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Food Transportation Safety: Characterizing Risks and Controls by Use of Expert Opinion

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ABSTRACT

Federal regulations stipulate that food products be protected against physical, chemical and microbial contamination during transportation and holding. An expert opinion elicitation was conducted to assess food safety hazards and preventive controls associated with the transportation and holding of food commodities. Frequency and severity risk rankings suggest five food safety hazards of greatest concern across all modes of transport: (1) lack of security; (2) improper holding practices for food products awaiting shipment or inspection; (3) improper temperature control; (4) cross-contamination; and (5) improper loading practices, conditions, or equipment. Factor analysis suggests that "in-transit" and "organizational" risk factors might explain the relationships among the various food safety hazards. Raw seafood, raw meat and poultry, and refrigerated raw and ready-to-eat foods have the highest overall risk (in descending order) across all modes of transit. Our analysis also identified a range of preventive controls that may help eliminate/mitigate the risks to food during transport and storage, including: employee awareness and training, management review of records, and good communication between shipper, transporter and receiver.

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INTRODUCTION

Each year, 200 billion metric tons of food are transported globally — 35 percent by land, 60 percent by sea, and 5 percent by air *(3)*. The sheer quantity and variety of foods transported, along with the multitude of container, temperature, and handling requirements for each food product, emphasizes the vulnerability of the food industry to possible contamination during transport and storage *(8)*. Risk factors for contamination include improper production practices, temperature abuse, unsanitary cargo areas, improper loading or unloading procedures, damaged packaging, shipping containers in ill repair, bad employee habits, and road conditions. There is, however, currently very little information on the state of food transportation and holding practices in the United States.

Current federal regulations stipulate that food products be protected against physical, chemical and microbial contamination during transportation and holding (21 CFR § 110.93) *(19)*. The Sanitary Food Transportation Act of 2005 (Pub. L. 109-59, 119 Stat. 1144) reallocated responsibilities for food transportation safety among the US Department of Health and Human

Services (DHHS), the US Department of Transportation (DOT), and the US Department of Agriculture (USDA) and requires the Secretary of DHHS to issue rules setting up sanitary food transport practices *(13)*. It also amends section 402 of the Federal Food, Drug, and Cosmetic Act (21 USC § 342(i)) so as to render unsanitary transport adulteration *(1)*.

Supply chains are quite similar across most products, food and non-food. A tier of suppliers serves manufacturing/production facilities. These facilities then serve distribution facilities, which eventually serve retailer outlets, which in the case of food, include restaurant retail facilities that serve the end consumer. Such supply network systems might be quite complex as there can be additional first tier and second tier suppliers. Although many companies organize the transport of their goods internally, some food manufacturers use third-party logistics providers (3PLs) to outsource transportation procurement. A 3PL is a firm that provides outsourced, or "third party," logistics services to companies for part or sometimes all of their supply chain management function. Third-party logistics providers typically specialize in integrated warehousing and transportation services that can be scaled and customized to customers' needs based on market conditions and on the demands and delivery service requirements for their products and materials.

Although certain food supply chain systems require bulk transport, such as rail, barge or inland water, truck transportation dominates most food supply chain systems, especially toward the consumer end of the chains *(6)*. Truck transporters are typically involved in moving goods among manufacturers and distributors, distributors and retailers, and even further up the chain between suppliers and production points. Particularly for perishable foods, trucking remains the cheapest and most flexible mode of food transport *(4)*. In the United States, about 80 percent of all food shipments *(12)* and 91 percent of all temperature-controlled freight shipments, including about 28.5 million tons of refrigerated fruit and vegetables *(17),* are transported by truck *(9)*.

Railroad and intermodal transportation have received increased attention recently because of their potential cost savings and the trucking industry's current challenges with fuel surcharges, driver shortages, and Hours of Service (HOS) regulations for commercial motor vehicle drivers *(16).* Current law regulates the number of consecutive hours that commercial motor vehicle drivers may be on-duty (49 CFR § 395) *(18)*, thereby increasing the number of drivers required by the industry. Intermodal freight transportation involves the use of multiple modes of transportation (truck, rail and ship) for the same shipment without handling the freight between modes (e.g., truck trailer transferred to flatbed railcar). Some suppliers may be taking advantage of economies of scale in boxcar shipping and utilizing intermodal transportation to develop more regionalized trucking routes in response to driver preferences for short-haul rather than long-haul trucking *(16)*.

