Direct and indirect contact rates among beef, dairy, goat, sheep, and swine herds in three California counties, with reference to control of potential foot-and-mouth disease transmission

Thomas W. Bates, BS; Mark C. Thurmond, DVM, PhD; Tim E. Carpenter, PhD

Objective—To estimate direct and indirect contact rates on livestock facilities and distance traveled between herd contacts.

Sample Population—320 beef, dairy, goat, sheep, and swine herds, 7 artificial insemination technicians, 6 hoof trimmers, 15 veterinarians, 4 sales yard owners, and 7 managers of livestock-related companies within a 3-county region of California.

Procedure—A questionnaire was mailed to livestock producers, and personal and telephone interviews were conducted with individuals.

Results—Mean monthly direct contact rates were 2.6, 1.6, and 2.0 for dairies with < 1,000, 1,000 to 1,999, and ≥ 2,000 cattle, respectively. Mean indirect contact rates on dairies ranged from 234 to 743 contacts/mo and increased by 1 contact/mo as herd size increased by 4.3. Mean direct monthly contact rate for beef herds was 0.4. Distance traveled by personnel and vehicles during a 3-day period ranged from 58.4 to 210.4 km. Of livestock arriving at sales yards, 7% (500/7,072) came from ≥ 60 km away, and of those sold, 32% (1,180/3,721) were destined for a location ≥ 60 km away. Fifty-five percent (16/29) of owners of large beef herds observed deer or elk within 150 m of livestock at least once per month.

Conclusions and Clinical Relevance—Direct and indirect contacts occur on livestock facilities located over a wide geographic area and at a higher frequency on larger facilities. Knowledge of contact rates may be useful for planning biosecurity programs at the herd, state, and national levels and for modeling transmission potential for foot-and-mouth disease virus. (*Am J Vet Res* 2001;62:1121–1129)

Control of animal movement from 1 population to another has long been a key requirement in effective disease control programs. Recent interest in preventing indigenous diseases such as salmonellosis and Johne's disease has renewed efforts to strengthen herd and flock biosecurity procedures, including limiting direct contact with animals and indirect contact with fomites (eg, vehicles and personnel) from other herds. An aim of biosecurity programs is to prevent transmission of infectious agents to a herd by minimizing contact with livestock, personnel, and inanimate objects from other herds. Although restriction of contact with other herds may be an ideal biosecurity concept, the reality is that certain modern livestock management practices may increase the potential for herd-to-herd transmission of infectious agents.

A common goal of livestock management practices is to maximize efficiency, which increasingly includes subcontract rearing. Subcontract rearing involves movement of replacement livestock to and from herds, removing and replacing nonproductive animals within a herd, disseminating culled livestock through sales yards, and expanding use of personnel who provide professional and technical health care services to multiple herds. These changing dynamics of the livestock industry can be expected to increase the potential for herd-to-herd disease transmission by promoting direct animal contact and indirect contact among herds via personnel and vehicles.

The potential for herd-to-herd transmission is of particular relevance to control of foreign animal diseases such as **foot-and-mouth disease (FMD)**. Costs estimated to the swine industry alone as a result of the 1997 FMD epidemic in Taiwan may reach $1.6 billion.[1] The highly contagious nature of FMD virus and the often subtle clinical signs that resemble those of common indigenous diseases allows for the rapid spread of the virus over a wide geographic area before a diagnosis can be made. Although FMD has not been diagnosed in the United States since 1929, the expanded range and rate of livestock movement and the changing complexion of international politics and economics increase the probability of FMD virus entering the United States. Changes in trade policy that permit importation of animal products from designated regions of countries with FMD could increase the chance of inadvertent introduction of the virus, and the new threats of agroterrorism that include the release of exotic animal diseases increase the chance of intentional introduction of FMD into the United States.[2,3]

Preparation for control of FMD, should it enter the United States, includes an emergency plan that will be implemented immediately upon confirmation of FMD.

Received May 3, 2000.
Accepted Aug 17, 2000.
From the Department of Medicine and Epidemiology, School of Veterinary Medicine, University of California, Davis, CA 95616.
Supported in part by USDA Animal Health Formula Funds, USDA/NRICGP grant no. 35204-10173, and collaborative agreements with the California Department of Food and Agriculture and the USDA Animal Plant Health Inspection Service, Veterinary Services.
The authors thank Drs. Dana Nelson, Dorothy York, Connor Jameson, and John Leerhoff, and Debra Sumpter for technical assistance with interviews; Victor Velez for assistance with procedural guidelines; Doris Hooten for arranging prospective interviews; and Drs. Ken Thomazin, Richard Breitmeyer, Phil LaRussa, and Paul Ugstad for assistance in coordination of the study and providing lists of livestock producers.
Address correspondence to Dr. Thurmond.

Unauthenticated | Downloaded 02/09/25 01:59 AM UTC

The plan will need to address several assessments for spread, including probabilities of herd-to-herd transmission, estimates of how far exposed animals traveled within a few days after exposure, and the nature and range of travel for other contacts between exposed and susceptible populations, including wildlife. Models will need to be developed to offer some prediction of the many possible scenarios that could unfold in an FMD epidemic. Such models should simulate the probable rate and directions of FMD virus movement, given the estimated direct and indirect contact rates and ranges among herds. The estimates and probability functions that represent these direct and indirect contact rates and distances traveled are prerequisite elements of models aimed at predicting the geographic spread of FMD. The objective of the study reported here was to estimate rates of and distances for direct animal-to-animal contact and indirect personnel- or vehicle-to-animal contact among herds in a 3-county region of California with a large livestock population.

Materials and Methods

Study region—Fresno, Kings, and Tulare counties in the Central Valley of California were selected as the study region, because these counties contain a large variety and density of livestock and livestock facilities. The 3-county area covers 31,000 km^2 and is trisected by 2 major freeways. This region was well suited for the study, because it is sufficiently large to allow modeling of herd-to-herd disease transmission yet is small enough to permit collection of data necessary to create realistic contact simulation models. Moreover, these 3 counties are heavily populated with large dry-lot dairies, beef and swine herds, and sheep flocks. In 1997, it was estimated that this region contained 67,000 beef cows, 462,000 dairy cows, 124,000 pigs, and 94,000 sheep,[4] many of which resided on small livestock facilities that were not enumerated. For purposes of the present study, livestock operations with ≤ 10 animals of any 1 species were considered backyard facilities.

