

# Investigating Herd Problems – *General Principles*

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Solving gnarly herd problem problems is a challenging but rewarding opportunity in food supply veterinary medicine. The easy problems are solved by knowledgeable producers without involving the veterinarian. The interesting problems knowledgeable producers can't solve are not straightforward, sometimes defying solution other than the passage of time. Just as a systematic strategy is the best approach to the individual case, such as the "RUMBA" (rumen, uterus, mastitis, bronchial tree, abomasum) for the cow, a systematic approach is best for herd problems. Haphazard approaches to either make one vulnerable to potentially embarrassing pitfalls, particularly overlooking what in hindsight was the obvious. While we are innate problem solvers, easily reasoning our way from cause to effect, being aware of pitfalls and reasoning errors can improve our approach and increases our chances for success.

To solve the gnarlier herd problems, considerable knowledge and creativity are required. Because of the diversity of livestock farms, the passage of time that often occurs between the cause and the effect, biological variability within and between animals, and the inevitable continual change (e.g., weather changes, feed changes, personnel changes, flow of the production cycle), figuring out the causal web is a challenge, even with a definitive clinical diagnosis. On commercial cow-calf operations, information is sparse because of infrequent animal observation and the lack of individual performance records. On dairies, uncertainty is present because of limitations in time and labor, constant change and procedural drift between what management expects to be done and what employees are actually doing. Producers maintain information in the manner that they need to run the operation rather than spending time and money recording the more detailed information useful to the veterinarian for solving herd problems. Historical information that is useful to veterinarians for making comparisons is of little use to producers. Farms are dynamic systems with variously lagged positive and negative feedbacks that interact in complex ways. Certainty about conclusions is rare and the costs of gaining additional information are high. Thus, the cost and delay of acquiring additional information must be balanced against the value of a more timely intervention and the potential cost of error due to incomplete information. The goal is to achieve enough certainty about what is going wrong to correct the situation.

## **Problem Detection**

The three general types of herd problems are:

1. **Acute:** The problem was precipitated by recent management or husbandry errors of sufficient magnitude to be cause the problem. Evidence of the problem is readily apparent.

2. **Additive or Cyclic:** The problem was precipitated by management or husbandry errors and the effects of cyclical factors, such as season or production cycle stages, that in combination precipitated the problem. For example, the summer coliform mastitis outbreak that is associated with the previous winter change to sawdust bedding. Because of seasonal breeding effects even in non-seasonal herds, problems related to animal density, such as the seasonal appearance of excessive numbers of DA's, are cyclical and reappear annually.
3. **Chronic:** The problem was precipitated by the long action of a combination of management or husbandry errors that required the passage of time before the consequences became sufficient to be recognized, such as the slow spread of a contagious mastitis agent or of *Mycobacterium avium* var *paratuberculosis*. For example, the recognition of a slowly spreading *Staph aureus* mastitis problem associated with the adoption of a less efficacious teat dipping procedure more than a year previously. Because of the long passage of time between cause onset and effect recognition, these problems are difficult to untangle and resolve, particularly because the change appears successful for some time.