In the complex food transportation system, the earlier an undetected problem is introduced into the system, the higher the risk (as measured by exposure likelihood and impact); that is, a problem that is introduced at an earlier stage in the supply chain can spread out to many distributors, retailers and then to consumers just because of the structure of the system. For example, "[in 1994], an estimated quarter of a million Americans got gastroenteritis after eating Schwan's ice cream — the largest outbreak of *Salmonella* poisoning in the United States ever traced to a single source. Environmental health specialists eventually tracked down the cause. Liquid eggs laced with the *Salmonella* bacteria were transported to a factory in tanker trailers. These same trucks later hauled pasteurized ice cream base to another plant, and the bacteria came too" *(7)*.

Saddle Creek Corporation, a third-party logistics provider (3PL), conducted a survey of food and beverage warehousing and transportation management executives *(12)*. The majority of respondents were grocery companies, food and beverage processors or other third-party logistics providers. The survey, intended to identify common practices, challenges, and emerging trends, found that:

- Capacity problems, driver shortages, and customer demands are the food transportation industry's top challenges.
- Food safety is the 6th highest logistics challenge (indicated by 9.6 percent of respondents).
- 58.3 percent of respondents engage in backhauling (transporting a different load in the empty truck on a return trip), although only 17.1 percent indicate achieving 81 to 100 percent of their backhauls.
- 63.5 percent of respondents outsource some or all of their transportation (34.1 percent outsource 75 to 100 percent of their transportation budget).

A number of these findings may be significant with regard to food transportation safety. Driver shortages and capacity problems may result in a lack of driver education in and adherence to proper procedures for the safe transportation of food. Backhauling increases the risk for cross-contamination if potentially hazardous foods or other items are carried in succession without proper sanitation between loads. Finally, manufacturers who outsource their transportation needs relinquish control of the safety of their product as it moves from the processing facility to the retailer. Good communication and management systems are required to maintain product integrity throughout the distribution chain.

Sources indicate that the greatest concerns for food safety during transportation are tampering and sabotage, temperature abuse, and cross-contamination *(8, 15)*. While there is limited data on food safety failures that are directly attributable to transportation and storage practices, some industry experience suggests that such incidents may be widely underreported *(8)*. An expert opinion elicitation study was conducted to characterize baseline practices in the sectors involved in food transportation (local and long distance general freight trucking, rail and deep sea freight transportation, refrigerated warehousing and storage, etc.) and identify areas where food is at risk for adulteration.

The objectives of this study were twofold: (1) To identify the main problems that pose microbiological, chemical, and/or physical safety hazards to food during transportation and storage, and (2) to determine the preventive controls that could address the problems identified. The study enables the identification of those food product types and modes of transportation where the hazards are

TABLE 1. Expert participants and affiliations

Expert	Affiliation
Jim Balestra	Safefreight Technology; Latium Fleet Management
Betsy Blair	AIB International, Inc.
Craig Cahill	Allen Lund Company, Perishable Logistics Division
Clifford M. Coles	Consulting Microbiology of California, Inc.
John Conley	National Tank Truck Carriers, Inc.
Roy Costa	Environ Health Associates
Patrick Floyd	Nordic Cold Storage
Peter Friedmann	Agriculture Transportation Coalition
Fletcher Hall	F.R. Hall & Associates, LLC
Dan Jenkins	Grapple Hook Marketing
Chris Kozak	Willis Shaw Express
Russell Laird	Agriculture and Food Transporters Conference (AFTC)
Peg Sarinyamas	Feeding America
Gary Sherlaw	Food Safety Consulting International (FSCI)
Richard F. Stier	Consulting Food Scientists
Gerald Wojtala	Association of Food and Drug Officials; Michigan Department of Agriculture

of high importance for public health. Further, information on preventive controls may help identify the most effective food transportation and storage practices.

MATERIALS AND METHODS

The study objectives required gathering current data not known or available. Moreover, they did not easily lend themselves to more precise analytical techniques, such as a statistical industry survey, given that it would entail asking food transporters to release potentially sensitive information. Thus, we used expert opinion elicitation to generate the necessary information from a panel of nationally recognized experts in food transportation safety. Expert opinion elicitation is a formal, heuristic process of obtaining subjective information or answers to specific questions about certain quantities and probabilities of future events *(2)*. The Delphi method is the first structured method for eliciting and combining expert opinion. The method requires indirect interaction among experts through a moderator *(5, 10, 11)*. Although variations of the method exist, in a typical Delphi study, experts make individual judgments. Next, these judgments are shared anonymously with the whole group. After viewing other experts' judgments, each expert is then given the opportunity to revise his own judgments, and the process is repeated. Theoretically, the goal of the Delphi is to reach a consensus after a few rounds; in reality, this rarely happens. Thus, at the end of the Delphi rounds, the experts' final judgments are typically combined mathematically.