Questionnaire—A 3-page questionnaire was developed to collect information on direct animal-to-animal contact and indirect contact by health personnel and vehicles on multiple types of livestock facilities. Lists of livestock producers in the study region were obtained from the **California Department of Food and Agriculture (CDFA)**, California Wool Growers Association, and California Pork Producers. The questionnaire was mailed during March 1999 to all addresses believed to have cloven-hoofed livestock (n = 1,406). The first mailing included a cover letter explaining the project and the importance of the research, letters of support from the CDFA and the USDA, the 3-page questionnaire, and a postage-prepaid return envelope. Nonresponders were notified once with a follow-up mailing 4 weeks later. The questionnaire mailed to dairies contained 4 additional dairy-specific management questions that were not considered in the present study.

Estimation of direct animal-to-animal contact—Direct contact was defined as contact from animals moving from 1 livestock facility to another. Questionnaire recipients were asked to record the frequency of animal movements to and from the facility (ie, once per day, once every n days, once every n months, or never), according to source and destination categories (ie, sales yard, feed yard, livestock dealer, slaughterhouse, or other), and the 3 most recent movements of livestock to and from their facility. Entries for each animal movement included date, purpose, and city and state of origin and destination.

Monthly frequency of movements for a given facility was estimated as the sum of the number of livestock movements for each category. For example, a response from a facility indicating receipt of livestock once every 30 days from a heifer ranch and once every 60 days from a sales yard was counted as 1 and 0.5 movements/mo, respectively, and 1.5 direct contacts/mo for the facility. Movement of animals shipped from a surveyed facility was calculated in a similar fashion and included movement of animals among geographically separated herds or pastures belonging to the same owner. For each movement, distance between herds was estimated as the straight-line distance between the reported origin and destination points. Data containing the latitude and longitude of the geographic center of each city and town were obtained from the United States Geological Survey[5] and used to determine the origin and destination points. When a movement was reported within the same town, 8 km (5 miles) was used as a local movement distance; this distance approximated the radius of town limits within the study region.

Estimation of indirect contact—Indirect contact was considered contact of the livestock facility by individuals and vehicles that visited multiple livestock facilities and that could act as fomites to transmit disease agents from 1 facility to another. Information was obtained from completed questionnaires regarding the frequency of visitation by 20 potential contacts known to regularly visit livestock facilities. Respondents were asked to record the frequency of visitation by each type of individual or vehicle (ie, 2 to 3 times/d, every day, once every n days, once every n months, or never). Visitation by individuals who were expected to come in contact with all livestock facilities, such as utility meter readers or postal delivery persons, were excluded from the list of potential contacts.

Monthly frequency of indirect contact was estimated as the sum of visits by 20 potential person and vehicle contacts plus the number of facility employees that did not reside at the facility. Contacts in the category 2 to 3 times/d were considered as 2.5 contacts/d. If the respondent left an answer blank, the response for that category was not included in data analysis. Additional indirect contact information was collected by interviewing 7 artificial insemination technicians, 6 hoof trimmers, and 15 veterinarians, all of whom worked primarily in the study region, and 7 owners or managers of companies with fleets of vehicles (n = 73) that made frequent visits to livestock facilities in the study region. These individuals were asked questions regarding the number and location of livestock facilities visited per day for a typical 3-day work period. The day of interview was randomly selected on the basis of when an interview could be scheduled.

Artificial insemination technicians were selected randomly from a list of technicians compiled from local telephone and county farming directories and interviewed during March and April 1999. One independent technician and 6 technicians working for 4 businesses were selected at random. Hoof trimmers were selected randomly from a list provided by a national hoof trimmers association; however, 5 could not be contacted or declined to be interviewed. A new list of 5 hoof trimmers was compiled from the remaining names and from local agriculture directories. Interviews with all 6 hoof trimmers were conducted from February through April 1999. Names of 78 veterinarians were obtained from the USDA contract veterinarian list, which is a list of veterinarians under federal contract who can be contacted in the event of an animal disease emergency. A random sample of food-animal veterinarians, stratified on county of practice, was selected. No more than 2 veterinarians were selected per veterinary clinic. Interviews with 15 veterinarians were conducted between February and May 1999. Managers of 2 com-

Unauthenticated | Downloaded 02/09/25 01:59 AM UTC

modity feed delivery companies, 2 rendering companies, and 3 creameries provided randomly selected routes for 12 commodity vehicles, 6 rendering vehicles and 55 milk tanker trucks operating during a typical 3-day period.

Sales yards—To estimate typical distances that livestock traveled to and from a sales yard, managers of 6 sales yards operating within the study region were asked to provide buyers' or sellers' addresses and the number and species of animals being consigned or sold at auction during a 2-week period in November 1998. Our primary interest was obtaining data regarding movement of restocking livestock or animals sold for individual consumption and not those sent to slaughter. Therefore, information from 8 livestock buyers who purchased > 200 head of livestock, which represented 53% of all livestock purchased, was omitted in the calculation of livestock delivery distances from sales yards, because livestock from these buyers were likely sent to slaughter. The addresses of buyers and sellers were used in the calculation of transport distances as a proxy for the origin and destination points, because actual origin and destination locations were unknown. Sales yard managers were also asked questions regarding potential seasonal variation of livestock movement to the sales yard and number and type of livestock handled by the sales yard.

Estimation of contact with cloven-hoofed wildlife—To assess the potential for transmission of disease agents by cloven-hoofed wildlife, survey participants were asked how many days per month and per year feral swine, deer, and elk were observed within 150 meters of their livestock.

Locations of livestock facilities—A list was obtained from CDFA and USDA containing the exact latitude and longitude, acquired by use of global positioning receivers, of all dairies in the 3-county region. Locations of livestock facilities for beef, swine, sheep, and goats were obtained through use of geocoding software[a] that provided a point estimate to the address provided. If an exact match was not made, however, less precise methods were used to approximate location, including the zip code or the geographic center of the nearest city or town.

