = number of letters with 10^2 to 10^3 spores at node 4	$L[5]_3$ = number of letters with 10^2 to 10^3 spores at node 5
	$L[2]_4$ = number of letters with 1 to 10^2 spores at node 2	$L[3]_4$ = number of letters with 1 to 10^2 spores at node 3	$L[4]_4$ = number of letters with 1 to 10^2 spores at node 4	$L[5]_4$ = number of letters with 1 to 10^2 spores at node 5

It is assumed that there are N originally contaminated letters at node 1 locations. It is also assumed that none of the originally contaminated letters are lost and that their spore counts remain > 10^{10}. Thus

$$\vec{L}[1] = \begin{bmatrix} N \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

In the fall 2001 attack there were $N = 6$ (possibly more) originally contaminated letters placed in mailboxes in New Jersey.

At each node level *m = 1, 2, 3* a contaminated letter in spore class

$$L[m]_k \quad (k = 1, 2, 3)$$

produces an average $c[m]_{ik}$ cross contaminated letters arriving at node *m+1* locations in spore class

$$L[m+1]_i \quad (i = k+1,\ldots, 4).$$

The value of $c[m]_{ik}$ accounts for all cross-contamination events at a node *m* location or in route between node m locations and node *m+1* locations. For simplicity, conservation of spores is not considered specifically, and it is assumed that no letters are lost in routing and all remain in the same spore class as they move from node to node.

Under the assumption of the model the number of contaminated and cross contaminated letters at node 2 is obtained from the cross contamination matrix $C[1]$ **by**

$$\vec{L}[2] = (I_4 + C[1])\,\vec{L}[1]$$

$$\vec{L}[2] = \begin{bmatrix} L[2]_1 \\ L[2]_2 \\ L[2]_3 \\ L[2]_4 \end{bmatrix} = \left(\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} + \begin{bmatrix} 0 & 0 & 0 & 0 \\ c[1]_{21} & 0 & 0 & 0 \\ c[1]_{31} & 0 & 0 & 0 \\ c[1]_{41} & 0 & 0 & 0 \end{bmatrix} \right) \begin{bmatrix} N \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

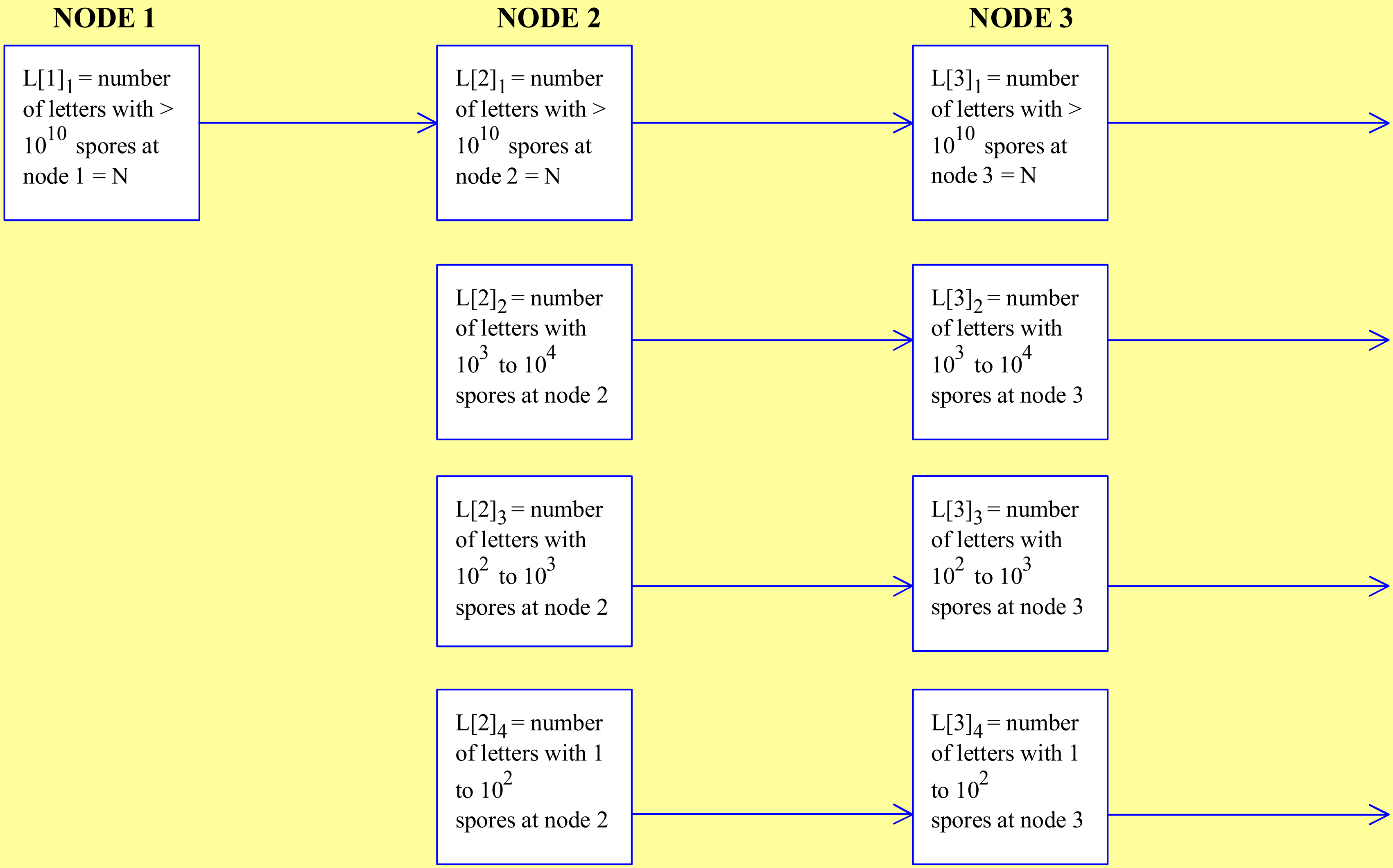
$$= \begin{bmatrix} N \\ c[1]_{21}\,N \\ c[1]_{31}\,N \\ c[1]_{41}\,N \end{bmatrix}$$