Study design

We recruited a 16-member panel comprising experts with experience in all areas of food transportation and food safety. Participants were selected based on their ability to contribute industry views as well as their willingness to participate in the process. On average, panel members possessed over 24 years of related food industry experience. The expert panel included participants from trade associations, logistic research institutes, academia, third-party logistics firms, companies that provide logistics support, and independent consultants with experience in consulting to food companies of varying sizes on logistics and transportation safety issues (Table 1). In identifying the experts, we relied on recommendations from FDA, various food industry personnel, and other experts in food transportation and food safety.

The study utilized a four-round design, with iterations following each round. In Round 1, we solicited background information from the experts on: (1) the types of food safety hazards that may increase the risk of food contamination during transportation and warehousing/storage; (2) the food product categories and modes of transportation for which the risk and severity of hazards could potentially vary; (3) intermodal transportation considerations; and (4) possible differences between food safety hazards for imported and domestic food products. Specifically, we presented our findings based on a literature review and

TABLE 2. Risk scoring grid

	Severity	
Frequency	**Low**	**High**
Low	1	3
High	2	4

discussions with industry experts and asked each expert to expand the various lists and provide additional comments on these issues.

The objective of Round 2 was to assess the risk posed by each of the fifteen food safety hazards by food sector and transport mode identified in Round 1. Experts were asked to assign a risk score from 1 to 4 based on the hazard's frequency and severity (Table 2). Thus, each expert first had to assess whether the problem occurred at a high or low frequency for the specified food sector and mode of transport (i.e., how widespread the problem is) and then to evaluate whether the probability that the problem could render the food unsafe was high or low (i.e., assess the severity of potential consequences, such as mortality, morbidity, and economic impacts, of the problem). Panel members were directed to skip questions for which they lacked sufficient knowledge for an informed assessment.

The objective of Round 3 was to obtain background information on preventive controls that may eliminate or mitigate the risk of food safety hazards in food transportation and warehousing/storage from our expert panel. Again, we presented our own findings on preventive controls to the panel and asked them to expand the list. In Round 4, experts identified the set of preventive controls necessary to eliminate or mitigate the risk posed by each of the fifteen food safety hazards. Experts were asked to ensure that the controls had the broadest applicability across all food product sectors and modes of transport.

As noted above, we used the Delphi technique to reach consensus for each round of questioning. Iteration rounds helped to stabilize results and increase agreement among participants. At the completion of all rounds, including iteration rounds, we sent each participant a summary of his responses for review and final confirmation. Because full consensus was not attainable, we relied on accepted aggregation procedures to pool expert estimates, where applicable.

Data analysis

We used Stata *(14)* to perform descriptive univariate analysis as well as factor analysis on the data collected. For factor analysis, we used Stata's *factor*, *rotate*, and *score* functions. Factor analysis is a data reduction technique that reduces the number of variables used in an analysis by creating new variables (called factors) that combine redundancy in the data. A factor analysis looks for correlations among the variables and the first step is to determine the number of relevant factors. While Stata's algorithms used to solve factor analyses include methods of determining an appropriate number of factors, it is also possible to specify (fix) the number of factors in the analysis. For this study, we allowed the algorithms to determine the number of factors and also used judgment in determining the appropriate number of factors. The output from the factor analysis generates a table that relates each variable to each factor and assigns a numerical value between -1 and 1 to each relationship. The numerical values are referred to as factor loadings and reflect the strength of relationship between the factors and the variables. Variables that are closely related to one another should all load highly on the same factor. Stata's *score* command produces estimates of these factors, which we used to develop indices of riskiness by food sector. Specifically, the method allowed us to generate an overall risk score for each food sector by mode of transport that combines the information in all of the fifteen food safety hazards, as well as multi-factor risk scores separately by food sector and mode of transport.

RESULTS

Descriptive analysis

Experts identified 15 food safety hazards that pose microbiological, chemical, and/or physical safety hazards to food during transportation and warehousing or storage (Table 3). The panel also identified 11 food product sectors to be considered when assessing the frequency and severity of these food safety hazards. In addition, the experts collectively identified the following modes of transport, as well as storage/warehousing, as having distinct risk rankings for food safety hazards: truck; rail; water; air; and intermodal. Different types of water transportation (e.g., deep sea freight versus inland water freight) were not considered separately, because of experts' suggestions that food safety hazards are not related specifically to the type of water transportation.