Distance traveled—Range of distance traveled was estimated as the diameter of a circle that encompassed 95% of all livestock facilities visited by artificial insemination technicians, hoof trimmers, veterinarians, and commodity and rendering vehicles over a 3-day period. Diameter and ellipse dimensions were calculated, using spatial statistical analysis functions described elsewhere,[6] and programmed by use of commercial software.[b] The radius of the circle encompassing 95% of all livestock facilities visited (ie, the 95% **confidence interval [CI]**) by individuals and vehicles was estimated as 1.96 X the standard distance deviation. The distance deviation was calculated as the latitude and longitude of the mean center of all livestock facilities visited by each individual or vehicle during a 3-day period minus the mean center of all facilities visited (**Fig 1**). To permit combining the different mean centers of facilities visited to obtain a typical range of travel, mean center from and standardized coordinates for each group of facilities visited were calculated according to the following equations:

$$\text{Mean center of livestock facilities} = (\bar{x}, \bar{y}) = \left(\frac{\sum x_i}{n}, \frac{\sum y_i}{n}\right)$$

$$\text{Standardized coordinates } (x', y') = (\bar{x} - x_i, \bar{y} - y_i)$$

where x_i = longitude of facility i, y_i = latitude of facility i, and n = number of facilities visited by all individuals or vehicles.

As an illustration, the geographically independent herd locations visited by 15 veterinarians were combined, using the mean center of all herds visited by each veterinarian as the center point. The radius and dimensions of an ellipse that enclosed at least 95% of all livestock facilities contacted by all veterinarians was calculated according to the following equations:

$$SD = \sqrt{\left(\frac{\sum x_i^2}{n} - \bar{x}^2\right) + \left(\frac{\sum y_i^2}{n} - \bar{y}^2\right)}$$

$$\sigma_x = \sqrt{\frac{\sum(x'^2)\cos^2\theta - 2(\sum x'y')\sin\theta\cos\theta + \sum(y'^2)\sin^2\theta}{n}}$$

$$\sigma_y = \sqrt{\frac{\sum(x'^2)\sin^2\theta - 2(\sum x'y')\sin\theta\cos\theta + \sum(y'^2)\cos^2\theta}{n}}$$

where SD = standard distance deviation of a circle, σ_x = standard deviation of the x-axis distance of the ellipse, σ_y = standard deviation of the y-axis distance of the ellipse, and θ = the angle of rotation of the ellipse typically encompassing 95% of facilities visited by a person or vehicle.

Each location was weighted by the inverse of the number of veterinarians interviewed (n = 15) and multiplied by the number of livestock facilities visited by each veterinarian. The sum of the weights for all livestock facilities visited by veterinarians equaled 1. The ratio of ellipse length to ellipse width provided a measurement of narrowness, indicating a north-south directional point pattern, or width, indicating an east-west point pattern. A ratio of 1 indicated a circle. The rotation angle of the ellipse was calculated according to the following equation:

$$\tan\theta = \frac{(\sum x'^2 - \sum y'^2) + \sqrt{(\sum x'^2 - \sum y'^2)^2 + 4(\sum x'y')^2}}{2\sum x'y'}$$

Statistical analyses—Mean, median, and 95% confidence intervals were calculated for all variables by use of commercially available statistical analysis software.[c] The χ^2 test was

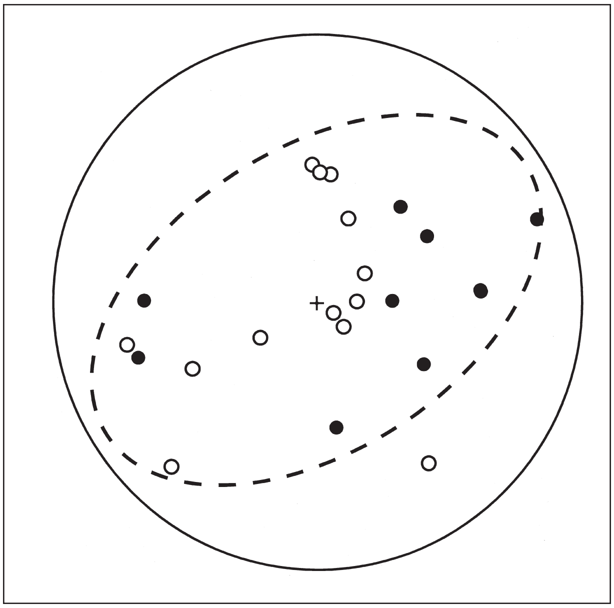

Figure 1—Illustration of a circle (solid line) and ellipse (dashed line) enclosing 95% of livestock facilities (closed and open circles) visited by 2 veterinarians in the Southern San Joaquin Valley of California (ie, Fresno, Kings, and Tulare counties). Locations of livestock facilities were standardized by subtracting the mean center from each cluster of livestock facilities and combined, using the individual mean centers as a common center point (plus sign).

Unauthenticated | Downloaded 02/09/25 01:59 AM UTC

used to assess differences in the percentage of responses to the mailed questionnaire among livestock facility types. Differences in number of indirect contacts among beef and dairy herds of different sizes were assessed by use of 1-way ANOVA and linear regression. The linear regression model used to assess contact rates on beef and dairy facilities was $c = b_0 + b_1h$, where c is the mean number of indirect contacts per month, b_0 is the monthly contact rate for a herd size of 0, b_1 is the change in monthly contact rate as herd size changed, and h is the interval-scaled herd size. For all analyses, probability of a type-I error < 0.05 was considered significant.

Results

Response to questionnaire—Questionnaires were mailed to 1,273 valid addresses; responses were received from 374 (29.4%) of those addresses, but only 320 (25.1%) surveys were complete (**Table 1**). Percentage of responses varied from 28.4 to 33.3% among the livestock facility categories but did not differ significantly ($\chi^2 = 0.09$; *df* = 3; *P* = 0.93) among categories. Three surveys returned by horse ranches were not included in analyses.