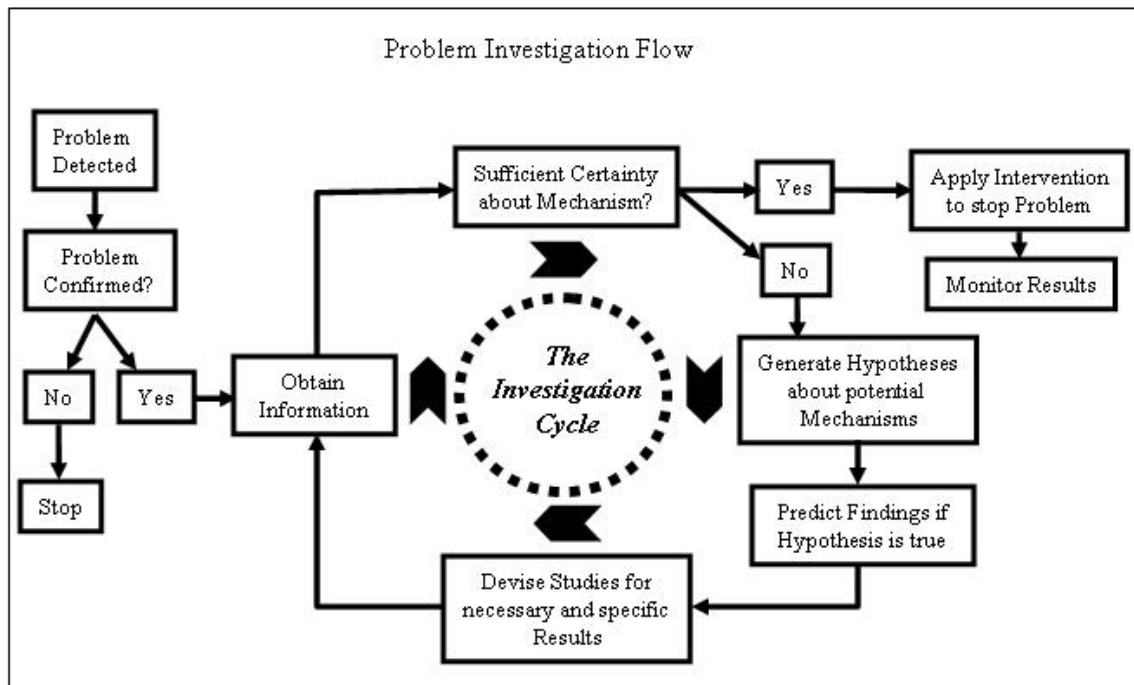
Some farm event triggers the veterinarian being asked to solve the herd problem. Remember, "*He who detects the problem is often called on to solve it*" (Fetrow). The goal is to identify the key determinants, which are those specific risk factors acting in the causal pathway on that farm that can be modified or eliminated to prevent or reduce the problem. Although their presence is necessary, few infectious agents cause disease solely by themselves but rather operate more as opportunists, exploiting weaknesses in livestock management systems. Focusing exclusively on an agent overlooks the fact that the opportunity is present for other similar opportunistic agents. For example, the risk factors on a given farm for the transmission of calf scour agents are the key determinants rather than the presence of the agents themselves. Such agents are essentially holoendemic, meaning that they are everywhere and that most all cattle are exposed to them at some point in their lives. In these circumstances the objective is to delay exposure until the animal is older, minimize exposure dose when it occurs and maximize host resistance at that time. In the midst of a scours outbreak, the questions are why is the exposure earlier, the dose higher or the host more susceptible on this particular premises? Rather than biologics or pharmaceuticals, the best long term interventions involve altering facilities or changing human behavior, which is the most difficult, particularly when the current way apparently worked without problems previously.

The event can be dramatic, such as the sudden appearance of unexpected deaths or dramatic production decline, or it can be finally the recognition of a chronic problem which appears new but actually has been occurring for some time. The earlier problems are detected, generally the more successful the investigation and resolution. Once an infectious agent reaches outbreak levels, more animals are carriers, the environmental load is higher and control has to be more effective to stop transmission. Herd production medicine is geared toward establishing systems for the early detection if not the outright prevention of common problems, hence the development of herd scoring systems, such

as for body condition and lameness, routine monitoring, such as BTSCC and DMI, beef herd calving strategies and metaphylaxis for BRD (Brand 1997, Chenoweth 2005, Radostits 2001).

What is actually the initial primary complaint? Recognize situations where the producer has reasoned from a primary complaint (e.g. low milk production) to what they suspect is the cause (e.g., pneumonia in adult cows) due to a ubiquitous bovine infectious agent (e.g., *Mannheimia hemolytica*) to a key determinant that could initiate this causal pathway (e.g. poor barn ventilation). In the actual herd problem, the cause of the production loss was a mis-calibrated scale on a grain auger, not poor barn ventilation for which the producer requested assistance. In this case, starting down the path of solving a barn ventilation problem, which was present, would not have resolved what actually initiated the producer's primary complaint.

Problem investigation is the thorough search for and comparison of clues, the veterinary version of CSI. In contrast to individual animal investigation, the opportunity for solid comparisons is the power of herd investigation. Individuals and the factors acting on them are compared between affected animals, both clinical and subclinical, and unaffected animals and between groups, in both cross-sections (at one point in time) and over time to identify the differences and the similarities between the animals themselves, the groups and the factors affecting them. The flow is "multithreaded", meaning that multiple comparisons are occurring at once, and "recursive", meaning that new information causes previous steps to be revisited. What is relevant changes as the workup proceeds and differentials (hypotheses) are ruled in or out. Too little information leads to errors, too much to overload and excess cost.



## Systematic Approach

The 10 basic components of the systematic approach are:

0. Confirm that the problem is real
1. Establish the pathologic and etiologic diagnosis
2. Establish a working case definition
3. Establish the magnitude of the problem with data
4. Description
  - a. Elucidate the mechanics and flow of the production system
  - b. Establish the timing of the problem (When?)
  - c. Establish the demographics of affected vs. non-affected animals (Who?)
  - d. Establish the place of the problem (Where?)
5. Assemble, verify and analyze the data
6. Generate hypotheses (differential diagnoses) about key determinants
7. "Test" your hypotheses
8. Design interventions or prospective studies
9. Document findings and recommendations
10. Monitor results

This systematic investigation approach is used by public health epidemiologists to investigate human disease outbreaks (CDC 2004, Gregg 2008, WHO 2008) and is described in the veterinary literature (Lessard 1988, Waldner 2001, Waldner 2006).