In general the number of contaminated and cross contaminated letters at node $m+1$ is obtained from the cross contamination matrix $C[m]$ by

$$\vec{L}[m+1] = (I_4 + C[m])\vec{L}[m], m = 1, 2, 3, 4$$

$$\vec{L}[m+1] = \begin{bmatrix} L[m+1]_1 \\ L[m+1]_2 \\ L[m+1]_3 \\ L[m+1]_4 \end{bmatrix} = \left(\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} + \begin{bmatrix} 0 & 0 & 0 & 0 \\ c[m]_{21} & 0 & 0 & 0 \\ c[m]_{31} & c[m]_{32} & 0 & 0 \\ c[m]_{41} & c[m]_{42} & c[m]_{43} & 0 \end{bmatrix} \right) \begin{bmatrix} L[m]_1 \\ L[m]_2 \\ L[m]_3 \\ L[m]_4 \end{bmatrix}$$

$$= \begin{bmatrix} L[m]_1 \\ L[m]_2 + c[m]_{21} L[m]_1 \\ L[m]_3 + c[m]_{31} L[m]_1 + c[m]_{32} L[m]_2 \\ L[m]_4 + c[m]_{41} L[m]_1 + c[m]_{42} L[m]_2 + c[m]_{43} L[m]_3 \end{bmatrix}$$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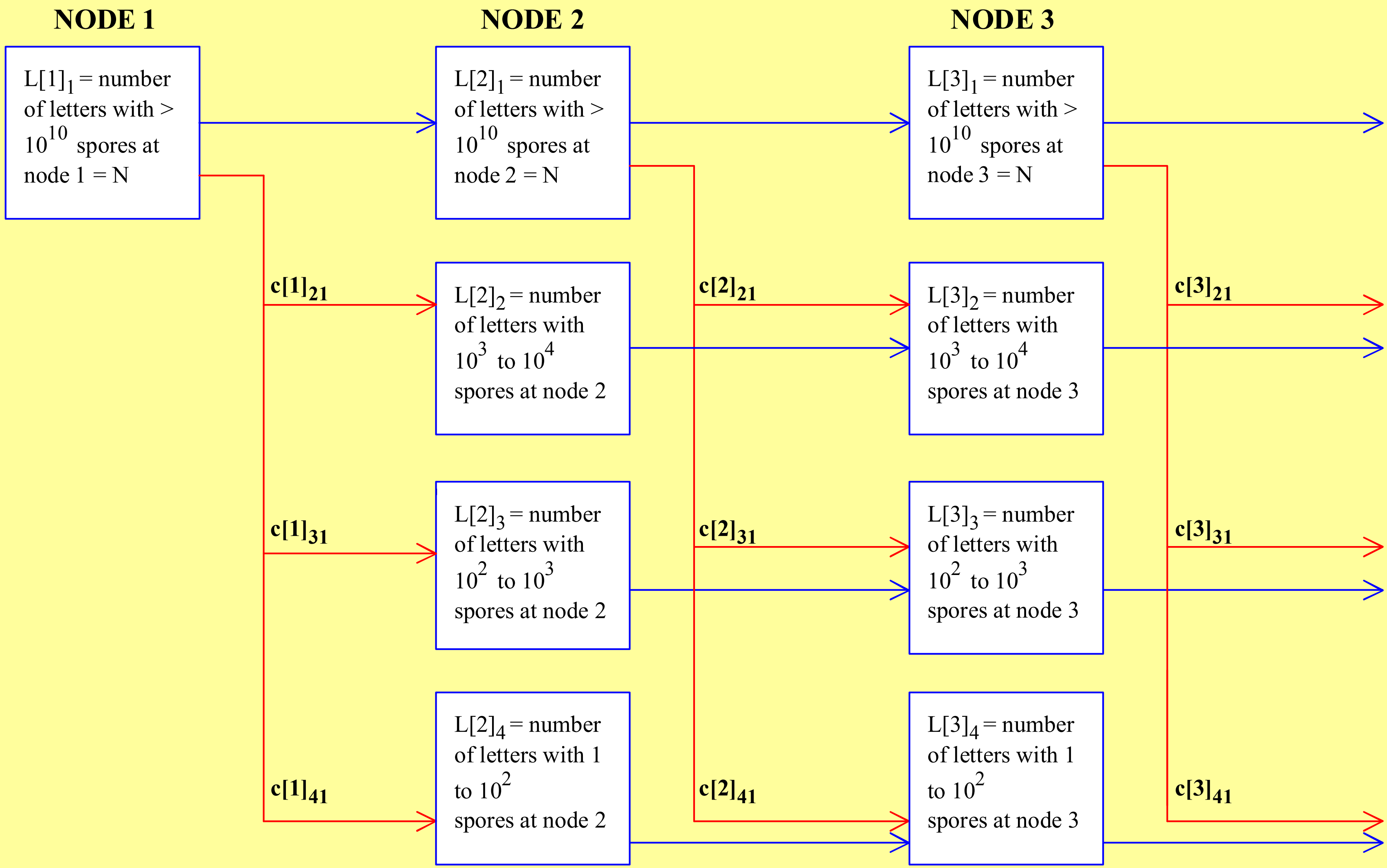