Direct animal contact—Dairy calf and heifer ranches with ≥ 250 animals had the greatest number of direct animal contacts resulting from animal shipments arriving to (mean, 17.0 contacts/mo; 95% CI, 2.3 to 28.8 contacts/mo) and leaving from (22.4 contacts/mo; 0 to 58.8 contacts/mo) their facilities (**Table 2**). Large swine operations (≥ 2,000 pigs) reported the fewest mean shipments arriving to their facilities (0.2 contacts/mo), whereas dairy calf and heifer ranches with < 250 animals reported the fewest mean shipments leaving from their facilities (0.7 contacts/mo; 95% CI, 0.3 to 1.1 contacts/mo). Twenty percent (114/560) of animals originated from and 7% (50/727) were delivered to locations ≥ 160 km from the reporting facility (**Fig 2 and 3**).

Indirect animal contact—Estimated mean monthly indirect contacts varied from 22.1 (95% CI, 15.9 to 36.3) for beef herds with < 250 cattle to 807.3 (374.9 to 1,239.5) for swine operations with ≥ 2,000 pigs. Most reported indirect contacts were by individuals classified as employees, followed by friends, neighbors or relatives, and commodity vehicles (**Table 3**). Indirect contacts on dairies increased by 1 contact/mo as herd size increased by 4.3 cattle; this increase was significant (*P* = 0.001; $R^2 = 0.40$). A similar association between increase in number of indirect contacts and herd size was found for beef herds (*P* = 0.006; R^2 = 0.095); however, only 9.5% of the variation in indirect contacts was explained by herd size. Larger beef herds (≥ 250 animals) had significantly (*P* = 0.02) more mean indirect contacts per month, compared with smaller beef herds (< 250 animals; 46.0 contacts vs 22.1 contacts).

Table 1—Responses to questionnaire mailed to livestock producers in Fresno, Kings, and Tulare counties of California during March 1999

Facility category	No. mailed	No. undeliverable (%)	No. returned (%)	No. completed (%)
Dairy	534	16 (3.0%)	156 (30.1%)	156 (30.1%)
Sheep	53	2 (3.8%)	16 (31.4%)	15 (28.3%)*
Swine	54	1 (1.9%)	17 (32.1%)	17 (32.1%)
Other†	765	114 (14.9%)	185 (28.4%)	132 (20.3%)*
Total	**1,406**	**133 (9.5%)**	**374 (29.4%)**	**320 (25.1%)**

*36 respondents no longer raised livestock; their responses were not included in analyses. One sheep and 17 beef producers returned incomplete questionnaires. †Beef herds, goat dairies, and dairy calf/heifer facilities.

Table 2—Number of direct monthly contacts attributable to animal shipments to and from livestock facilities in Fresno, Kings, and Tulare counties of California

		Animal shipments to facility		Animal shipments from facility	
Facility type	No. responding	No. reporting shipments (%)	Mean shipments/mo (95% CI†)	No. reporting shipments (%)	Mean shipments/mo (95% CI†)
Backyard*	31	23 (74.2%)	1.8 (0–7.1)	29 (93.5%)	1.7 (0–4.2)
Goat	3	3 (100.0%)	0.3 (0–1.9)	3 (100.0%)	6.6 (0–16.8)
Sheep	15	10 (66.7%)	2.0 (0–6.3)	15 (100.0%)	7.9 (0–18.8)
Beef					
< 250 cattle	52	36 (69.2%)	0.4 (0–2.0)	52 (100.0%)	0.9 (0.5–1.3)
≥ 250 cattle	29	25 (86.2%)	0.4 (0–1.4)	28 (96.6%)	2.0 (0–3.0)
Dairy					
< 1,000 cattle	54	40 (74.1%)	2.6 (0–7.3)	52 (96.3%)	8.2 (4.3–12.1)
1,000-1,999 cattle	54	38 (70.4%)	1.6 (0–4.0)	54 (100.0%)	17.4 (12.5–22.3)
≥ 2,000 cattle	48	36 (75.0%)	2.0 (0–6.3)	48 (100.0%)	16.4 (11.9–20.9)
Calf/heifer					
< 250 cattle	10	10 (100.0%)	0.3 (0–1.1)	10 (100.0%)	0.7 (0.3–1.1)
≥ 250 cattle	4	4 (100.0%)	17.0 (2.3–31.7)	4 (100.0%)	22.4 (0–58.8)
Swine					
< 2,000 pigs	12	9 (75.0%)	1.2 (0–3.8)	11 (91.7%)	4.8 (1.1–8.5)
≥ 2,000 pigs	5	1 (20.0%)	0.2	5 (100.0%)	20.0 (0.2–39.8)

*Facilities with ≤ 10 animals of any 1 type. †95% CI calculated by use of a normal or *t*-distribution, depending on sample size.
CI = Confidence interval.

Unauthenticated | Downloaded 02/09/25 01:59 AM UTC

Three hundred and one indirect contacts, identified through personal interviews, were attributable to visits by 7 artificial insemination technicians, 6 hoof trimmers, and 15 veterinarians to 207 different livestock facilities. The precise geographic location of 147 (71%) of these livestock facilities was identified by use of geocoding software. The remaining 60 (29%) facility locations were identified by use of zip code or the geographic center of the town listed in the address. The radii of circles required to encompass at least 95% of the facilities visited by artificial insemination technicians, hoof trimmers, and veterinarians were within 29.2, 42.5, and 28.6 km, respectively, of the geographic mean centers of the facilities (**Table 4**). Indirect contacts decreased as distance increased, with most contact by artificial insemination technicians, hoof trimmers, and veterinarians occurring within a 40-km radius of the mean center of all facilities visited (**Fig 4**).

Commodity and rendering vehicles visited 83 and 245 different facilities, respectively. Precise geographic locations were obtained for 60 (73%) of the facilities visited by commodity vehicles and 195 (80%) visited by rendering vehicles; remaining locations were determined by use of zip code or the center of the city or town visited. Typical distances (95th percentile) traveled by commodity and rendering vehicles over a 3-day period were 210.4 and 102.4 km, respectively.