#### **0. Confirm that the Problem is Real**

With the more vague problems, be careful of "pseudoepidemics" caused by the onset of producer awareness of a chronic problem or caused by a definition change. For example, changing from detection of fetal loss by visual detection of a conceptus to detection of open cows by repeat palpation post early pregnancy diagnosis will cause a pseudoepidemic of fetal loss in virtually any dairy herd. In one case, veterinarian invested almost \$1,000 in lab fees attempting to establish the etiologic cause of such a pseudoepidemic. The dairy had recently switched to a dairy herd records program that classified any cow returning to heat after a positive pregnancy exam as an abortion in addition to those with visible signs of late gestation fetal losses. Obviously, if an abnormal number of animals are dead, clearly sick or or production has dropped sharply, this step is unnecessary.

#### **1. Establish the Pathological and Etiological Diagnosis**

If the diagnosis is not definitive but one is warranted, start collecting samples to obtain a definitive pathologic and etiologic diagnosis. Be careful of accepting a provisional etiologic diagnosis as definitive without clear evidence. Doing so may lead to overlooking important contrary clues and thus seriously mislead the investigation, which can have serious consequences both for the producer and for the clinician's credibility. The previously cultured mastitis cases may have been *S. aureus* but this outbreak

may be due to *M. bovis*. On the other hand, recognize that only establishing a definitive pathological and etiologic diagnosis does not solve the producer's problem; something has to be changed but what? Remember that outbreaks of many emerging agents are controlled long before they are isolated and identified (e.g., HIV, Enzootic Bovine Abortion)

If dead or dying animals are involved, have complete field necropsies been done of a sufficient number of representative animals? The mistake is to select a few of the worst rather than enough of the representative. When taking samples, consider the regret factor vs. current cost of obtaining samples. For example, when working up a reproductive problem in a grazed beef herd, taking and holding blood samples from palpated animals only to discard them later if they are not needed is less expensive than finding such samples are needed when new hypotheses emerge and that to obtain them the herd must be rounded up and corralled again.

A common complaint of diagnostic labs is that practitioners fail to submit a full set of properly handled and preserved tissue samples from complete necropsies, rather submitting only those samples that would confirm their diagnosis. To counter this tendency, some diagnostic labs structure their fees to encourage the submission of a complete set. In a major continuing problem in a large dairy herd, the underlying problem was believed to be a severe respiratory condition but laboratory findings on the lung samples from partial necropsies of several thoraxes were inconclusive, frustrating both the practitioner and the diagnostic lab. Complete gross necropsies performed later on several euthanized moribund cases revealed a severe uterine condition subsequent to an improper but widely applied uterine infusion. The pathologists indicated that the uterine lesions were the most severe they had ever seen. The potential "regret" cost of missing a major gross diagnosis or failure to obtain a laboratory diagnosis must be balanced against the marginal cost of doing more complete necropsies compared to partials.

## **2. Establish a Working Case Definition**

Establish a working case definition, as precise as reasonable and changing it as warranted. A case definition is that set of criteria an animal has to meet to be considered a case of the problem, such as a set of clinical signs. As one works through a problem, this definition changes. Consider the expected number of cases that are due to endemic background problems, the "red herrings". For example, in a group of pregnant cattle approximately 10% of all pregnancies diagnosed prior to 45 days of gestation are lost and approximately 20% of these losses are observed. Including cases that are due to other problems weakens the comparisons and impedes problem solving. For example, if death is a component of the problem, was an individual's death likely due to the problem or better explained by another condition? If animals experiencing the problem are culled, was an individual's culling likely due to the problem or better explained by something else?

Remember the iceberg principle, that subclinical cases outnumber clinical cases several fold, and the spectrum of disease, that animals can be incubating, clinical and recovered. Even in general herd problems (e.g. low milk production), some individuals are affected more severely than others, the more severely affected animals having experienced higher levels of a risk factor or a greater combination of risk

factors than lesser affected animals. If necessary, establish degrees of certainty (i.e., certainly affected, uncertain, certainly unaffected). Overlooking these concepts can lead to comparing clinically-affected animals with subclinically-affected and recovered animals instead comparing definitely affected to definitely unaffected.