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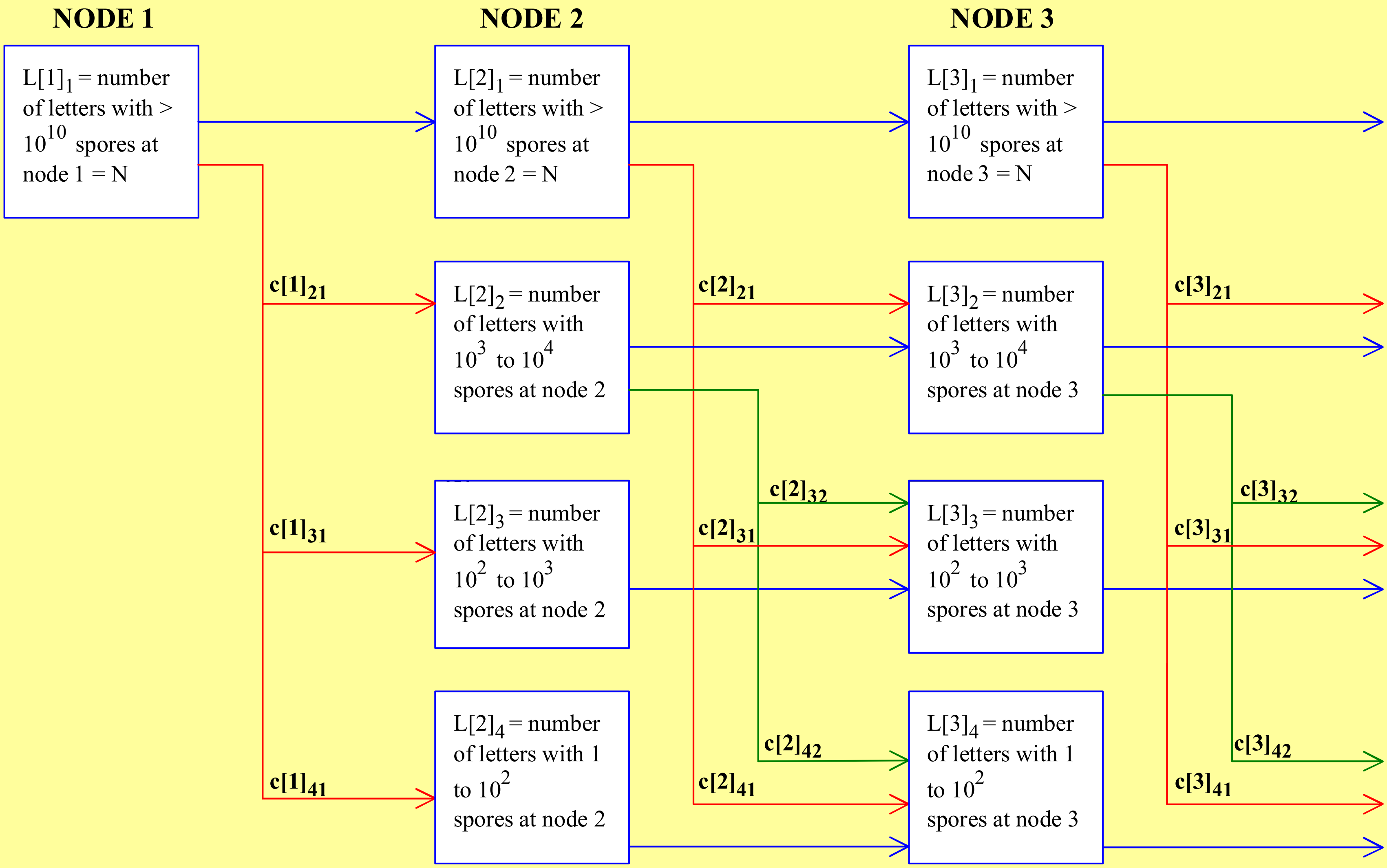

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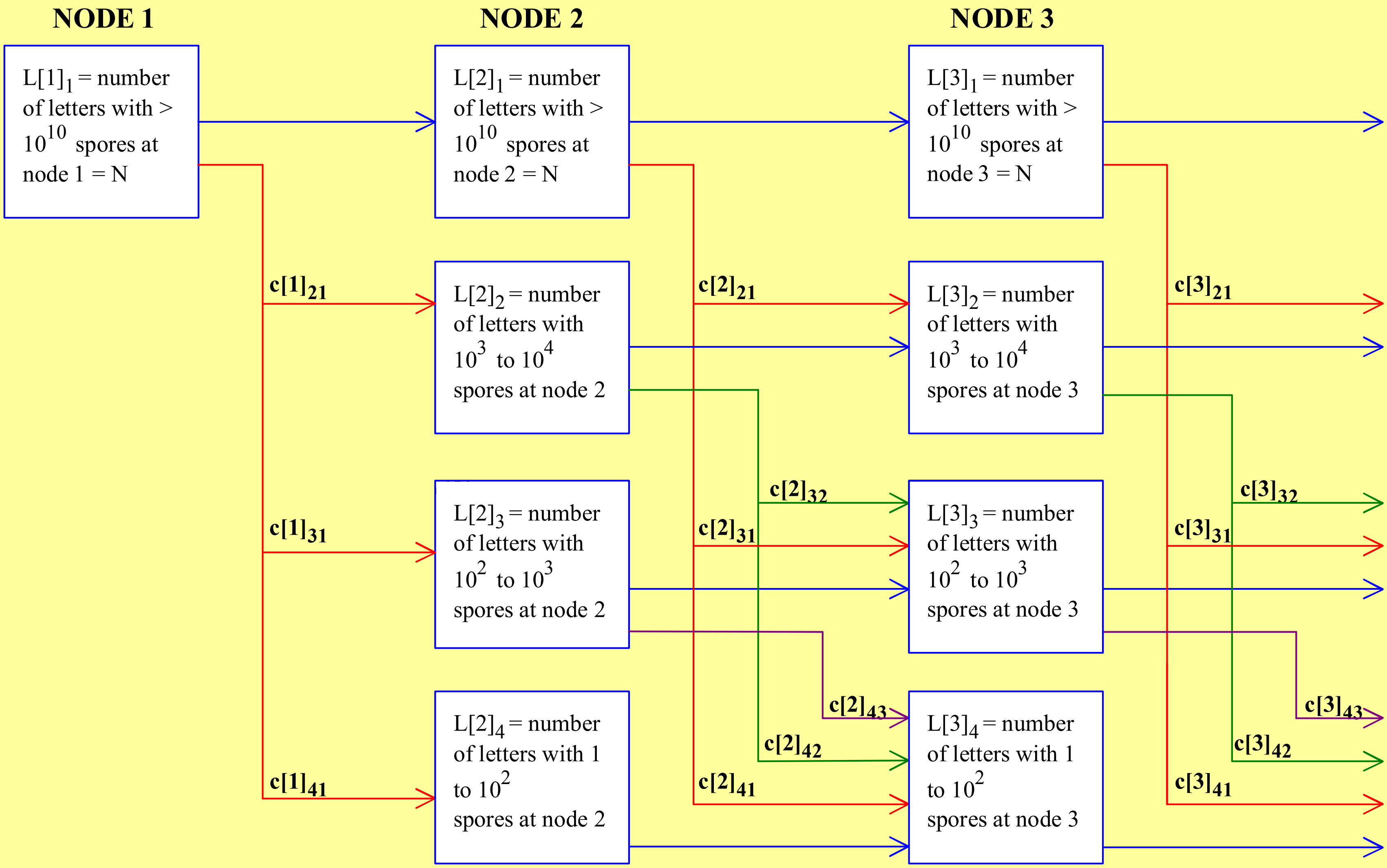