One creamery did not keep records sufficient to trace the route of a specific milk truck; however, records were obtained from the 2 other companies surveyed. These records represented 55 truck routes. Truck route scheduling systems differed between the 2 companies. One company used a system that dispatched the next available truck for milk pickup, and the other company scheduled the same truck to return to the same dairies every day. Because of the scheduling difference, route data for milk tanker trucks were analyzed for a 24-hour rather than a 3-day period. The minimum, maximum, and mean number of dairies visited by milk tanker trucks before returning to the creamery were 1, 5, and 1.8 (95% CI, 1.6 to 2.0),

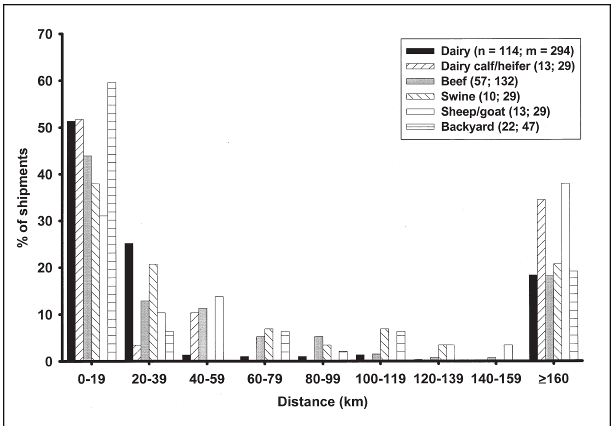

Figure 2—Percentage of livestock shipments to livestock facilities in the Southern San Joaquin Valley of California that originated from locations at various straight-line distances from reporting facilities. Backyard facilities comprised ≤ 10 animals of any 1 type. n = No. of producers. m = No. of animal shipments.

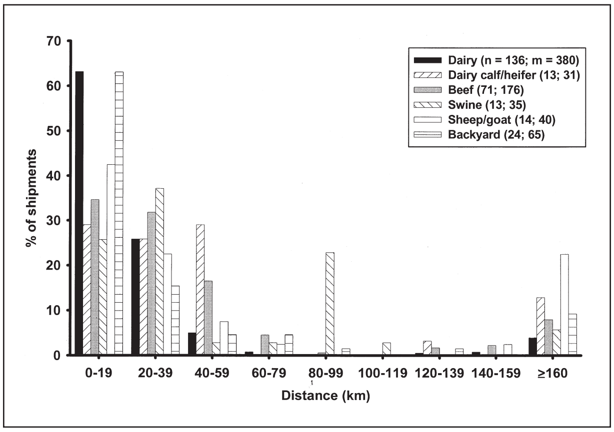

Figure 3—Percentage of livestock shipments leaving livestock facilities in the Southern San Joaquin Valley of California that were destined for locations at various straight-line distances from reporting facilities. *See* Fig 2 for key.

Table 3—Mean number of monthly indirect contacts on livestock facilities in Fresno, Kings, and Tulare counties of California

	Beef*		Dairy†			Dairy calf/heifer‡		Swine§				
Visitor type	**Small**	**Large**	**Small**	**Mid**	**Large**	**Small**	**Large**	**Small**	**Large**	**BackyardII**	**Goat**	**Sheep**
Persons												
AI technician	0	1.1	9.4	18.7	19.5	0	6.7	2.5	0	0.1	0	0
Employee	9	30	89.4	213.3	439.8	22.5	463.2	76.2	750.0	4.2	39.9	8.1
Friend¶	9.3	6.2	16.5	13	17.9	3.8	17	9.4	1.7	18.2	3	14.4
Hoof trimmer	0.1	0.4	1.2	3	4	0	1.7	0.1	0	0.1	0	0.1
Veterinarian	0.2	1.5	2.2	2.5	4.6	0.2	2.8	0.4	0.5	0.3	0.2	0.2
Other#	2.3	2.6	21.7	39.5	69.4	0.2	52.2	5.3	12.8	0.7	3	1.1
Vehicle												
Animal hauler	0.2	0.7	18.9	26.7	30.1	0.6	14	1.3	3.2	0.1	0	0.4
Commodity truck	0.1	0.8	7	16.6	40.6	0	18.6	1.4	23.7	0	2.4	0.9
Hay truck	0.1	0.2	3.2	5.5	15.6	0.2	10.2	0.1	0	0.2	1.1	2.2
Milk tanker	NA	NA	54	54	54	NA	NA	NA	NA	NA	NA	NA
Other**	0.8	2.5	10.8	25.8	47.7	0.3	23	1.2	15.4	2.2	1	3.1
Total	**22.1**	**46**	**234.3**	**418.6**	**743.2**	**27.8**	**609.4**	**97.9**	**807.3**	**26.1**	**50.6**	**30.5**
(95%CI)	**(13.7-30.5)**	**(28.0-64)**	**(220.8-247.8)**	**(401.7-435.5)**	**(716.3-770.1)**	**(15.5-40.1)**	**(128.3-1,090.5)**	**(36.0-159.8)**	**(374.9-1239.5)**	**(15.9-36.3)**	**(0-137.2)**	**(16.4-44.6)**

*Small beef herd, < 250 cattle; large beef herd, ≥ 250 cattle. †Small dairy herd, < 1,000 cattle; mid dairy herd, 1,000 to 1,999 cattle; large dairy herd, ≥ 2,000 cattle. ‡Small dairy calf/heifer facility, < 250 cattle; large dairy calf/heifer facility, ≥ 250 cattle. §Small swine facility, < 2,000 pigs; large swine facility, ≥ 2,000 pigs. IIFacilities with ≤ 10 animals of any 1 type. ¶Includes neighbors and relatives. #Consultant, government inspector, individual seeking employment, maintenance worker, placenta collector, and sales person. **Rendering vehicle, downer animal vehicle, lunch wagon, package delivery, and manure spreader.
AI = Artifical insemination. NA = Not applicable.