### **3. Establish the Magnitude of the Problem with Data**

Remember the principle "*In God we trust, all others bring data*" (W. Edwards Deming). Obtain objective data documenting the magnitude of the problem; do not rely only on the recall and perception of management and employees. Unless based on objective evidence (e.g., actual counts or analysis of records), their perception of the problem may be well off the mark. Subjective perceptions of employees and managers are valuable sources of hypotheses about risk factors. To be credible, the clinician must consider these and may need to support or refute these with objective empirical evidence. Compare the actual number of cases to the expected number to determine whether or not the frequency is excessive and if it has changed. Be careful of "dangling numerators", which is counting the number of cases without considering the number of animals actually at risk of becoming a case during that time period. Even when the underlying risk remains constant, an increase or decrease in the number of animals susceptible to a condition causes a corresponding change in the number of cases of that condition. Because of seasonal effects, few herds maintain a constant number of animals passing through the period of susceptibility year around.

In a large registered dairy herd, one-third of the retained heifer calves were dying due to salmonellosis. However, the producer did not recognize these losses because the calves were dying acutely one by one and were regularly picked up by the rendering service running a route. Only by comparing the current youngstock inventory with the calving events recorded with calf gender on a calendar did the producer recognize the magnitude of this loss. In another large dairy, the manager knew that 10% of the cows calving during a two week period were clinically affected by a problem. However, when the records of their calving cohort, which is all of the cows that calved during this period, were reviewed, much to his surprise all had been culled in the intervening two months. In both situations the problem was considerably larger than the producer recognized and provided additional motivation to adopt recommendations. The lesson is to construct a list of all the animals that entered a risk period or were exposed during the time period of interest and not basing the investigation on the surviving animals.

Be careful of what a producer accepts as "normal" (endemic) occurrence. In a small high producing herd the producer believed that 3<sup>rd</sup> or higher parity Holsteins going down with milk fever was a "normal" occurrence. Thus, he accepted most of his older cows going down with milk fever, did not recognize that as an abnormal situation that could be corrected and neither his veterinarian nor his nutritionist were aware of the high incidence. Be careful of overlooking relevant events that the producer is omitting because of assuming that they are not related to the problem of concern. For example, the recent episode of late term abortions that isn't mentioned may well be related to the metritis problem being investigated.

Above all, remember the old aphorism: "*More mistakes are made from not looking than from not knowing!*"

#### **4. Description**

##### **1. Elucidate the Mechanics of the production system**

A systems analysis expert states: "Starting with the behavior of the system directs one's thoughts to dynamic, not static analysis—not only to 'what's wrong?' but also to 'how did we get there?' . . . And finally, starting with history discourages the common and distracting tendency we all have to define a problem not by the system's actual behavior, but by the lack of our favorite solution." (Meadows) In other words, start by obtaining a solid understanding of how the system works before trying to fix it. Establish the flow of animals through the production cycle including locations, the timing and criteria for moves and for the relevant management practices, such as vaccinations, feed changes, and any recent changes in these. Start by drawing a map of the general layout of the premises, labeling the animal locations (e.g. pens, lots, pastures, barns, hospital pens) with the names or numbers that the producer uses, the animal numbers that are typically in each and the typical routes between these. Include feed storage and processing areas and animal processing facilities. Often large farms already have such maps. The Johns risk assessment tools provide useful templates (<http://www.jd-rom.com/riskassessment.asp>) for bovine enteric infectious diseases.

With the manager or herdsman establish the timing of the events in a relevant animal's life as it moves through the production cycle including the criteria or triggers for the steps and who is responsible for each. Generally, starting at animal entry or birth is easiest for a producer. If the problem involves potential carryover from the previous production cycle, such as postparturient or neonatal problems, start there. Use questions such as "Now what happens?" and ask "Did I miss anything important?" at each step. Ask if there have been any changes in these procedures and events and "When did you start doing it this way?" for the important ones. The two goals of these questions are for you to understand the details of the process and policies and to jog the responder's mind to recall events they might otherwise not. Similarly, ask what happens to the exceptions, such as how the sick and the poor doers are handled. Where are they moved, how are they treated and what happens after recovery? Ask if any unusual or extreme events have impacted the affected animals compared to what normally happens. Don't assume that they are using your vaccination program as you laid it out. Ask about cleaning, animal waste and excess feed handling practices and policies.

Estimate the amount of deviation from intended policy, which inevitably occurs, in the relevant areas. Stating the questions in terms of recent numbers yields better answers than asking for percents. For example, ask "Of the last 30 cows calving, how many calved in (the location prior to where they are supposed to calve)?" and "Of the last 30 cows that calved, how many calved after less than (the number of days they are intended to spend) days in the (location they are intended to be prior to calving)?" Ask if these deviations were unusual for the affected group. When the opportunity arises, quietly verify these flows, event timings, policies and deviations with the employee doing that work. On larger operations with

layers of supervision and language difficulties, the discrepancies between what the management intends to happen and what actually happens or what and when major procedure changes were actually implemented are sometimes amazing.