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c[3]$_{41}$

EXAMPLE CORRESPONDING TO THE US OUTBREAK IN 2001

In the fall 2001 outbreak there were 6 (possibly more) originally contaminated letters placed in mailboxes in New Jersey. Take

$N = 6$ **and the cross contamination matrices as**

$$C[1]=\begin{bmatrix} 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 10 & 0 & 0 & 0 \\ 100 & 0 & 0 & 0 \end{bmatrix}, C[2]=\begin{bmatrix} 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 10 & 1 & 0 & 0 \\ 100 & 10 & 1 & 0 \end{bmatrix}, C[3]=\begin{bmatrix} 0 & 0 & 0 & 0 \\ 3 & 0 & 0 & 0 \\ 30 & 3 & 0 & 0 \\ 300 & 30 & 3 & 0 \end{bmatrix}, C[4]=\begin{bmatrix} 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 10 & 1 & 0 & 0 \\ 100 & 10 & 1 & 0 \end{bmatrix}$$

OUTPUT OF THE MODEL

The number of contaminated letters at nodes 1, 2, 3, 4, 5 classified by spore count:

Spore Count	Node 1	Node 2	Node 3	Node 4	Node 5
$> 10^{10}$	6	6	6	6	6
$10^3 - 10^4$	0	6	12	30	36
$10^2 - 10^3$	0	60	126	342	432
$1 - 10^2$	0	600	1320	3858	5100

OUTPUT OF THE MODEL

The number of contaminated letters at Node 5 classified by spore count and generation level:

Spore Count	Original Letters	First Generation	Second Generation	Third Generation
$> 10^{10}$	6	0	0	0
$10^3 - 10^4$	0	36	0	0
$10^2 - 10^3$	0	360	72	0
$1 - 10^2$	0	3,600	1,440	60

The total number of cross contaminated letters is 5,568.

EXAMPLE CORRESPONDING TO AN AMPLIFICATION OF THE US OUTBREAK IN 2001

Take the number of original contaminated letters as $N = 100$ and take the cross contamination matrices as

$$C[1]=\begin{bmatrix} 0 & 0 & 0 & 0 \\ p & 0 & 0 & 0 \\ 10p & 0 & 0 & 0 \\ 100p & 0 & 0 & 0 \end{bmatrix}, C[2]=\begin{bmatrix} 0 & 0 & 0 & 0 \\ p & 0 & 0 & 0 \\ 10p & 1 & 0 & 0 \\ 100p & 10 & 1 & 0 \end{bmatrix}, C[3]=\begin{bmatrix} 0 & 0 & 0 & 0 \\ 3p & 0 & 0 & 0 \\ 30p & 3 & 0 & 0 \\ 300p & 30 & 3 & 0 \end{bmatrix}, C[4]=\begin{bmatrix} 0 & 0 & 0 & 0 \\ p & 0 & 0 & 0 \\ 10p & 1 & 0 & 0 \\ 100p & 10 & 1 & 0 \end{bmatrix}$$

where $p \geq 1$ is an amplification parameter corresponding to the capacity of the original letters to cross contaminate other letters.