Unauthenticated | Downloaded 02/09/25 01:59 AM UTC

Table 4—Number of facilities visited and distances traveled by persons or vehicles that contributed to indirect contacts on livestock facilites in Fresno, Kings, and Tulare counties of California

Visitor type (n)	No. of facilities/d*	No. of facilities/3d*	Distance† (km)	Ratio of ellipse axes‡	Elliptical rotation§
Persons					
AI technician (7)	5.1 (3.4–6.8)	16.9 (13.4–20.4)	29.2	1.8	293.3º
Hoof trimmer (6)	1.8 (1.1–2.5)	6.3 (4.3–8.3)	42.5	1.4	304.1º
Veterinarian (15)	3.6 (2.5–4.7)	10.2 (7.4–13.0)	28.6	1.2	300.4º
Vehicles					
Commodity (12)	3.5 (2.2–4.8)	8.9 (4.5–13.3)	105.2	2.5	299.4º
Rendering (6)	19.7 (11.9–27.5)	59 (43.1–74.9)	51.2	4.4	308.4º

*Data reported as mean (95% CI). †Radius of the circle encompassing 95% of all livestock facilities visited. ‡Ratio of the length of the north-south axis divided by the east-west axis of an ellipse encompassing 95% of all livestock facilities visited. §Rotation of the ellipse encompassing 95% of all livestock facilities visited (North = 360º; West = 270º).

respectively, whereas the minimum, maximum, and mean number of dairies visited per day by each truck were 2, 17, and 9.4 (95% CI, 8.3 to 10.6), respectively. The distance traveled per 24-hour period was 209.2 km, as estimated by the diameter of a circle required to encompass at least 95% of all dairies visited by each truck.

Ratios of the lengths of ellipse axes encompassing 95% of the facilities visited by persons and vehicles were consistently > 1, indicating that both individuals and vehicles traveled more frequently in the north-south direction than in the east-west direction. The direction of most frequent travel was consistently northwest/south-east and ranged from 293.3º to 308.4º (Table 4).

Sales yards—Managers of 4 of the 6 sales yards contacted agreed to participate in the study; combined records from these yards included 631 unique addresses from 254 livestock buyers and 437 sellers. Seven thousand nine hundred eighty-nine animals were consigned and sold, including 3,220 beef cattle, 173 dairy heifers, 2,149 dairy cows, 885 sheep or goats, and 1,562 pigs. The origins of 499 pigs, 47 goats, and 12 sheep consigned by a known livestock importer and dealer were unknown, as were the origins of 359 other animals consigned by owners whose addresses could not be determined. No address was available for 42 buyers and sellers. Precise geographic locations of 470 (79.8%) of the remaining 589 unique addresses were determined by use of geocoding software. One hundred nineteen (20.2%) locations were determined by use of zip code or city center. Livestock typically arrived at and were transported from the sales yard within 24 hours of the sale day. Of livestock arriving at a sales yard, 7% (500/7,072) came from a location ≥ 60 km away, and of those sold to buyers other than large meat processing plants, 31% (1,180/3,721) were destined for a location ≥ 60 km away **(Fig 5)**.

Each sales yard sold multiple types of livestock, but each also focused on specific markets such as culled dairy cows, beef cows, or pigs. Managers reported little fluctuation in the number of animals sold during the year but noted that they sold more beef and feeder dairy steers during spring and fall and more culled dairy cows during winter and summer. Reported distances that livestock traveled to or from the sales yard did not vary appreciably from season to season.

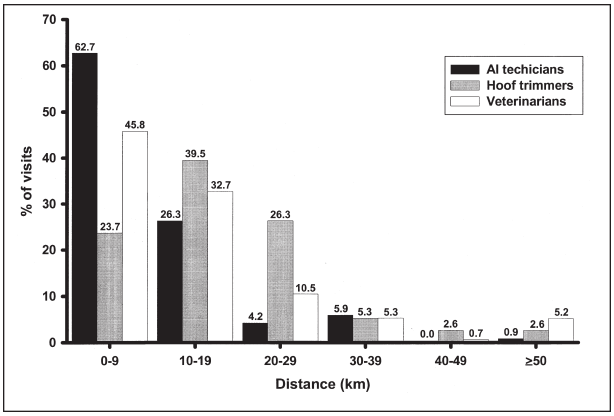

Figure 4—Percentage of visits by 7 artificial insemination (AI) technicians, 6 hoof trimmers, and 15 veterinarians to livestock facilities within a given distance from the mean geographic center of facilities visited. Data were collected during a 3-day period in March and April 1999.

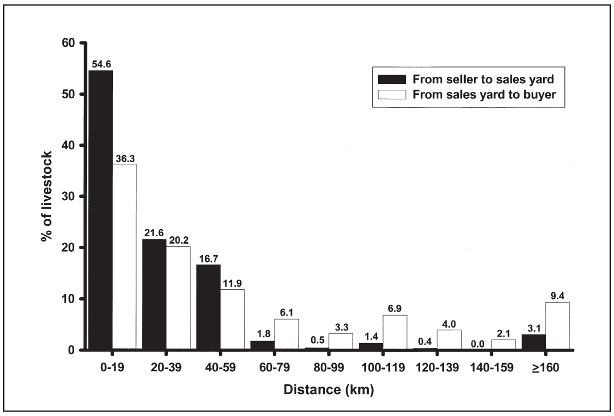

Figure 5—Percentage of livestock shipped within various straight-line distances from sellers to sales yards (n = 7,072 animals) and sales yards to buyers (3,721 animals) in the Southern San Joaquin Valley of California. Data from 4 sales yards were combined for 12 sale days during a 2-week period in November 1998. Slaughterhouses and other large buyers were not represented.

Contact with cloven-hoofed wildlife—Beef herds were the only livestock facility type reported to have consistent close contact with feral swine, deer, or elk. Thirteen percent (6/47) of small (< 250 cattle) and 31% (9/29) of large (≥ 250 cattle) beef-herd owners reported seeing feral swine within 150 m of their livestock at least once per month. Twenty-one percent

Unauthenticated | Downloaded 02/09/25 01:59 AM UTC

(10/47) of small and 55% (16/29) of large beef-herd owners reported similar contact with deer or elk at least once per year. Six percent (3/47) of small and 21% (6/29) of large beef herds had contact with both feral swine and deer or elk at least once every 30 days. Seventeen percent (8/47) of small and 34% (10/29) of large beef herds had contact with both species during 12 months preceding the survey. In contrast, only 1% (2/149) of dairy owners reported seeing deer, elk, or feral swine near their livestock.