Next, walk systematically through the facility, following the pathway of the relevant animals from the start through the point of the problem, verifying the information and documenting with a digital camera. Check feed storage areas, feed handling equipment and feedbunks, including measuring adequacy in critical areas. Check water sources, including cleanliness and access. Observe waste effluent flows and opportunity for contact between groups. Check the storage and handling of the relevant supplies, such as biologics and pharmaceuticals. If animals are regularly passing through a step involving these, a supply is likely on hand and their waste in evidence. Check refrigerators, shelves and wastebins for this evidence and observe out dates. If no evidence is there, why not, and if substantial amounts of something unmentioned or illegal is there, why? When possible, quietly observe the relevant processes. In an intractable adult dairy cow diarrhea problem in which a feed toxin was initially suspected, the veterinarian finally observed the producer putting far too much MgO in the mixer wagon. The producer had mistaken the unit of measure.

*I keep six honest-serving men: (They taught me all I knew) Their names are What and Where and When and How and Why and Who. (Rudyard Kipling)*

## **2. Establish the Timing of the problem (the temporal pattern - *When?*)**

When did the index cases likely occur? When in calendar time did the problem actually begin? When in the production cycle? What is the pattern of performance over time? Don't rely on fallible human recollections alone; verify. When did the numbers of deads, culls or treatments go up? Did the production per animal suddenly drop or is this actually a long downward trend that was finally recognized? Has such a drop occurred previously but performance recovered? If the herd is seasonal, how does this season compare to previous seasons? Clearly establishing the timing of the onset from objective data (i.e., herd records, pocket notebooks, receipts) is crucial to determining the relationship between management or input changes, such as feed batches, or other sporadic events and the problem onset. Those things that occurred after the onset are likely not a major key determinant. Changes in individual animal performance must be distinguished from changes in total output that are due to changes in the numbers of producing animals. Plot an epidemic curve, which is a plot of the number affected within intervals over a time line. The interval width, such as by week month or season, depends on the numbers at hand. Intervals that are too wide or too narrow obscure trends.

## **3. Establish the Demographics of affected vs. non-affected animals - *Who?*)**

The strength of herd-focused investigation compared to individual-focused investigation is the opportunity to compare affected to unaffected animals, both as individuals and as groups. What are the characteristics of affected vs. unaffected animals in terms of exposure to potential risk factors, age, production level, stage of production cycle and source? As noted above, because of the spectrum of

disease be careful when classifying animals into affected and unaffected groups. A serious but common error is to overlook the culled or dead animals from the cohort of susceptible animals that entered the risk period with the remaining animals but are now missing from the group and have been removed from the records.

#### **4. Establish the Place of the problem (the spatial pattern - *Where?*)**

Where were the affected vs. unaffected animals located during the likely exposure period? Because different groups or pens of animals have different levels of exposures (e.g., different amounts of feed ingredients, different water sources, different housing, different pasture, different origins, different stages of the production cycle) and a dose-response relationship exists for many etiologic agents, this may be provide an important set of clues.

#### **5. Assemble, Verify and Analyze the Data**

Concentrate on that data that which will support or refute hypotheses (differential diagnoses). Gathering and analyzing this objective data on a herd problem is an examination process analogous to using laboratory tests or imaging procedures in individual animal diagnosis. This objective data supports or refutes clinical impressions of the herd problem, much like the testing or imaging supports or refutes clinical impressions of the clinical case.

Spreadsheets are convenient for entering, validating and manipulating the relevant individual and group information. Relevant data can be downloaded from herd record systems and processors, minimizing hand entry. When accessing herd data through a production accounting system, first evaluate the data quality by verifying that known relevant events identified by other means are present and correct in the records. In large herds, different employees often use different descriptors to label the same problem. In a large dairy herd experiencing early post-partum deaths, the best information was in the pocket notebook of the employee treating fresh cows rather than the herd records system in the manager's office. Detect outliers and logical inconsistencies in the data by sorting variables into numerical order and looking at the minimums and maximums. Do these make sense? Does the data have realistic variability or is someone entering the policy number, such as body condition score at dry off, rather than the actual number?

Plot production data with a smoothed trend line over time. This enables trends to appear amid the noise of random variation. From count data of the numbers of affected and the numbers of susceptible animals, calculate case morbidity and fatality rates by exposure and relative risks. For the more endemic problems, plot risk over time by cohort groups. Construct cohorts of at risk animals passing through a critical point in the production cycle associated with the problem (e.g., calving, weaning) over a time interval (e.g., day, week, month) that on average have enough animals to reduce the effects of natural variation but doesn't obscure trends over time, wider intervals being needed for smaller herds. Examine the effects of other factors that vary over time (e.g., calving pen density, average of weekly high temperature, sources of animals) on risk of occurrence or production. Weather data from nearby

automated weather stations can be downloaded from on-line government sources. If the herd doesn't have a good production accounting system for animal performance information, don't overlook clues in indirect sources of similar information. For example, the delivery dates and weights on feed invoices can provide approximate information on feed batch disappearance and thus approximate information on consumption patterns. On this basis, expected disappearance of feeds can be compared to actual disappearance. Invoices from rendering services may provide information on dates of animal deaths if they have not been recorded. Events such as calvings and breedings are written on walls, calendars or in pocket books. In one herd, the producer was only entering the last breeding of the month for a cow into the record system but kept all of them in a card file.