The total number of food safety hazards scored by panel members across food product sectors and transport modes substantially increased the respondent burden in the third round. An average of 13 out of 15 experts provided risk scores for each of the 990 individual risk rankings requested. Only 7 percent of all problem-sector-mode combinations resulted in an average risk score of 4 (high frequency, high severity) (61%). The majority of problem-sector-mode combinations resulted in average risk scores of 1 (low frequency, low severity) and 3 (low frequency, high severity) (28%). An analysis of the risk score data leads to the following observations:

- The top 5 food safety hazards that were the greatest concern across all modes of transportation were:
  - Lack of security for transportation units or storage facilities,
  - Improper holding practices for food products awaiting shipment or inspection,
  - Improper refrigeration or temperature control of food products,
  - Improper management of transportation units or storage facilities to preclude cross-contamination, and
  - Improper loading practices, conditions, or equipment.

TABLE 3. Fifteen food transportation safety hazards that increase the risk for physical, chemical, and/or microbial contamination, as identified by the expert panel

Food Transportation Safety Hazard
(1) Improper refrigeration or temperature control of food products (temperature abuse), including intentional (abuse or violation of practices by drivers, i.e., turning off refrigeration units) or unintentional (due to improper holding practices or shortages of appropriate shipping containers or vessels, etc.)
(2) Improper management of transportation units or storage facilities to preclude cross-contamination, including improper sanitation, backhauling hazardous materials, failure to maintain tanker wash records, improper disposal of wastewater, and aluminum phosphide fumigation methods in railcar transit
(3) Improper packing of transportation units or storage facilities, including incorrect use of packing materials and poor pallet quality
(4) Improper loading practices, conditions, or equipment, including improper sanitation of loading equipment, failure to use dedicated units where appropriate, inappropriate loading patterns, and transporting mixed loads that increase the risk for cross-contamination
(5) Improper unloading practices, conditions, or equipment, including improper sanitation of equipment and leaving raw materials on loading docks after hours
(6) Lack of security for transportation units or storage facilities, including lack of or improper use of security seals and lack of security checks or records of transporters
(7) Poor pest control in transportation units or storage facilities
(8) Lack of driver/employee training and/or supervisor/manager/owner knowledge of food safety and/or security
(9) Poor transportation unit design and construction
(10) Inadequate preventive maintenance for transportation units or storage facilities, resulting in roof leaks, gaps in doors, and dripping condensation or ice accumulations
(11) Poor employee hygiene
(12) Inadequate policies for the safe and/or secure transport or storage of foods
(13) Improper handling and tracking of rejected loads and salvaged, reworked, and returned products or products destined for disposal
(14) Improper holding practices for food products awaiting shipment or inspection, including unattended product, delayed holding of product, shipping of product while in quarantine, and poor rotation and throughput
(15) Lack of traceability for food products during transportation and storage

Note: Food safety hazards are listed in random order (as compiled by the expert panel).

- High-risk foods across all modes of transportation included:
  - Fresh produce (including all whole, raw, uncut, non-refrigerated fruits and vegetables, i.e., fresh, field-packed or bulk, fresh loads or bulk, fresh for processing);
  - Refrigerated raw and ready-to-eat (RTE) foods, (i.e., dairy products, prepared foods, deli items, raw ingredients, fresh-cut produce);
  - Frozen foods (i.e., frozen fruits and vegetables, entrees, meat, seafood, par-baked goods, ice);
  - Raw meat and poultry (i.e., carcasses and primal cuts, ice-packed chicken, frozen, bulk raw meat ingredients, rendering material, etc.);
  - Eggs and egg products (pasteurized and unpasteurized); and
  - Raw seafood.

Effective preventive controls are important in ensuring product safety in transportation and storage of food products. In addition to risk rankings, experts identified 23 preventive controls that may eliminate or mitigate the risk of food safety hazards in food transportation and warehousing/storage (Table 4).