OUTPUT OF THE MODEL FOR THE AMPLIFIED OUTBREAK

Take $N = 100$ and $p = 10$. The number of contaminated and cross contaminated letters at nodes *1, 2, 3, 4, 5* classified by spore count is

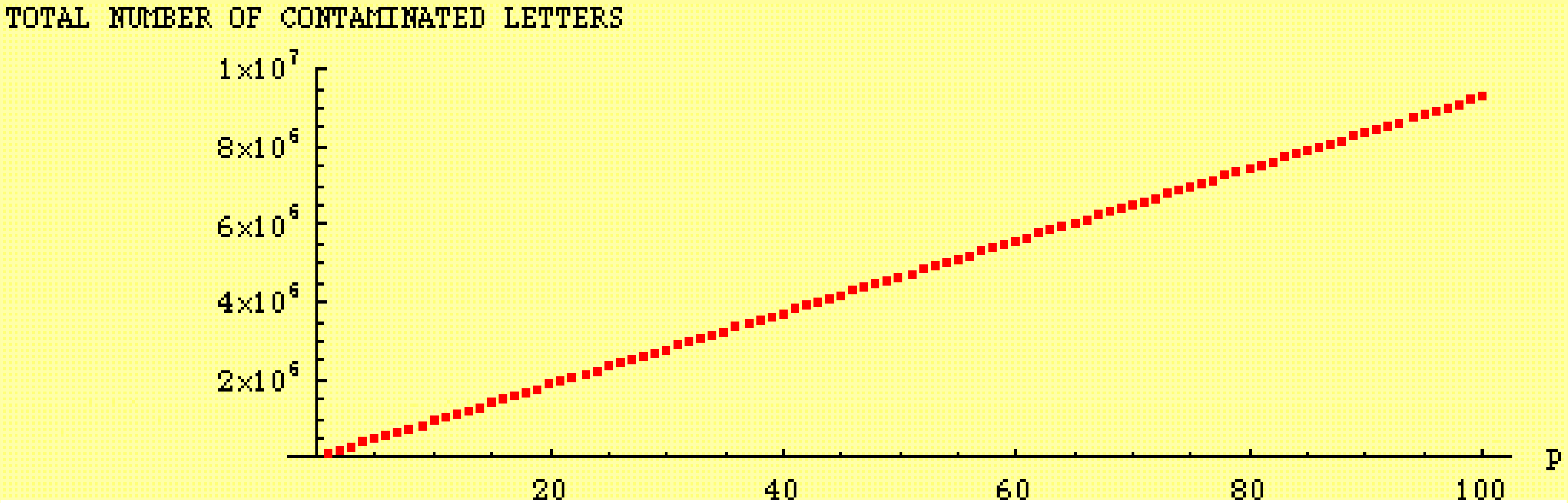
Spore Count	Node 1	Node 2	Node 3	Node 4	Node 5
$> 10^{10}$	100	100	100	100	100
$10^3 - 10^4$	0	1,000	2,000	5,000	6,000
$10^2 - 10^3$	0	10,000	21,000	57,000	72,000
$1 - 10^2$	0	100,000	220,000	643,000	850,000

OUTPUT OF THE MODEL ($N = 100$ and $p = 10$)

The number of contaminated letters at node *5* classified by spore count and generation level:

Spore Count	Original Letters	First Generation	Second Generation	Third Generation
$> 10^{10}$	100	0	0	0
10^3 - 10^4	0	6,000	0	0
10^2 - 10^3	0	60,000	12,000	0
1 - 10^2	0	600,000	240,000	10,000

THE TOTAL NUMBER OF CONTAMINATED LETTERS AS A FUNCTION OF THE AMPLIFICATION PARAMETER *p*



The number of original contaminated letters is $N = 100$. The amplification parameter p ranges from *1* to *100*.

COUNTING THE NUMBER OF CASES OF INHALATIONAL ANTHRAX OF NODE 5 RECIPIENTS PRODUCED BY CROSS CONTAMINATED LETTERS ---

It is assumed that the number of infections in recipients of cross contaminated letters at Node 5 locations is a function of

(1) the spore count of the letter received;

(2) the average number of recipients exposed to each letter;

(3) the probability of infection based on the number of spores inhaled from the letter and the age of the recipient (older individuals have a higher probability of infection).

Assume that recipients are divided into 4 age brackets (< *25, 25 - 44, 45 - 65*, and > *65*). For age bracket n $(n = 1,2,3,4)$ the probability of infection when S spores are inhaled is

$$Pr_n(S) = \frac{b_n\left(\exp\left(\frac{S}{a_n}\right) - 1\right)}{1 + b_n\left(\exp\left(\frac{S}{a_n}\right) - 1\right)}$$

where a_n and b_n are constants. The $Pr_n(S)$ curves are sigmoidal and satisfy $Pr_n(ID_{50}) = .5$ and $Pr_n(ID_{10}) = .1$, where ID_{50} and ID_{10} are the number of inhaled spores that produce inhalational anthrax in 50% and 10%, respectively, of individuals in age bracket n.

Assume the average number of recipients exposed to each letter received at a Node 5 location is E, the fraction of spores inhaled by each exposed recipient is I, and the fraction of the recipients in age bracket n is $f[n]$. An estimate of the average number of infectious cases by spore count of letter received and age of recipient is

Spore Count	Age Bracket		Number of Cases
$10^3 - 10^4$	n=1	< 25	$.5\, f[1]\, E\, (Pr_1 (I \times 10^3) + Pr_1 (I \times 10^4))$
	n=2	25 - 44	$.5\, f[2]\, E\, (Pr_2 (I \times 10^3) + Pr_2 (I \times 10^4))$
	n=3	45 - 64	$.5\, f[3]\, E\, (Pr_3 (I \times 10^3) + Pr_3 (I \times 10^4))$
	n=4	> 65	$.5\, f[4]\, E\, (Pr_4 (I \times 10^3) + Pr_4 (I \times 10^4))$
$10^2 - 10^3$	n=1	< 25	$.5\, f[1]\, E\, (Pr_1 (I \times 10^2) + Pr_1 (I \times 10^3))$
	n=2	25 - 44	$.5\, f[2]\, E\, (Pr_2 (I \times 10^2) + Pr_2 (I \times 10^3))$
	n=3	45 - 64	$.5\, f[3]\, E\, (Pr_3 (I \times 10^2) + Pr_3 (I \times 10^3))$
	n=4	> 65	$.5\, f[4]\, E\, (Pr_4 (I \times 10^2) + Pr_4 (I \times 10^3))$
$1 - 10^2$	n=1	< 25	$.5\, f[1]\, E\, (Pr_1 (I \times 1) + Pr_1 (I \times 10^2))$
	n=2	25 - 44	$.5\, f[2]\, E\, (Pr_2 (I \times 1) + Pr_2 (I \times 10^2))$
	n=3	45 - 64	$.5\, f[3]\, E\, (Pr_3 (I \times 1) + Pr_3 (I \times 10^2))$
	n=4	> 65	$.5\, f[4]\, E\, (Pr_4 (I \times 1) + Pr_4 (I \times 10^2))$