## **6. Generate Hypotheses (Differential Diagnoses) about Key Determinants**

Key determinants are those risk factors in the causal web, the pathways by which they act, on this premises that can be altered to control or prevent the problem. Based on knowledge of the natural history of the disease problem and the objective information collected to this point, generate hypotheses about what key determinants are likely involved. If needed, review the literature and current texts (e.g., Radostits 2007) for hypotheses about plausible risk factors and their pathways. Thrushfield (2007) includes an appendix with a long list of risk factor studies and Cornell Consultant (<http://www.vet.cornell.edu/consultant/consult.asp>) lists current clinical literature. Subjective observations by the producer, employees and other professionals are valuable. These hypotheses are important because they guide further strategic sampling and data analysis instead of scatter-shot sampling and data overload. New hypotheses may lead to revisiting prior steps in this process. Just as in working up individual cases, prioritize the hypotheses by their likelihood and focus efforts on those with the highest priority until these are either sufficiently supported or are refuted.

A serious error is to jump to generating hypotheses without first developing the quantitative information (the "who, when, where" counts) beyond vague clinical impressions (e.g., these animals seem to be affected more than those) to support or refute a specific hypothesis. This is analogous to "scattershot" ordering of laboratory tests in working up individual animal cases, hoping something will pop up rather than using the laboratory tests to rule specific differentials in or out, and will likely be as unrewarding. Be wary of jumping to "canned" solutions. Remember, "*There is always a well-known solution to every human problem – neat, plausible and wrong*" (HL Mencken). Be careful communicating a leading hypothesis to a manager or employee before it is substantiated because returning later to a more open mind and more objective recall is difficult for both parties.

## **7. "Test" Hypotheses**

Establishing and executing good "tests" requires ingenuity. Based on each hypothesis, predict what should be found in other animals, such as test results or production effects, and evaluate the predictions. Make predictions of the form "if this cause is present, then this finding should be present". Finding what was predicted supports a hypothesis; not finding what is predicted weakens it. The ingenuity is figuring out what predictions provide good "tests" and are "doable". Because single causes have multiple effects,

finding these multiple effects provides stronger support for the cause than finding only one. As much as possible avoid scattershot sampling and data collecting because doing so without an objective in mind is seldom useful and is expensive in money for the client and in credibility and time for the clinician. What is the simplest set of explanations that covers the most findings?

Example predictions are: "If this infectious agent is being transmitted between animals in this manner, then these other animals are at risk and some should be infected while these others are not and will not be." "If this risk factor (e.g. overcrowding in the fresh pen) is causing the metabolic disease (e.g., displaced abomasums), then a pattern should appear in the associated data (e.g., higher proportion of cows experiencing DA's in the cohorts with more crowding in the fresh pen compared to those with less crowding)" or "If I'm seeing this in the neonates due to this cause, then I should find that in the fresh cows."

For counts, comparing groups by calculating odds-ratios in two-by-two tables and for continuous data, such as milk production, comparing averages between groups often suffice for evaluation. Calculate risk measures, such as odd-ratios and relative risks, by hand, with freeware such as EpiInfo (<http://www.cdc.gov/EpiInfo/>) or with on-line programs. For guidance in calculating and interpreting these measures, see Sanderson (2005), Slenning (2001, 2006) or on-line resources, many of which are accessible through "WWWeb Epidemiology & Evidence-based Medicine Sources for Veterinarians" at <http://www.vetmed.wsu.edu/courses-jmgay/EpiLinks.htm>. Spreadsheet charts are useful for comparing risk trend lines between groups and present visual evidence that is easy for clients to understand. Although tests for statistical significance have their place, insufficient sample sizes and the costs of obtaining sufficient numbers limit their utility.

## **8. Design Interventions or Prospective Studies**

Generate action items that are compatible with the specific facilities, resources and management ability available on the premises. Considering how the limitations of the facilities and of management led to the occurrence of the problem in the first place is crucial to intervention success. If uncertain about the effectiveness of an intervention and the management situation is appropriate, propose a prospective clinical trial or other follow-up study to evaluate a specific hypotheses or intervention. Judge the number of recommendations that the client can handle and prioritize these. A list of 4 items is much more likely to be successful than a list of 15. Provide sufficient technical detail of what, where and when something is to be done such that an employee can carry out the recommendation successfully. Provide clear evaluation criteria so that performance can be appraised. How quickly will the problem likely resolve if the changes are made? How large an improvement is reasonable to expect? When should the problem be revisited if improvement doesn't occur and what are possible next steps? Otherwise, procedural drift will likely occur back to the prior state of affairs, particularly if the personnel doing the work expect results too soon.