The following seven controls had the broadest applicability across all food sectors and modes of transport: (1) employee awareness and training; (2) management review of records; 3) good communication between shipper, transporter and receiver; (4) appropriate loading procedures for transportation units; (5) appropriate unloading procedures for transportation units; (6) appropriate documentation accompanying each load (tanker wash record, seal numbers, temperature readings, time in-transit and time on docks, etc.); and (7) appropriate

TABLE 4. Preventive controls for food transportation safety hazards, as identified by the expert panel

Preventive Controls for Food Transportation Safety Hazards
(1) Appropriate packaging/packing of food products and transportation units (i.e., good quality pallets, correct use of packing materials)
(2) Proper use of refrigeration equipment
(3) Thermal insulated blankets over refrigerated/frozen items
(4) Temperature monitoring/recording devices
(5) Appropriate loading procedures for transportation units
(6) Appropriate unloading procedures for transportation units
(7) Use of appropriate transportation vehicles (i.e., dedicated vehicles when necessary)
(8) Physical security measures for facilities and transportation units (cargo locks, seals, etc.)
(9) Security checks and records of transporters
(10) Use of tracking technologies (i.e., satellite (GPS) or radio frequency identification)
(11) Appropriate documentation accompanying each load (i.e., tanker wash record, seal numbers, temperature readings, time in transit and time on docks, etc.)
(12) Vendor or food transporter certification programs
(13) Sanitation/Maintenance of transportation units, storage facilities, and/or containers
(14) Sanitation/Maintenance of loading/unloading equipment
(15) Proper disposal of wastewater
(16) Employee awareness and training
(17) Pest control programs
(18) Good communication between shipper, transporter and receiver
(19) HACCP or other management systems
(20) Third party audits of systems/policies/procedures
(21) Availability of handwashing/hygienic devices
(22) Proper labeling and/or signage and/or transporter instructions
(23) Management review of records

Note: Preventive controls are listed in random order (as compiled by the expert panel).

packaging/packing of food products and transportation units (i.e., good quality pallets, correct use of packing materials).

Factor analysis

Given the degree of overlap among various food safety hazards, we expect that some underlying factors (root causes), which are smaller in number than the number of variables (i.e., number of food safety hazards), are mainly responsible for the covariance among our variables. For example, improper loading procedures may be a result of lack of employee training, improper holding practices for food products awaiting shipment or inspection may result in improper refrigeration or temperature control of food products, and inadequate policies for the safe transport of food products may be responsible for the lack of security during transportation. Therefore, we performed a factor analysis to determine the number of underlying dimensions in the risk score data collected and how the information contained in the fifteen hazards could be combined to provide summary information.

The factor analysis technique allowed us to generate an overall risk score that combines the information for all of the 15 food safety problems. That is, we calculated the relationship among all of the variables and one underlying factor that we call "overall risk." An index of overall risk for each food product sector is presented in Table 5 by mode of transportation. Each index (read by the column only) has a mean of 100 and standard deviation of 10. This provides an indication of the relative risk of the food product sectors for each mode of transportation. A value that exceeds 100 indicates that overall risk in the relevant sector is greater than average risk. Index values are rounded to the nearest tenth to highlight subtle differences in relative risk between food product sectors.

TABLE 5. Overall risk indices for the fifteen food safety hazards by food product sector

Food Product Sector	Truck	Rail	Water	Air	Intermodal	Storage
Bulk liquids (dedicated tanker)	94.9 (8)	95.3 (8)	96.5 (7)	95.1 (10)	94.3 (8)	94.4 (8)
Bulk raw ingredients	95.2 (7)	95.4 (7)	95.9 (8)	95.9 (8)	96.1 (7)	96.6 (7)
Eggs and egg products	103.6 (6)	102.1 (6)	102.1 (5)	101.6 (4)	101.4 (6)	99.8 (6)
Frozen foods	104.6 (5)	104.0 (5)	101.8 (6)	100.7 (6)	102.7 (5)	103.0 (5)
Fresh produce	105.4 (4)	106.0 (4)	103.7 (4)	101.1 (5)	102.8 (4)	105.2 (4)
Meat & poultry (raw)	107.1 (2)	110.1 (2)	108.6 (2)	108.1 (2)	109.9 (2)	109.1 (2)
Other nonperishables	92.1 (10)	90.3 (10)	92.8 (10)	95.7 (9)	92.1 (9)	92.0 (10)
Packaging materials	89.3 (11)	86.7 (11)	90.1 (11)	91.1 (11)	89.5 (11)	89.4 (11)
Refrigerated raw & RTE	105.5 (3)	107.3 (3)	107.4 (3)	104.3 (3)	106.6 (3)	107.9 (3)
Soft-packed nonperishables	92.8 (9)	90.5 (9)	92.6 (9)	96.3 (7)	92.0 (10)	91.9 (9)
Seafood (raw)	109.0 (1)	111.9 (1)	108.7 (1)	109.7 (1)	111.9 (1)	111.3 (1)

Note: Obtained by factor analysis as described in the Materials and Methods Section. Each index (read by the column only) has a mean of 100 and standard deviation of 10 and provides an indication of the relative risk of the food product sectors for each mode of transportation. A value that exceeds 100 indicates that overall risk in the relevant sector is greater than average risk. Numbers in parentheses represent the rankings of food product sectors by overall risk index.