EXAMPLE CORRESPONDING TO THE US OUTBREAK IN 2001

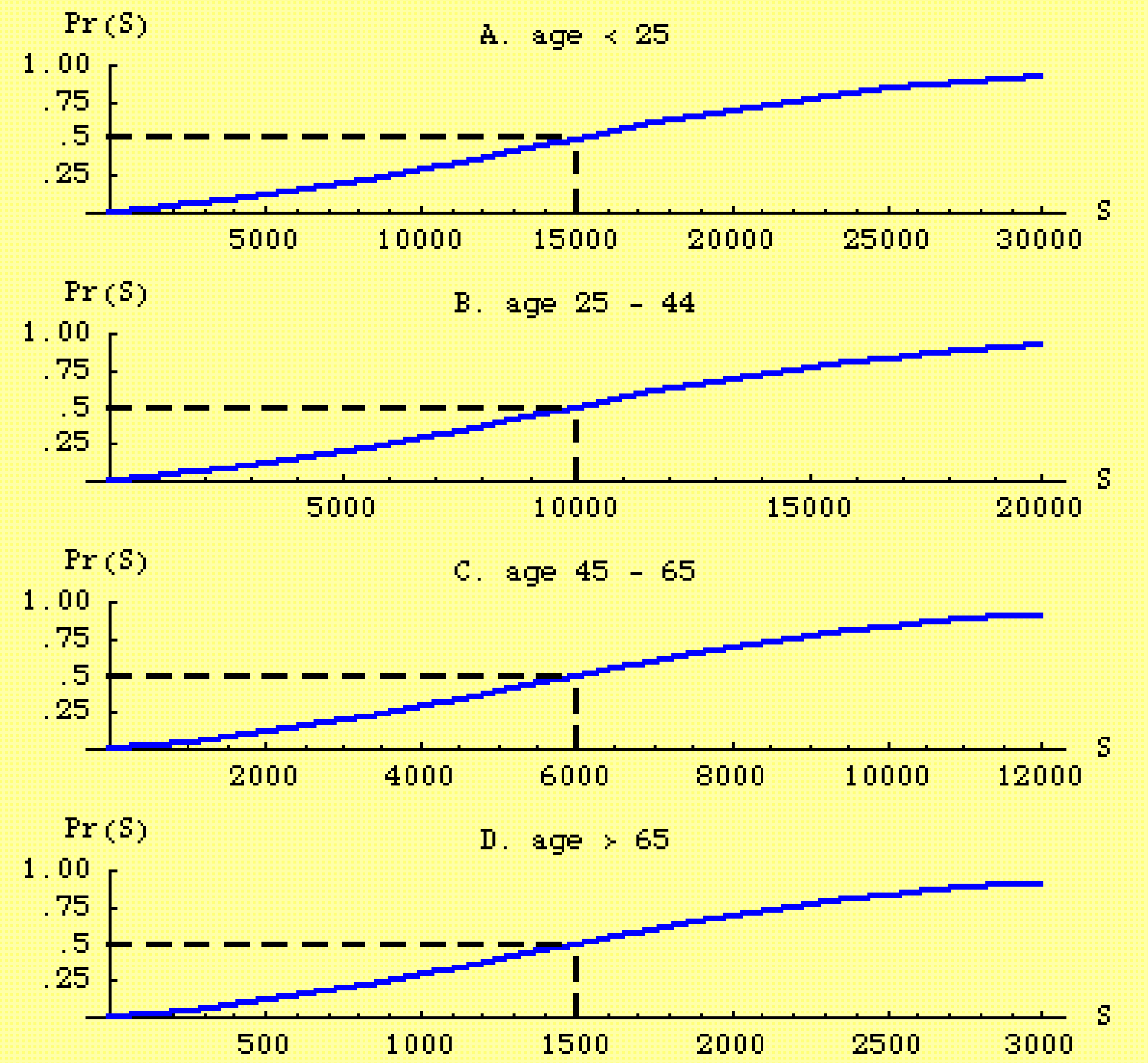
Take $N = 6$ (the number of original contaminated letters), the cross contamination matrices as

$$C[1]=\begin{bmatrix}0&0&0&0\\1&0&0&0\\10&0&0&0\\100&0&0&0\end{bmatrix},C[2]=\begin{bmatrix}0&0&0&0\\1&0&0&0\\10&1&0&0\\100&10&1&0\end{bmatrix},C[3]=\begin{bmatrix}0&0&0&0\\3&0&0&0\\30&3&0&0\\300&30&3&0\end{bmatrix},C[4]=\begin{bmatrix}0&0&0&0\\1&0&0&0\\10&1&0&0\\100&10&1&0\end{bmatrix}$$

the average number of exposed recipients as $E = 1.5$, the fraction of spores inhaled from a cross contaminated letter as $I = .03$, and the age bracket fractions and infectious dose parameters as

Age Bracket	Fraction $f[n]$ of Recipients	ID_{50} [n]	ID_{10}[n]
n=1 (< 25)	.05	15,000	4,500
n=2 (25 - 44)	.35	10,000	3,000
n=3 (45 - 65)	.35	6,000	1,800
n=4 (> 65)	.25	1,500	450