Discussion

Results of this study indicate that dairies, dairy calf and heifer ranches, and large swine producers in our study area can be expected to have frequent indirect contact with animals on other livestock facilities located over a wide geographic range. For dairy calf and heifer ranches with ≥ 250 cattle, for example, one could expect approximately 609 indirect contacts/mo. Such indirect contacts may be a commonly overlooked means of disease transmission among facilities and provide evidence that increased biosecurity awareness may be necessary on these facilities. Even though swine producers with ≥ 2,000 pigs had the lowest direct contact rate (0.2 contacts/mo), suggesting a low risk of disease transmission as a result of additions to the herd, monthly indirect contact rate (807.3 contacts/mo) on large swine operations was the highest among facilities surveyed. This high indirect contact rate indicates considerable potential for disease introduction on large swine operations when strict biosecurity procedures are not practiced. Unlike on other types of facilities, the percentage of indirect contacts attributable to employees was high on large swine operations (93% [750/807.3]). However, if properly educated about biosecurity, the probability of disease transmission attributable to indirect contact by employees may be low. The actual number of indirect contacts would be higher than indicated by results of the present study, because number of contacts by persons or vehicles that regularly visited all facilities with similar frequency (eg, postal delivery persons and utility meter readers) were not included in the study; inclusion of such data likely would have increased all indirect contact rates by a constant number. The range of distance traveled for persons and vehicles not included in this study, however, would likely be within the distance required to encompass 95% of all indirect contacts reported.

To our knowledge, no other study has described the potential for and scope of contacts among US livestock facilities. However, authors of 2 similar studies in The Netherlands[7] and New Zealand[8] examined animal contact among livestock facilities and estimated the typical geographic range of livestock travel. In those studies, contacts among livestock facilities were estimated by asking producers to log all visitors during a 2-week period. Our approach was to collect similar herd and flock contact information but to remove the requirement of record-keeping from the livestock producer, because it would have been unrealistic to expect owners of large and midsized dairies to record all indirect contacts. As expected, a large number of indirect contacts were reported on these dairies (midsized, 195 indirect contacts per 2-week period). Although not directly comparable with results of the other studies because of differing study designs, estimates from the present study indicate that a contact rate on a midsized dairy in the Central Valley of California would be expected to be 2- to 4-fold higher than that of a mean-sized farm in The Netherlands or New Zealand. Findings of the present study that indicated herd size was a significant predictor of indirect contact rate, however, were similar to results of the 2 previous studies. Consequently, a possible explanation for the higher indirect contact rates found in the present study is that herd sizes in California are typically several times larger than in New Zealand and The Netherlands.

In the event of a foreign animal disease outbreak such as FMD in the United States, a primary objective would be to prevent widespread dissemination of subclinically infected animals from livestock auctions or sales yards. In the present study, large numbers of livestock were purchased from (7%; 500/7,072) and sold to (31%; 1,180/3,721) locations ≥ 60 km from the sales yard, and animals were typically transported within 24 hours of the sale. These results indicate that sales yards could contribute to rapid and widespread disease dissemination if subclinically infected animals are sold at auction. However, because most livestock were bought and sold from locations within 60 km of the sales yard, the greatest risk of disease transmission would be to local livestock operations. Although we were not able to estimate seasonal variation in types and numbers of animals sold at auction, sales yard managers interviewed believed that little variation would be expected from season to season. Consequently, for the region of California studied here, we believe that the estimates offered provide a reasonable estimate of animal movements to and from sales yards throughout the year.

Herd and flock contact with wild cloven-hoofed animals was rare within the study region. Only 1% (2/149) of dairy owners reported seeing deer, elk, or feral swine near their livestock. Large beef herds (≥ 250 cattle) were most likely to have monthly contact with deer (55% [16/29] of facilities) and feral swine (31% [9/29]), probably because many beef herds graze on open ranges in the foothills located on the eastern side of the study region. This area is populated with deer, elk, and feral swine. A national study conducted in 1996,[9] however, indicated that livestock on 49.3% (1,253/2,542) of dairies in the United States could have physical or feed contact with deer or other cervidae.[9]

Estimates of direct and indirect contact rates obtained from the present study are necessary to develop simulation models aimed at formulating strategies to control spread of exotic diseases such as FMD, should they be introduced into the United States. Realistic FMD outbreak simulation models require appropriate estimates of contact among animal populations and estimates of the probability of disease spread given such contact rates. The terms effective contact or adequate contact have been used to describe contact between susceptible and infected herds sufficient to

Unauthenticated | Downloaded 02/09/25 01:59 AM UTC

transmit disease to a susceptible herd.[10,11] Direct and indirect contact rates reported in this study do not necessarily represent effective contact rates but, instead, represent estimated numbers of contact. These reported rates would only represent effective contact rates if every direct and indirect contact resulted in disease transmission. The number of direct or indirect contacts required to cause an effective contact within this 3-county region of California was unknown but would depend on the infectiousness of the disease agent. For example, FMD virus is a highly infectious agent and would likely require fewer direct and indirect contacts before causing an effective contact, compared with less infectious agents. The type of indirect contact also determines the number of indirect contacts that may, on average, cause an effective contact. For example, the number of indirect contacts by artifical insemination technicians, hoof trimmers, or veterinarians that would result in an effective contact is likely to be much less than the number of indirect contacts from fomites with less livestock interaction such as commodity, milk tanker, and rendering vehicles.

Results of the present study also may assist in development of the necessary and appropriate models capable of analyzing benefits of potential eradication strategies. The circular and ellipse methods used to estimate travel range of animal health personnel and vehicles provided estimates of travel distance and the dominant direction traveled. Interestingly, the dominant direction traveled mirrored the northwest-southeast directions of the 2 major freeways that divide the study region. Because contact information with a directional component indicates the potential for disease transmission in 1 direction, compared with another, such information may be useful in modeling where emergency response personnel should implement vaccination protocols to create a safety buffer around infected facilities. In the 3-county region of the present study, an elliptical-shaped vaccination ring mirroring the northwest-southeast direction of the freeway corridors may be more effective in limiting disease transmission during the early stages of an epidemic, compared with a circular ring vaccination strategy. The latter strategy is standard protocol but would result in vaccination of livestock on fewer susceptible facilities in the northwest-southeast direction.