The high-risk food groups for each mode of transportation, as well as storage/warehousing of food products, can be discerned from Table 5. Across all modes of transit, the food sectors with the highest overall risk, in descending order, are raw seafood, raw meat and poultry, and refrigerated raw and ready-to-eat foods. Other food product sectors with overall greater-than-average risk for all modes of transport are eggs and egg products, frozen foods, and fresh produce. Packaging materials and both categories of non-perishables present less-than-average overall risk. The rankings of food product sectors by overall risk are the same for truck and rail transportation and warehouse/storage, however, they vary slightly for water, air, and intermodal transport (Table 5). The rankings by food product sector for food transportation by air are most different from rankings for the other modes of transportation.

We also performed exploratory factor analysis to consider food safety hazards across truck, rail, air, water and intermodal means of transportation (excluding storage). The results suggest that two underlying factors help to explain the risk score data for these modes of transport: "in-transit risk" and "organizational risk" (Table 6). The names of these factors are subjective and are derived from the food safety hazards that contribute most to each factor. For example, the "in-transit risk" factor gets its name from the fact that the food safety hazards that contribute most to it are "improper refrigeration," "improper loading," "improper unloading," and "improper holding practices for products awaiting shipment or inspection." Likewise, the food safety hazards that contribute most to the "organizational risk" factor are "lack of driver/employee training," "inadequate preventive maintenance," and "lack of traceability."

The same high-risk food products (as indicated by each factor risk index) show above-average risk for both the "in-transit risk" factor and the "organizational risk" factor (Table 6). However, the risk rankings by food product sector are not identical for the two risk factors. The food product sectors with the highest index value for the "in-transit risk" factor are raw seafood, raw meat and poultry, and fresh produce. The food product sectors with the highest index value for the "organizational risk" factor are raw meat and poultry; refrigerated raw and ready-to-eat foods, and raw seafood.

Because some 80 percent of food products are transported domestically by truck, we also conducted an analysis to consider the food safety hazards in truck transportation alone. Our analysis shows that truck transportation risks are best described by four underlying factors.

- In-transit product risk,
- Equipment-related risk,
- In-transit process risk, and
- Organizational or policy-related risk.

Table 7 shows that the rankings of risk by food product sector are not identical for each truck transportation risk factor. In some cases, certain sectors appear higher in the rankings than one might expect. For instance, soft-packed non-perishables are ranked sixth overall for the "equipment-related risk" factor. However, this sector has, on average, lower equipment-related risk, with an index of 99.1 compared to the mean for the equipment-related risk index of 100 (Table 7). This ranking, however, may reflect the potential for damage to soft-

TABLE 6. Factor risk indices by food product sector, all modes of transportation[a]

Food Product Sector	In-transit Risk[b]	Organizational Risk[c]
Bulk liquids (dedicated tanker)	95.5 (8)	97.3 (8)
Bulk raw ingredients	95.6 (7)	98.1 (7)
Eggs and egg products	102.1 (6)	100.1 (5)
Frozen foods	104.0 (5)	99.4 (6)
Fresh produce	105.1 (3)	100.6 (4)
Meat & poultry (raw)	107.3 (2)	106.9 (1)
Other nonperishables	92.3 (10)	95.9 (9)
Packaging materials	89.8 (11)	93.8 (11)
Refrigerated raw & RTE	104.8 (4)	106.2 (2)
Soft-packed nonperishables	93.3 (9)	95.6 (10)
Seafood (raw)	109.7 (1)	106.0 (3)

Note: Obtained by factor analysis as described in the Materials and Methods Section. Each index (read by the column only) has a mean of 100 and standard deviation of 10 and provides an indication of the relative risk of the food product sectors for each risk factor. A value that exceeds 100 indicates greater than average risk for that factor. Numbers in parentheses represent the rankings of food product sectors by the applicable risk factors. The names of factors are derived from those variables that contribute the most to the factor values.

[a]Includes truck, rail, water, air, and intermodal.

[b]The in-transit risk factor loads very highly on "improper refrigeration," "improper management of transportation units," "improper loading," "improper unloading", and "improper holding practices for products awaiting shipment or inspection."