The ID curves for the 4 age brackets are



OUTPUT OF THE MODEL

The number of cross contaminated cases of recipients at Node 5 locations classified by spore count of letter received, age of recipient, and the proportion in each generation level:

Spore count of letter received	Age of infected recipient				Fraction of cases by the generation level of letter received		
	< 25	25 - 44	45 - 65	> 65	First	Second	Third
10^3 - 10^4	.007	.08	.14	.45	1.0	.0	.0
10^2 - 10^3	.009	.10	.16	.47	.83	.17	.0
1 - 10^2	.011	.11	.19	.54	.71	.28	.1

EXAMPLE CORRESPONDING TO AN AMPLIFICATION OF THE US OUTBREAK IN 2001

Take $N = 100$ (the number of original contaminated letters), $E = 1.5$ (the average number of exposed recipients), $I = .03$ (the fraction of spores inhaled), the age bracket fractions $f[n]$ and the infectious dose parameters as before, and the cross contamination matrices

$$C[1]=\begin{bmatrix} 0 & 0 & 0 & 0 \\ p & 0 & 0 & 0 \\ 10p & 0 & 0 & 0 \\ 100p & 0 & 0 & 0 \end{bmatrix}, C[2]=\begin{bmatrix} 0 & 0 & 0 & 0 \\ p & 0 & 0 & 0 \\ 10p & 1 & 0 & 0 \\ 100p & 10 & 1 & 0 \end{bmatrix}, C[3]=\begin{bmatrix} 0 & 0 & 0 & 0 \\ 3p & 0 & 0 & 0 \\ 30p & 3 & 0 & 0 \\ 300p & 30 & 3 & 0 \end{bmatrix}, C[4]=\begin{bmatrix} 0 & 0 & 0 & 0 \\ p & 0 & 0 & 0 \\ 10p & 1 & 0 & 0 \\ 100p & 10 & 1 & 0 \end{bmatrix}$$

where $p \geq 1$ is an amplification parameter corresponding to the capacity of the original letters to cross contaminate other letters.

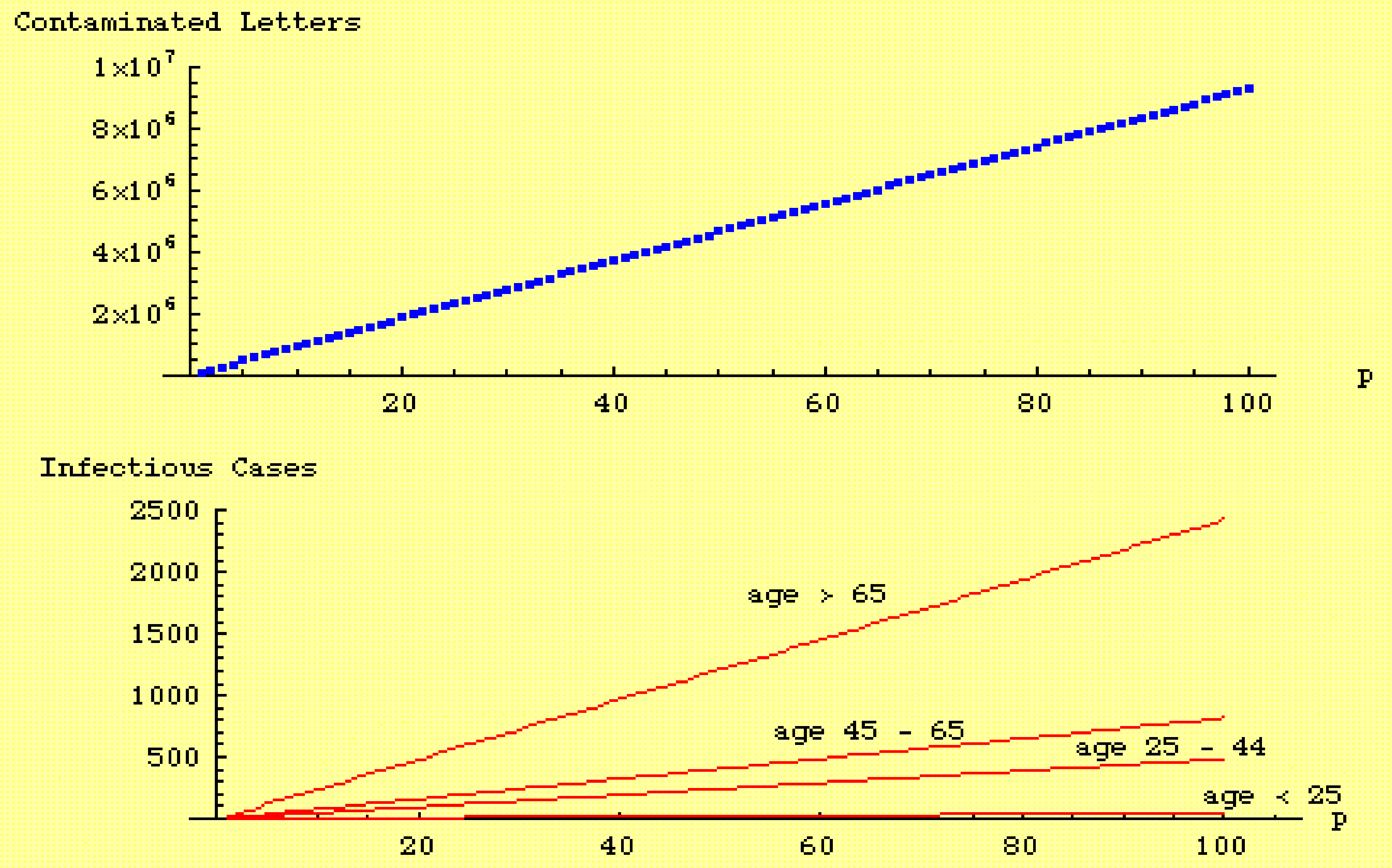
OUTPUT OF THE MODEL FOR THE AMPLIFIED OUTBREAK

The number of cross contaminated cases (rounded to the nearest integer) of recipients at Node 5 locations classified by spore count of letter received and age of recipient, when $N = 100$ and the amplification parameter $p = 10$:

Spore count of letter received	Age of infected recipient			
	< 25	25 - 44	45 - 65	> 65
10^3 - 10^4	1	14	23	75
10^2 - 10^3	2	16	27	78
1 - 10^2	2	19	32	90

The total number of infectious cases is 379 and the total number of cross contaminated letters is 928,000.

