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Spatio-temporal assessment of food safety risks in Canadian food distribution systems using GIS

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ABSTRACT

While the value of geographic information systems (GIS) is widely applied in public health there have been comparatively few examples of applications that extend to the assessment of risks in food distribution systems. GIS can provide decision makers with strong computing platforms for spatial data management, integration, analysis, querying and visualization. The present report addresses some spatio-analyses in a complex food distribution system and defines influence areas as travel time zones generated through road network analysis on a national scale rather than on a community scale. In addition, a dynamic risk index is defined to translate a contamination event into a public health risk as time progresses. More specifically, in this research, GIS is used to map the Canadian produce distribution system, analyze accessibility to contaminated product by consumers, and estimate the level of risk associated with a contamination event over time, as illustrated in a scenario.

1. Introduction

Since risk assessments related to public health incorporate important spatio-temporal components, geographic information systems (GIS) have been used for many years as a tool to model and assess risks in various areas such as drinking water (Kistemann et al., 2001a,b; Adriaens et al., 2003; Liang et al., 2010; Jiménez-Moleón and Gómez-Albores, 2011), water quality associated with irrigation in agriculture (Knox et al., 2011), floods (Taylor et al., 2011), or transport of hazardous materials throughout road networks (Verter and Kara, 2001; Ak and Bozkaya, 2008). An index is required to quantify and illustrate risk in GIS. There are numerous examples of indices being used both in risk assessment and specifically in GIS applications (Vairavamoorthy et al., 2007; Planas et al., 2006; Zhijun et al., 2009; Nadal et al., 2006; Zamorano et al., 2008). The basic premise in all these applications is that a complex process is summarized into a single composite measure. A good example of a complex physical process characterized by a simple index applied in a GIS context can be found in Bigras-Poulin et al. (2004).

Issues related to public health, agricultural products and food supply chains have received a great deal of attention of late (Ahumada and Villalobos, 2009; Bosona and Gebresenbet, 2011). A recent report describes the development of an innovative GIS-based interface that can dynamically map and predict the spread of specific microbiological threat agents along the farm-to-fork continuum (Hashemi Beni et al., 2011). One challenge encountered in this research was the quantification of public health impact related to a spatio-temporal distribution of contaminated product in a food supply system, for example to multiple retail outlets. Under such circumstances, calculating customer accessibility to the product is as important as estimating the level of

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contamination and number of contaminated items in each retail outlet in a food supply system.

Eckert and Shetty (2011) have documented the increased application of GIS to map accessibility to retail outlets. Various approaches have been used depending on objectives and structure of the supply chain (Apparicio et al., 2007; Larsen and Gilliland, 2008; Sharkey, 2009; Smith et al., 2010; Michimi and Wimberly, 2010; Eckert and Shetty, 2011; Van Meter et al., 2011; Gordon et al., 2011). Parameters such as proximity (distance to the nearest outlet), diversity (number of outlets within a distance of less than 1000 m) and variety (average distance to the three closest outlets of different banners) were used as part of food desert assessments (Apparicio et al., 2007). Physical parameters such as distance (urban versus rural areas) (Smith et al., 2010), and socioeconomic characteristics such as affordability or availability of public transit (Larsen and Gilliland, 2008), may also affect accessibility.

Once accessibility to a public health risk is determined, quantifying the risk is necessary. The level of risk can be estimated directly by calculating the number of infections resulting from exposure to a pathogen. This approach requires a significant amount of information about the dose–response relationship for the pathogen as well as detailed knowledge about consumer purchasing and handling practices. Alternatively, a risk index that can help gauge the potential relative risk associated with a contamination scenario could be used in lieu of the exact or absolute risk. This approach has been applied successfully in different settings. For example, Bigras-Poulin et al. (2004) developed a risk index that predicts the health pressure on a community as a function of agricultural land use behaviors in the watersheds around the community. The public health risk associated with exposure through a retail food product could be estimated by use of a similar risk index.

The objectives of the research reported herein were to demonstrate how GIS can be used to: (1) conduct spatio-temporal analyses in a complex food distribution system; (2) conduct a spatial accessibility analysis on a national scale, rather than on a community scale; and (3) translate a food contamination event into a public health outcome by analysis of consumer accessibility to contaminated product and the estimation of risk associated with the event.

This paper also includes background information on a Canadian food distribution system, details of the spatio-temporal analyses conducted and the outcomes of a fictitious contamination event.

2. Characterization of a food distribution system

A detailed description of movement through the production-to-consumption chain is required to accurately assess safety risks associated with a food product in a distribution system. Since the steps encountered between production and consumption can vary considerably between food commodities a single product was chosen to develop the approach, specifically retail portioned packaged, ready-to-eat lettuce. In Canada, packaged salads sold in retail generally move through a four-step supply chain consisting of growers/suppliers, processors, distribution centres and retail stores, as illustrated in Fig. 1 (Hashemi Beni et al., 2011). The geographical data of the different establishments involved in this supply chain and the flow of product between establishments were captured from various sources and in different formats.

2.1. Database construction

A relational database was designed and constructed to store and manage the heterogeneous data needed to characterize the flow of packaged ready-to-eat lettuce through the distribution systems of five retail chains in Canada (Fig. 2). The data included:

- Location of processors, origin of lettuce supplied to each processor (both domestic and imported), quantities processed on a seasonal basis for the domestic retail sector, distribution centres being supplied by each processor, probability of shipment to each distribution centre, time spent in storage at processor, and temperature of salads during storage at processor;
- Transit time between each processor and distribution centre, and product temperature during transit;
- Location of retail distribution centres, quantities received (both domestic and imports) on a seasonal basis, probability of shipment to each retail store serviced by distribution centre, time spent in storage at distribution centre, and temperature during storage at the distribution centre;
- Transit time between each distribution centre and retail store, and temperature during transit; and
- Locations of retail stores, distribution centre supplying each retail store, quantities received on a seasonal basis, time spent in storage at retail, and temperature in retail storage.

In addition to these data, the database included provincial and municipal data layers, transportation routes and demographic data. GIS was invaluable in ensuring co-registered input data layers for the model and data analyzing to extract the required information such as transit times between processors and distribution centres, transit times between distribution centres and retail outlets and populations potentially affected by contaminated product.

2.2. Spatial–temporal modeling in the Canadian distribution system

For this project, the space–time modeling involves simulating the distribution chain from the time the lettuce is processed, packaged, boxed, palletized at the processing plant and shipped to distribution centres for subsequent transportation to retail locations. The model recognizes that contaminated product can experience an increase or decrease in contamination levels as a result of the type of contamination and the time and temperature that the product experiences between the processing plant and the retail location. The growth or death of microbial contaminants as a result of time–temperature exposure is