[c]The organizational risk factor loads highly on "lack of driver/employee training," "inadequate preventive maintenance," "lack of traceability," and "poor employee hygiene."

packed non-perishables due to improper equipment used during transportation and storage of these products.

We also performed an exploratory factor analysis to consider the risks in the warehousing and storage of food products. Our analysis concluded that the risks for storage of food products are best described by the following three underlying factors (Table 8):

- Process-related risk,
- Equipment and/or facility risk, and
- Organizational or policy-related risk.

For this analysis, the rankings for the "equipment and/or facility-related risk" factor seem to be opposite, in a sense, from the other two factors. This is particularly apparent in the top ranking of bulk liquids (ranked first) and eggs and egg products (ranked second) for "equipment and/or facility-related risk." This ranking may reflect the high severity of food safety problems related to dedicated tankers and the possible consequences of a contamination event like the 1994 *Salmonella* outbreak following the transport of ice cream mix in tankers previously used for unpasteurized egg products.

Additional considerations

Throughout each round of the elicitation, experts were provided the opportunity to comment openly on food transportation risks. A number of comments described direct or indirect relationships between food safety concerns and cost saving measures for transporting food products. For example, experts expressed concern about the implications of rising energy costs and cost-saving measures such as shutting off engines until within distance of ports or raising temperature settings to marginal or inappropriate levels. Damage was noted as the biggest concern related to improper packing, where damage can be one function of cost-cutting measures leading to weaker packaging materials. Similarly, concern was expressed about cost-saving measures resulting in the use of inappropriate or inadequate equipment for transportation or storage.

DISCUSSION

This study was designed to characterize the baseline practices in the sectors involved in food transportation, such as refrigerated warehousing and storage, farm product warehousing and storage, deep sea freight transportation, coastal and great lakes freight transportation, inland water freight transportation, local

TABLE 7. Factor risk indices by food product sector, truck transportation

Food Product Sector	In-transit Product-related Risk[a]	Equipment -related Risk[b]	In-transit Process-related Risk[c]	Organizational or Policy-related Risk[d]
Bulk liquids (dedicated tanker)	94.9 (7)	96.1 (11)	95.0 (11)	104.6 (3)
Bulk raw ingredients	94.9 (8)	98.4 (8)	98.9 (5)	99.3 (7)
Eggs and egg products	104.4 (5)	97.3 (9)	96.7 (8)	101.2 (6)
Frozen foods	103.9 (6)	100.8 (5)	96.2 (10)	106.2 (1)
Fresh produce	106.4 (3)	101.5 (4)	104.6 (4)	98.4 (8)
Meat & poultry (raw)	107.6 (2)	101.7 (3)	106.0 (2)	103.9 (4)
Other nonperishables	92.3 (10)	97.2 (10)	96.8 (7)	92.6 (10)
Packaging materials	87.8 (11)	98.6 (7)	97.6 (6)	91.9 (11)
Refrigerated raw & RTE	105.6 (4)	105.8 (1)	106.2 (1)	104.6 (2)
Soft-packed nonperishables	92.5 (9)	99.1 (6)	96.5 (9)	95.2 (9)
Seafood (raw)	109.7 (1)	103.6 (2)	105.7 (3)	102.1 (5)

Note: Obtained by factor analysis as described in Methods Section. Each index (read by the column only) has a mean of 100 and standard deviation of 10 and provides an indication of the relative risk of the food product sectors for each risk factor. A value that exceeds 100 indicates greater than average risk for that factor. Numbers in parentheses represent the rankings of food product sectors by the applicable risk factors. The names of factors are derived from those variables that contribute the most to the factor values.

[a]The in-transit product-related risk factor loads very highly on "improper refrigeration," "improper management of transportation units," "improper loading," "improper unloading," and "improper holding practices for products awaiting shipment or inspection," and moderately high on "lack of driver/employee training and/or supervisor/manager/owner knowledge of food safety and/or security."

[b]The equipment-related risk factor loads very highly on "poor transportation unit design and/or construction" and moderately high on "inadequate preventive maintenance for transportation units."

[c]The process-related risk factor loads highly on "poor employee hygiene" and "lack of traceability," and moderately high on "improper handling/tracking of rejected loads, etc."

[d]The organizational or policy-related risk factor loads highly on "inadequate policies" and "lack of security," and moderately high on "lack of driver/employee training and/or supervisor/manager/owner knowledge of food safety and/or security."

and long distance general freight trucking, and others. It provides a global perspective on current food safety hazards in the food transportation and warehousing industry as well as information on the relative importance of these problems across various food sectors and modes of transport.