## **9. Document Findings and Recommendations**

Remember the old aphorisms that "*The faintest pen is stronger than the strongest mind*" and that "*Success has many fathers but failure is an orphan.*" If the recommendations are successful, with the passage of time you will not get credit due unless the recommendations were clearly documented. What isn't written is at risk of being forgotten or, worse, misconstrued. Keep the report short, direct and concise with the action times first followed by the supporting information. Summarize data in brief tables and remember that graphs are worth a 1,000 words. If other parties are involved in the problem, such as feed mills, be careful of making statements that you are not willing to defend in court, whether as a party or an expert witness. In such circumstances, include all the information as appendices that you want in a report that is part of a lawsuit. Clearly note any human health risks, such as those from zoonotic agents. Avoid creating overly optimistic expectations.

## **10. Monitor Results of Interventions**

How can the producer best determine if the changes are working or if the problem is recurring? For problems with a significant subclinical component, consider proposing a monitoring scheme to provide early warning of problem recurrence. What can the producer do to detect or prevent the problem earlier? If the herd doesn't have a good production accounting system to monitor changes in production but one is warranted, propose one. In productivity problems, propose benchmarks of performance if they aren't already in place. Monitoring recommendation results also provides important information about their efficacy. The key is to figure out an economical, easily doable scheme for monitoring the specific herd. For example, for problems caused by an infectious agent, can pooled samples of effluent or milk or from culls be obtained on a routine basis to effectively but economically monitor for the continuing presence of that agent?

## **Common Reasoning Errors**

When determining cause and effect, both veterinarians and their clients are subject to lapses and biases in reasoning and memory that can lead investigations astray. We tend to weigh information that is consistent with our current belief heavier and to ignore or discount discordant information, to weight or recall the unusual or more recent heavier than the common or the more distant, and to limit the search for additional information to that which has the potential of confirming rather than that potentially refuting our belief (e.g. selective tissue submission to confirm a gross diagnosis). By nature we are programmed to develop explanations from limited, incomplete information without considering the weaknesses in the information or the assumptions being made, which results in the fallacy of misplaced concreteness.

The following are the major thinking errors involved in medical decisions (Croskerry 2002, 2003):

- **Aggregate Bias (Ecological Fallacy):** The tendency to substitute the relationship between group averages of two variables for what is happening between these two variables at the individual animal level. Group aggregate data (e.g., bulk tank ship weights, pen intakes) is more readily available than individual data (e.g., individual daily milk weights, individual intakes).

- **Anchoring Bias ("Jumping to Conclusions"):** The tendency to fixate on limited information too early in the investigation process.
- **Ascertainment Bias:** The tendency to allow prior expectations to shape thinking and observation of information, particularly of subtle, vague clues.
- **Availability Bias:** The tendency to judge things as more likely if they readily come to mind, which tend to be the more recent, the more prevalent, the more striking or the more readily available. The lesion in the pathology textbook is likely the most striking one the pathologist has seen.
- **Confirmation Bias:** The strong tendency to look for further confirming evidence to support a weak diagnosis or hypothesis rather than looking for refuting evidence, which is logically more definitive. It is more powerful to ask "What would disprove this hypothesis if found?" than "What else would support this hypothesis if found?"
- **Diagnostic Momentum Bias:** A weak diagnosis may gain momentum without gaining verification, particularly if it is communicated to others without the associated evidence, biasing their reasoning and recall.
- **Framing Bias:** Biased thinking or recall that occurs due to the way the problem is stated, the question asked or the information presented. Asking open-ended questions, presenting facts without interpretation, and avoiding value judgments reduces this problem.
- **Fundamental Attribution Bias:** The tendency to take excess credit for our successes and to deflect responsibility for our failures while attributing to others insufficient credit for successes and excess responsibility for failures.
- **Hindsight Bias:** Knowing the outcome profoundly alters interpretation of the events prior to the outcome, leading to underestimation (illusion of failure) or overestimation (illusion of control) of abilities. In hindsight, events appear to fit together and to be explained better than they did at the time.
- **Multiple Alternatives Bias (Paralysis by Analysis, "Wallpaper phenomenon"):** Multiple options (e.g., multiple differential diagnoses) multiply the conflict and uncertainty compared to fewer, leading to paralysis of action and irrational decision making. Instead of comparing all competing options with each other, compare each with a common benchmark such as the status quo, starting with the more relevant or the more likely. Limit the number of recommendations.
- **Null Feedback Bias:** The failure to regularly obtain feedback, positive or negative, on the outcomes of previous workups and recommendations after the passage of time, instead concluding that they were successful in the absence of evidence. Follow up on how the recommendations turned out.
- **Order Bias:** Information communicated at the beginning and at the end of an exchange is remembered better than the information communicated in the middle. Having a systematic process with question threads worked out in advance and taking notes during interviews rather than relying on recall later reduces this bias. Capture visual observations with a digital camera.

