Swiss Cheese Model of food safety incidents: preventing foodborne illness through multiple layers of defence

Diogo Thimoteo da Cunha[1] Multidisciplinary Food and Health Laboratory, School of Applied Sciences, State University of Campinas (UNICAMP), Limeira, Brazil.

Mariana Piton Hakim Multidisciplinary Food and Health Laboratory, School of Applied Sciences, State University of Campinas (UNICAMP), Limeira, Brazil.

Jan Mei Soon Faculty of Allied-Health and Wellbeing, University of Central Lancashire, Preston, PR1 2HE, UK

Elke Stedefeldt Department of Preventive Medicine, Universidade Federal de São Paulo (UNIFESP), São Paulo, Brazil.

Address: 1300 Pedro Zaccaria St, Jd Santa Luzia, Limeira, São Paulo, Brazil, Zip Code 13484-350.
E-mail: diogo.cunha@fca.unicamp.br; +55 (19) 3701-6732

Abstract

This study aims to discuss the use of multiple layers of defence to prevent foodborne illness in restaurants. A defence model was developed based on Reason's Swiss Cheese Model. Reason's model was extended by adding the concept of Hazard Analysis and Critical Control Points, as well as Five Keys to Safer Food. The defence system was divided into seven layers of defence: 1) adequate facilities and 2) training as administrative controls; 3) safe ingredients and water; 4) environmental hygiene; 5) personal and food hygiene and 6) safe food temperature as behavioural controls; and 7) control and systems. The hypothesis was that the layers would act as barriers to prevent hazards from causing losses. To test the model, a dataset (secondary data) of food safety assessments from 1,536 different restaurant establishments in Brazil was used. A checklist of 51 items was organised into seven layers of defence system. The model was tested with a Partial Least Square Structural Equation Model. Errors in administrative controls (facilities and training) led to errors in behavioural controls. A 'cascade effect' was observed where errors in distal behavioural controls (safe ingredients and water and environmental hygiene) impacted proximal controls (personal and food hygiene and; safe food temperature) and system controls. It was discussed how latent conditions and active failures can string together and cause a foodborne illness incident. The Swiss Cheese Model of food safety incidents is proposed as a new perspective for food safety. This model can be used for risk management and food safety education.

Key-words: risk management; inspection; foodborne disease; outbreak; Brazil; risk assessment; HACCP; training; organisational culture

---

[1] Corresponding author

1. Introduction

Despite years of innovation and technology, food safety in the restaurant industry is still a challenge for all countries. According to a study by the Centres for Disease Control and Prevention (CDC), approximately 9.4 million foodborne illnesses (FBI) occur in the United States each year (Scallan et al., 2011). In this case, FBI is defined as diseases caused by contaminated food or beverages, mainly by various bacteria or their toxins, viruses, and parasites (Centers for Disease Control and Prevention, 2018). FBI has many health-related consequences such as deaths, and disabilities like liver disease such as those caused by Hepatitis A and E viruses (Di Cola et al., 2021), neurological disorders (e.g. neurocysticercosis caused by *Taneia solium* (Bustos et al., 2021) and kidney failure (e.g. caused by *Escherichia coli* O157:H7 infection) (World Health Organization, 2019). In addition, such illnesses have a sizable economic impact, increasing the costs for society, agro-food industry, and governments (Focker & van der Fels-Klerx, 2020). Restaurants and cafeterias were avoided during the COVID-19 pandemic (Hakim et al., 2021) because of the high risk of transmitting the virus through the environment (Chang et al., 2021). Despite the slow pace of development, the foodservice sector is expected to grow in the coming years (i.e. 2022 – 2024) as spending on food outside the home increases (Pizam, 2021; Statista, 2021), making risk FBI mitigation strategies favourable. In Brazil, most FBI outbreaks reported occurred in food services (e.g. school cafeterias, restaurants, and workplaces) (Finger et al., 2019).

