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Progression to multi-scale models and the application to food system intervention strategies

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ABSTRACT

The aim of this article is to discuss how the systems science approach can be used to optimize intervention strategies in food animal systems. It advocates the idea that the challenges of maintaining a safe food supply are best addressed by integrating modeling and mathematics with biological studies critical to formulation of public policy to address these challenges. Much information on the biology and epidemiology of food animal systems has been characterized through single-discipline methods, but until now this information has not been thoroughly utilized in a fully integrated manner.

The examples are drawn from our current research. The first, explained in depth, uses clinical mastitis to introduce the concept of dynamic programming to optimize management decisions in dairy cows (also introducing the curse of dimensionality problem). In the second example, a compartmental epidemic model for Johne's disease with different intervention strategies is optimized. The goal of the optimization strategy depends on whether there is a relationship between Johne's and Crohn's disease. If so, optimization is based on eradication of infection; if not, it is based on the cow's performance only (i.e., economic optimization, similar to the mastitis example). The third example focuses on food safety to introduce risk assessment using *Listeria monocytogenes* and *Salmonella* Typhimurium. The last example, practical interventions to effectively manage antibiotic resistance in beef and dairy cattle systems, introduces meta-population modeling that accounts for bacterial growth not only in the host (cow), but also in the cow's feed, drinking water and the housing environment. Each example stresses the need to progress toward multi-scale modeling. The article ends with examples of multi-scale systems, from food supply systems to Johne's disease.

Reducing the consequences of foodborne illnesses (i.e., minimizing disease occurrence and associated costs) can only occur through an understanding of the system as a whole, including all its complexities. Thus the goal of future research should be to merge disciplines such as molecular biology, applied mathematics and social sciences to gain a better understanding of complex systems such as the food supply chain.

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1. Introduction

We veterinary epidemiologists are "big picture" people, but unfortunately competitive research funding is not for "big picture" research. It is good to understand the "big picture", but money goes to hypothesis driven (mechanistic) research. Therefore, I have advised my Ph.D. students to write their proposals to address a specific question to which they are able to give a definite answer. Similarly, we should acknowledge that we hardly ever develop new (mathematical) methods; however, we should encourage our students to find the best, state of the art methods for their needs and use them with proper citations. Now, I am perhaps contradicting myself because I would like to advocate systems thinking (Sterman, 2000; Galea et al., 2010) and to discuss how the systems science approach can be used to optimize intervention strategies in food animal systems. The reason for my 'conversion" is the realization that if we want to make a real impact in food safety we have to acknowledge the complexity of the modern food safety system (Fig. 1). Given the complexity of the food supply system in which many components interact and exhibit nonlinear properties such as positive and negative feedback, the overall behavior cannot be merely explained by the properties of the constituent parts. In the traditional approach, the whole system is first compartmentalized into convenient subsystems or even parts of subsystems; these parts are then rigorously studied often using a single discipline. After each part is described, an attempt is made to understand the system as a whole by aggregating knowledge of its parts. The difficulty in this approach is that it ignores interdependence and instead simplifies what are actually quite complex, multidirectional relationships into convenient, unidirectional relationships. An implication of ignoring the interdependence existing in the system is that we can wrongly predict the effects of the interventions. A novel approach to food safety research would be to treat the entire food supply chain as an ecosystem comprising not only the industry sectors, with the specific relationships among processing, retail and consumers, but also regulatory and intervening factors that are generally qualitative in nature. The applicability of systems thinking to complex systems, which are composed of simple components whose nonlinear interactions and lack of central control produce emergent behaviors, has been recently explored in various disciplines and topics such as smoking cessation policies, proliferation of type 2 diabetes, and obesity monitoring (Tobias et al., 2010; Milstein et al., 2007; Luke and Stamatakis, 2012). The aim of this article is to discuss how the systems science approach can be used to optimize intervention strategies in food animal systems. In our first example, we use clinical mastitis to introduce the concept of dynamic programming, which can be used to optimize management decisions in dairy cows. In our second example, we use Johne's disease to demonstrate how optimization of different intervention strategies depends on whether the goal is to eradicate infection or not. The third example focuses on food safety to introduce risk assessment using *Listeria monocytogenes* and *Salmonella* Typhimurium. The last example, practical interventions to effectively manage antibiotic resistance in beef and dairy cattle systems, introduces meta-population modeling that includes bacterial growth in host (cow), and the host's feed,

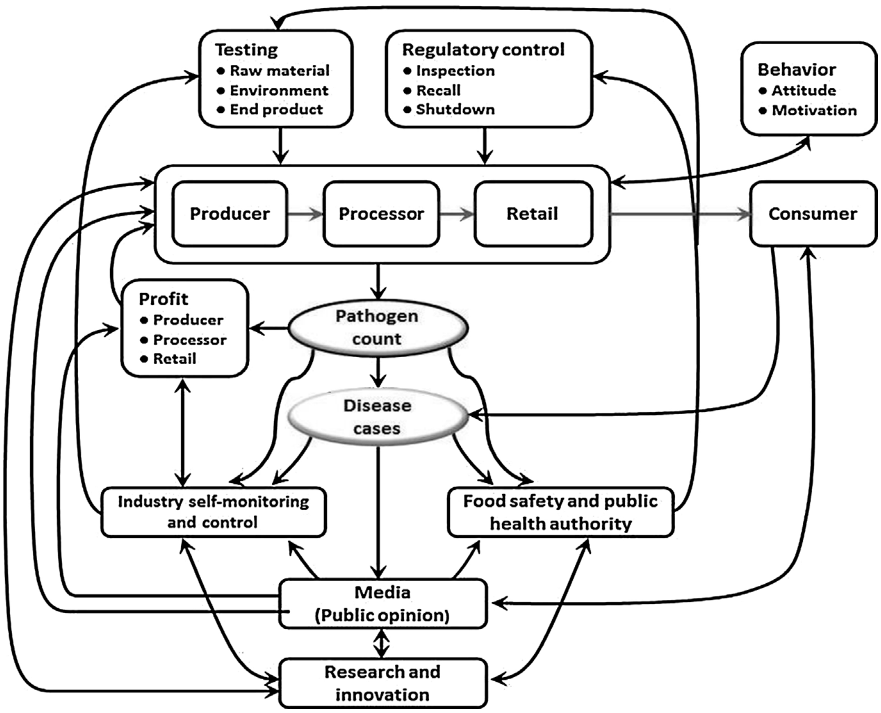

Fig. 1. Basic concept map for a generic pathogen's transmission through the food chain and its implications for food safety.