- **Overconfidence Bias:** The tendency to spend too little time gathering and synthesizing information before taking action because of placing too much faith in our opinions and hunches. Ask: "Has information been gathered in a logical, thorough and logical fashion? Does it support my opinion?"
- **Premature Closure Bias:** The tendency to accept a conclusion before it has been sufficiently verified by tests for adequacy, coherence, parsimony and falsification.
- **Satisfying Bias:** The tendency to stop searching for further information once something is found. The questions to ask are: "Is there anything else to be found?", "Did I look in the right places?" and "Are any clues inconsistent with this conclusion?"
- **Support Bias:** The tendency to judge the hypothesis with the more detailed information as being more likely.
- **Sunk Cost Bias:** The greater the investment of funds, time and mental energy in a diagnosis, the greater the reluctance to let it go and consider other alternatives.
- **Vertical Thinking Bias:** The failure to think laterally or "outside of the box", which is reduced by asking the question "What else might explain this?".

## Logical Basis of Causal Reasoning

The following, which are the logical basis for reasoning about findings in the presence of uncertainty, provide guidance for constructing and evaluating useful comparisons. For more detail on these general principles, see a general epidemiology text, such as Thrushfield (2007), or a text such as Gregg (2008).

**Mill's Eliminative Methods of Induction** (System of Logic, 1843):

**Method of Agreement:** "If two or more instances of the phenomenon have only one circumstance in common, the circumstance in which alone all instances agree is the cause or effect of the given phenomenon."

**Method of Difference:** "If an instance in which the phenomenon under investigation occurs, and an instance in which it does not occur, have every circumstance in common save one, that one occurring in the former, the circumstance in which alone the two instances differ, is the effect, or the cause, or an indispensable part of the cause, of the phenomenon."

**Joint Method of Agreement and Difference (Indirect Method of Difference):** The application of both the method of agreement and the method of difference in the same evaluation of cause; ". . . it proceeds by ascertaining how and in what the cases where the phenomenon is present differ from those in which it is absent."

**Method of Residues:** "Subduct from any phenomenon such part as is known by previous inductions to be the effect of certain antecedents, and the residue of the phenomenon is the effect of the remaining antecedents."

**Hill's Criteria for Causation** (Hill 1965):

1. **Strength of Association:** The larger the relative effect, the more likely the causal role of the factor. Although the presence of an association alone is not sufficient to prove causation, at minimum a biologically significant association must be present for cause to be present.
2. **Consistency:** If similar associations are found in different studies in different populations, the more likely the causal role of the factor.
3. **Specificity:** If the effect does not result from other causes, the more likely the factor is causal.
4. **Temporality:** Risk factor exposure must precede the outcome.
5. **Dose-response (biological gradient):** If the risk increases with increasing dose or longer exposure to the risk factor, the more likely the causal role of the factor.
6. **Biological Plausibility:** Given the state of existing knowledge, the mechanism is biologically plausible in that it does not contravene well-established understanding.
7. **Coherence:** Associations between the risk factor and the outcome is consistent with existing knowledge and does not conflict with the generally known facts of the natural history and biology of the disease.
8. **Intervention (Experiment):** Reduction or removal of the risk factor reduces the risk of the outcome, the strongest evidence of causation.
9. **Analogy:** That a similar but not identical cause and effect relationship has been observed and established elsewhere as causal provides weak evidence for causality.

**Evan's Postulates** (Evans 1976):

1. Prevalence of the disease should be significantly higher in those exposed to the risk factor than those not.
2. Exposure to the risk factor should be more frequent among those with the disease than those without.
3. In cohort studies, the incidence of the disease should be higher in those exposed to the risk factor than those not.
4. The disease should follow exposure to the risk factor with a normal or log-normal distribution of incubation periods.
5. A spectrum of host responses along a logical biological gradient from mild to severe should follow exposure to the risk factor.
6. A measurable host response should follow exposure to the risk factor in those lacking this response before exposure or should increase in those with this response before exposure. This response should be infrequent in those not exposed to the risk factor.
7. In experiments, the disease should occur more frequently in those exposed to the risk factor than in controls not exposed.

8. Reduction or elimination of the risk factor should reduce the risk of the disease.
9. Modifying or preventing the host response should decrease or eliminate the disease.
10. All findings should make biological and epidemiological sense.

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