Most FBI outbreaks in food services are due to predictable errors in the food chain. Ready-to-eat meals are often implicated in FBI incidents, indicating errors in the middle to end of the production chain (Soon et al., 2020). Following this train of thought, food handlers are implicated and blamed for unsafe food handling because they work on the front line (de Freitas et al., 2020; Pereira et al., 2021). The literature often suggests that food handlers may be the cause of FBI, waiving the responsibility of management. Blaming individuals is more convenient than targeting institutions (Reason, 2000). In this case, many behaviour-based strategies are used to prevent errors based on risk perception, the need for education, and disciplinary measures. In the hospitality industry, for example, training is often used (da Cunha, 2021). However, many authors argue about the importance of a prevailing proactive food safety culture, adequate facilities, leadership, and many other core ‘management-related’ (or organisational) strategies (de Andrade et al., 2020; Jespersen et al., 2019; Zanin, Stedefeldt, & Luning, 2021). According to the World Bank report, the burden of unsafe food can be avoided through low-cost behavioural and infrastructural changes (Jaffee et al., 2018). In this sense, applying organisational strategies can also benefit restaurant management, not just large companies.

Although the study draws on widely known concepts of food safety, it is inventive in drawing inspiration from the Swiss Cheese Model (SCM) to explain food safety. The results can show the importance of assessing and improving each layer of defence in a food safety system and how a possible 'cascade effect' of failures can compromise consumer safety. Therefore, the aim of this study is to discuss the use of multiple layers of defence to prevent FBI in restaurants. To this end, data analysis was conducted to examine the combined impact of failures at each level. First, we present the theoretical background on which the model is based. Then, results are presented and discussed.

2. Theoretical background

2.1 The Swiss Cheese Model

James Reason is a psychology professor who proposed the Swiss Cheese model to discuss the occurrence of errors. Reason explains that the problem of human error can be viewed through a person or system approach (Reason, 2000). The person approach focuses on explaining unsafe actions by 'frontline' actors such as doctors, train drivers, pilots, and food handlers. Such errors are explained in terms of lack of motivation, recklessness, carelessness and forgetfulness on the part of employees. The systems approach, on the other hand, assumes that humans are inherently prone to error (Reason, 2000). In this approach, the conditions under which people work contributed to the errors. Garfield & Franklin (Garfield & Franklin, 2016) suggested that people who apparently make the most errors are those who carried out high-risk and time-pressured tasks (*e.g.* food handlers working under tight time frames) (Tongchaiprasit & Ariyabuddhiphongs, 2016) or those who work in difficult environments (*e.g*. working long hours in a crowded, hot and noisy kitchen environment) (Murray-Gibbons & Gibbons, 2007). Thus, system protection is put in place to address these tasks and environmental factors with barriers and safeguards that are adequately controlled to minimise human error.

In the person-centred approach, blame is assigned to the individual, focusing on the individual origin of the error and ignoring contextual or task-related factors (Aini & Fakhru'l-Razi, 2013) *e.g.* blaming the food handler for an FBI incident. The person(s) being blamed are not entirely or solely responsible for an adverse event, as their practises are also based on task-related factors (*e.g.* equipment design, lack of utensils, increased workload) and organisational factors (*e.g.* lack of leadership, poor training, lack of staff support). Accidents are complex and result from the unforeseen concatenation of multiple factors (Reason, 1990). However, this culture of blame is prevalent in the hospitality industry (de Freitas et al., 2020; Pereira et al., 2021), but can be improved by a fair treatment (Wiśniewska, Czernyszewicz & Kałuża, 2019).

Failures tend to follow recurring patterns and do not occur randomly. Therefore, similar circumstances can lead to similar failures (Reason, 2000). On this basis, Reason proposed the Swiss Cheese Model (SCM) for system failures (Reason et al., 2006). The SCM is a heuristic explanatory model based on a simple metaphor - several slices of Swiss cheese with holes in them (Reason et al., 2006). In this model, the slices of cheese are barriers in a system designed to prevent losses, and their holes are failures, errors or weakness (Larouzee & Le Coze, 2020). It conveys that a single failure is not sufficient to cause an accident, but is usually caused by the interaction of several factors emanating from different levels of the defence system (Reason et al., 2006). The gaps in the defence systems arise from active failures and latent conditions (Reason, 2000). Active failures are breaches that have an immediate negative impact and are generally associated with 'frontline' forces (Reason, 1990) i.e., they are acts - slips, omissions, errors, system violations - committed by those in direct contact with a system, and these acts have a direct impact on the integrity of that system's defences (Reason, 2000). On the other hand, latent conditions arise from top management decisions or actions. Latent conditions have no immediate negative impact but, in combination with local trigger factors can break through the system's defences (*e.g.* climate and organisational factors) (Reason, 1990). These conditions can remain dormant/latent in that system for a long period of time and may trigger a violation (or loss) when combined with other triggers or active failures (Reason, 2000). Behavioural controls are used to reduce or prevent active failures. Administrative and system controls are used to reduce or prevent negative latent conditions. A proactive organisational climate and culture supports the controls and the overall defence system.