Through a literature review and expert opinion elicitation, we identified 15 food safety hazards that increase the risk of microbiological, chemical, and/or physical contamination during the transport and storage of food. The top 5 food safety hazards of greatest concern across all modes of transportation include: (1) lack of security; (2) improper holding practices; (3) improper refrigeration or temperature control; (4) improper management of transportation units or storage facilities to preclude cross-contamination; and (5) improper loading practices, conditions, or equipment.

As expected, the level of contamination risk posed by improper transportation and storage practices varies across food sectors. Raw seafood, raw meat and poultry, and refrigerated raw and ready-to-eat foods have the highest overall risk (in descending order) across all modes of transit followed by eggs and egg products, frozen foods, and fresh produce. Packaging materials and non-perishables have the lowest overall risk.

The study findings may have implications for food policy in general. As regulators are increasingly embracing a more risk-based approach to setting priorities and allocating resources for food safety, the results of this study can help focus their efforts. For example, results from the study indicate that employee awareness and training are key compo-

TABLE 8. Factor risk indices by food product sector, storage/warehouse

Food Product Sector	Process-related Risk[a]	Equipment and/or Facility Risk[b]	Organizational or Policy-related Risk[c]
Bulk liquids (dedicated tanker)	96.4 (8)	107.7 (1)	100.8 (6)
Bulk raw ingredients	100.0 (7)	102.1 (6)	94.3 (8)
Eggs and egg products	103.2 (3)	106.6 (2)	102.0 (5)
Frozen foods	100.1 (6)	96.2 (7)	102.5 (4)
Fresh produce	103.0 (4)	90.8 (11)	97.6 (7)
Meat & poultry (raw)	104.1 (2)	93.3 (9)	107.7 (2)
Other nonperishables	95.2 (10)	105.2 (5)	93.8 (10)
Packaging materials	92.5 (11)	105.4 (4)	92.5 (11)
Refrigerated raw & RTE	100.2 (5)	90.9 (10)	108.2 (1)
Soft-packed nonperishables	95.8 (9)	105.8 (3)	93.9 (9)
Seafood (raw)	109.8 (1)	95.2 (8)	106.6 (3)

Note: Obtained by factor analysis as described in Methods Section. Each index (read by the column only) has mean of 100 and standard deviation of 10 and provides an indication of the relative risk of the food product sectors for each relevant risk factor. A value that exceeds 100 indicates greater than average risk for that factor. Numbers in parentheses represent the rankings of food product sectors by the applicable risk factors. The names of factors are derived from those variables that contribute the most to the factor values.

[a]The process-related risk factor loads very highly on "improper packing," and "improper loading," and highly on "improper refrigeration," "improper management of transportation units," "improper unloading", and "poor pest control."

[b]The equipment and/or facility risk factor loads very highly on "inadequate preventive maintenance for storage facilities," and moderately high on "poor storage facility design and/or construction" and "poor employee hygiene."

[c]The organizational or policy-related risk factor loads highly on "inadequate policies" and moderately high on "lack of driver/employee training and/or supervisor/manager/owner knowledge of food safety and/or security" and "improper holding practices."

nents in eliminating or mitigating safety hazards during transportation. Another finding is the critical nature of proper management of transportation units to preclude cross-contamination of foods, including adequate sanitization between loads. Policymakers may therefore want to further explore the role of government in improving employee training and establishing sanitation standards.

In light of industry challenges such as capacity problems, driver shortages, increasing consumer demands, and increasing costs, our findings may also aid the various industry players in prioritizing their food transportation safety initiatives. The study helps clarify which hazards are most likely to occur during transportation and storage, taking into account sector-specific challenges. This ranking can help transporters understand what processes pose the greatest risk in terms of food contamination. Furthermore, the study provides information on the most effective preventive controls available to increase the safety of the food that they transport. At the top of the list are better training and awareness of employees, management review of records, and good communication between shipper, transporter and receiver. In light of limited budgets, these data might help transporters determine where they should focus their resources to ensure that the foods that they transport are safe.

This study serves only as a preliminary assessment of current food transportation and holding practices for food commodities. Both the lack of literature on the subject and the broad nature of the expert elicitation suggest a need for further study regarding food safety hazards involved in food transportation. In particular, the food transportation industry may benefit from a baseline quantitative assessment of both the frequency and severity of food safety hazards and the degree of implementation for various safe food transportation practices and preventive controls.

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