Direct and indirect contact information with a geographic component also could be fit with probability distribution functions that describe risk of infection relative to distance from an infected facility. Results of the present study suggest that contact rate decreases as distance traveled between facilities increases. Thus, susceptible herds located near an infected herd would have a higher probability of becoming infected, compared with herds located further from the infected herd. In our study, contact information with a directional component was summarized as straight-line distances between herds rather than actual distances traveled, because knowledge of typical distances between herds in contact coupled with any directional trend could be used to identify optimally sized quarantine or vaccination zones within a specific distance from an infected facility.

Because contact rates estimated in this study were collected within a well-defined region in California, they may not be representative of those in other livestock producing regions in the United States. However, although contact rates may vary from region to region, proportions of direct and indirect contacts among different types of livestock facilities may be similar. In the present study, large herds had more indirect contact than small herds, and dairies had more direct and indirect contacts than beef, goat, and sheep facilities. Studies in other areas of the United States will be necessary to adjust rates to specific regions. Also, distances traveled by persons and vehicles may differ from region to region depending on herd densities and accessibility of facilities. Contact estimates provided in this report may be useful as guides for future studies or for comparison with results of other studies. Long-term studies also will be necessary to assess seasonal fluctuations in movements or distances traveled, because our study lasted < 3 years. We believe that indirect contact results of the present study, which includes information collected from animal health personnel during in-person interviews, should be considered representative of the study region only for March and April.

The low response rate to the mailed questionnaire may be partially explained by what some recipients may have considered to be an invasion of their privacy. The specific information requested may have led to a reluctance to answer questions that could compromise anonymity about a facility or reveal information considered to be confidential. In addition, because the questionnaire was designed for multiple types of livestock facilities, some recipients may have become disinterested and perceived little direct benefit by responding. However, the response rate may not necessarily reflect a disinterest in the study subject but, rather, a disinterest in completing survey forms, as suggested by the similar response rate (32.1% [458/1,429]) to a survey on papillomatous digital dermatitis mailed to California dairies.[12] It has been suggested that a survey response rate < 70 to 80% may lead to biased results, because the survey was conducted with self-selected volunteers whose management styles may differ from those who did not respond.[13] The extent or nature of bias that may have been introduced by nonresponders in the present study is unknown. However, we speculate that, because livestock producers receive many surveys, particularly from government agencies for purposes of livestock census and taxation, they may only complete surveys required by law. Also, as suggested by the evenly distributed response rates among different sized dairies and among different types of facilities, our sample population may not have been biased by an inordinate response from large- or small-herd owners.

Indirect contact information, combined with frequency of livestock movement and contact with wildlife, may be useful to producers examining biosecurity plans, to industry organizations developing biosecurity guidelines, and to state and federal emergency response personnel preparing to control an emerging or endemic animal disease. Ultimately, the knowledge gained from the present study may have

Unauthenticated | Downloaded 02/09/25 01:59 AM UTC

application toward further studies investigating direct and indirect animal contact among livestock facilities, general herd and flock biosecurity improvements, and methods to control an endemic or foreign animal disease such as FMD, should it be introduced into a region in the United States with a high livestock density.

[a]EZ-Locate, Etak Inc, Menlo Park, Calif.
[b]Visual Basic, release 6.0, Microsoft Corp, Redmond, Wash.
[c]MiniTab, release 11.13, Minitab Inc, State College, Pa.

References

1. Yang PC, Chu RM, Chung WB, et al. Epidemiological characteristics and financial costs of the 1997 foot-and-mouth disease epidemic in Taiwan. *Vet Rec* 1999;145:731–734.
2. Wilson TM, Logan-Henfrey L, Weller R, et al. Agroterrorism, biological crimes, and biological warfare targeting animal agriculture. In: Brown C, Bolin C, eds. *Emerging diseases of animals*. Washington, DC: ASM Press, 2000;23–57.
3. Gordon JC, Bech-Nielsen S. Biological terrorism: a direct threat to our livestock industry. *Mil Med* 1986;151:357–363.
4. USDA: National Agricultural Statistics Service. 1997 Census of agriculture highlights for California. Available at: http://www.nass.usda.gov/census. Accessed Mar 23, 2001.
5. US Geological Survey, Branch of Geographic Names. Geographic Names Information System Sept 1997. Available at: http://mapping.usgs.gov/pub/gnis. Accessed Nov 15, 1999.
6. Ebdon D. *Statistics in geography*. 2nd ed. Oxford: Blackwell Publishers, 1985;128–141.
7. Nielen M, Jalvingh AW, Horst HS, et al. Quantification of contacts between Dutch farms to assess the potential risk of foot-and-mouth disease spread. *Prev Vet Med* 1996;28:143–158.
8. Sanson RL, Struthers G, King P, et al. The potential extent of transmission of foot-and-mouth disease: a study of the movement of animals and materials in Southland, New Zealand. *N Z Vet J* 1993;41:21–28.
9. National Animal Health Monitoring System. *Information sheet: biosecurity practices in U.S. dairy herds*. Fort Collins, Colo: USDA, Animal Plant Health Inspection Services, Veterinary Services, 1996.
10. Abbey H. An examination of the Reed-Frost theory of epidemics. *Human Biol* 1952;24:201–233.
11. Garner M. Modeling foot-and-mouth disease in Australia, in Proceedings. *Nat Symp FMD* 1992:157–175.
12. Rodriguez-Lainz A, Hird DW, Walker RL, et al. Papillomatous digital dermatitis in 458 dairies. *J Am Vet Med Assoc* 1996;209:1464–1467.
13. Martin WS, Meek AH, Willeberg P. *Veterinary epidemiology: principles and methods*. Ames, Iowa: Iowa State University Press, 1987;149–175.

Unauthenticated | Downloaded 02/09/25 01:59 AM UTC