THE TOTAL NUMBER OF CONTAMINATED LETTERS AND THE TOTAL NUMBER OF INFECTIOUS CASES AS A FUNCTION OF THE AMPLIFICATION PARAMETER *p*



USPS EMERGENCY PREPAREDNESS PLAN FOR FUTURE TERRORISTS ATTACKS ON THE US POSTAL SYSTEM

Prevention – Reduce the risk that someone could use the mail as a tool of terror.

Protection and Health-Risk Reduction – Reduce risk of exposure to biohazards, and prevent cross-contamination of mail if biohazards should be introduced into the mail system.

Detection and Identification – Detect and identify potential hazardous materials as early as possible in the mail stream.

Intervention – As a precaution, neutralize potential contaminants in the mail.

Decontamination – Eliminate known contaminants, both in the mail and in equipment and facilities.

USPS MAIL ENTRY POINTS

Containment	Redesign collection box to contain mail in a separate box or containment bag
Detection	Use biohazard detection strips in collection box
Decontamination	Use sealed polyethylene bags in collection boxes and a decontaminating agent
Tracking	Modify existing system to track unit loads in collection boxes using Delivery Confirmation Scanner

USPS FACILITIES

Vacuum filtration systems	Install permanent vacuum (ventilation) systems on mail-processing equipment to automatically and continuously vacuum, and to extract and capture particulate matter
High-efficiency particulate air (HEPA) cleaning systems	Use filtered vacuums to clean mail-processing equipment and building surfaces
Protective wear	Equip workers with protective gloves and masks

TRIGGERING OF BIOHAZARDS

Particle counter	Continuously collect air from specified points in the mail stream where a biohazardous plume is most likely to occur
Particulate shape analyzer	Measure shape and size of particles in the 2-20 micron range from the continuously collected points
Laser discriminator	Collect particles amassed from the continuous air stream within a defined size range; fluoresce with laser to determine biohazard signature

CONFIRMATION OF BIOHAZARDS

Biological indicator strip	Use strips with indicator agents that react to compounds found in the biothreat
Immunoassay test strip	Introduce liquid sample of target substance on test strips to indicate presence of a biohazard
Polymerase chain reaction (PCR)	Introduce liquid sample into a self-contained cartridge that determines the presence of a biohazard
Mass spectrometer	Use electric and magnetic fields to precisely measure the mass of charged particles and match to library samples of known biohazards

MAIL SANITIZATION AND DECONTAMINATION

Irradiation - ionizing radiation (electron beam, x-ray, gamma ray)	Irradiate mail with electrons, x-rays, or gamma rays to break chemical bonds and damage DNA of bacteria
Irradiation - non-ionizing radiation (ultraviolet light (UV), microwave)	Use UV radiation to kill microorganisms by damaging DNA and microwave radiation to heat and kill microorganisms
Gas plasmas	Use plasma generators to produce high temperature reactive material (limited to equipment, not for mail)
Ultra-high pressure (UHP) sterilization	Use UHP to inactivate microorganisms by physically changing protein and nucleic acid structure
Gaseous treatment (chlorine dioxide, ethylene oxide, methyl bromide ozone)	Use gases with anti-microbial properties to kill potential biohazardous materials

QUESTIONS ABOUT ANTHRAX AS A WEAPON AND IMPLICATIONS OF THE MODEL FOR FUTURE ATTACKS

(1) What is the risk to the US civilian population in a future anthrax attack on the US Postal System? Are additional measures for preparation and response needed?

(2) What is the risk to the US civilian population generally in a future anthrax attack? What can we learn about this risk from the mailborne attacks?

(1) What is the risk to the US civilian population in a future anthrax attack on the US Postal System? Are additional measures needed?

The model predicts that a larger scale attack could result in hundreds of thousands or millions of cross contaminated letters with thousands or tens of thousands of infectious cases. Such an event would necessitate the suspension of the US Postal System. Apart from the human costs, the economics costs of such a suspension would be devastating.

The Emergency Preparedness Plan should include preparation for suspending the US Postal System, securing postal facilities, planning medical response for postal workers, and preparing the public for such an event. In the event of a suspension, local communities should prepare for emergency medical treatment, as well as alternative means of essential communication now provided by the US Postal System (electronic, e-mail, telephone, in-person, etc.).

(2) What is the risk to the US civilian population generally in a future anthrax attack? What can we learn about this risk from the mailborne attacks?

In the fall 2001 attack there were few casualties and limited economic losses, but the quantity of anthrax used was very small and the method of attack very restrained. The experience demonstrated, however, that very low exposure doses can lead to infection in a small proportion of individuals. A large scale attack, which would expose large populations to anthrax spores in low doses, could thus be devastating.

The risk to US civilian population of an anthrax attack on a major city must be viewed as potentially devastating in terms of human and economic costs. Weaponized anthrax spores will remain a serious threat to US civilian society until advances in medical treatment of anthrax renders it ineffective as a weapon of mass destruction.

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Ralph Frerichs
Department of Epidemiology and School of Public Health UCLA
http://www.ph.ucla.edu/epi/faculty/frerichs

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