FBI incidents have many common characteristics and features. They are caused by a variety of sequential failures due to organisational and technological factors, but mainly due to human factors, motivated by latent conditions or active failures (Todd et al., 2007; Wu et al., 2018). **Wiśniewska (2022) discusses in a theoretical paper how SCM could be useful in a food safety management system to avoid food safety hazards. Extending Wiśniewska's (2022) view, in this paper we propose a model to test some premises of SCM as a food safety model using real data. Therefore, we believe that SCM can be an interesting model or foundation to understand and discuss the gaps in food safety.**

2.2 HACCP and PAHO/WHO five keys to safer food principles

Hazard Analysis and Critical Control Points (HACCP) is a scientifically based and systematic control system for food safety that is used and recognised worldwide. It identifies specific hazards and measures to control them in order to ensure the safety (Codex Alimentarius Commission, 2020). The first concept was developed in the decade of 1960 by the US National Aeronautics and Space Administration (NASA) (Weinroth et al., 2018). HACCP is the process of evaluating and controlling biological, chemical (including allergens) and physical hazards to ensure food safety. Hazard analysis involves collecting and evaluating information about potential hazards in the environment and in food to decide whether or not these hazards are significant. The critical control point (CCP) is the step at which control is critical to ensure food safety by preventing, eliminating or reducing the hazard to an acceptable level (Codex Alimentarius Commission, 2020). The logic of the HACCP concept is therefore to identify critical control points and establish corrective actions for the significant hazards in the food chain. Its implementation must be supported by scientific evidence on the hazards to human health and good hygiene practices. In 2020, the *Codex Alimentarius* emphasised the need to make the HACCP system more detailed (Codex Alimentarius Commission, 2020) to ensure a more efficient application of the system. This greater clarity can potentially minimise active errors, for example, by better guiding the behaviour of those involved in each process. Because of these features, the HACCP system is considered a fundamental system for food safety management and control FBI.

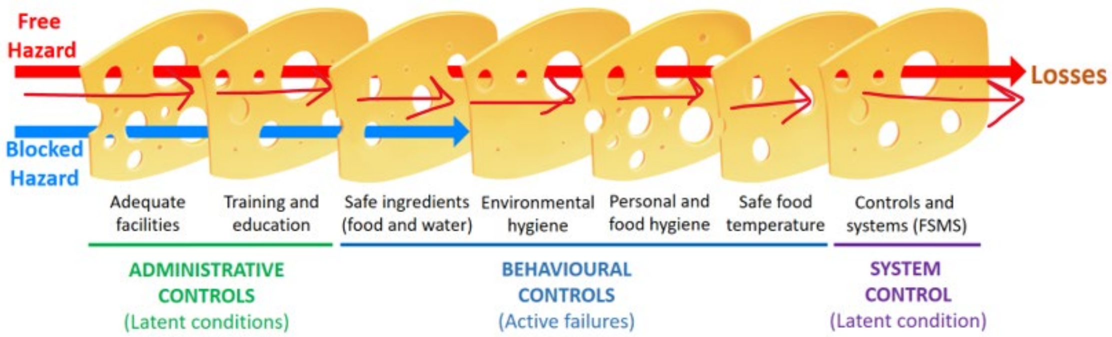
In addition to the health aspects, Liu et al. (2021) have shown the financial benefits for those who implement HACCP in the short and long term. Although HACCP is a reliable system, it can be difficult to implement in small businesses such as restaurants. One difficulty of successful HACCP operation is related to hazard identification and control (Eves & Dervisi, 2005; Wallace et al., 2014), which can also be observed in small businesses (Dzwolak, 2019). In addition to the difficulties associated with hazard identification, other difficulties in applying the HACCP approach in the food sector seem to be common: insufficient or inadequate knowledge, excessive documentation, increased initial costs and a team that does not have a positive perception and attitude towards the food sector system (Eves & Dervisi, 2005). Such aspects indicate that different ways of assessing, managing and communicating food safety might be helpful to foodservice owners, practitioners, educators, and government.

In a simpler form of communication, the Pan American Health Organisation (PAHO) and the World Health Organisation (WHO) published the five keys to safer food in 2006 (World Health Organization, 2006). Using a visual and didactic presentation the PAHO/WHO presents the main causes of FBI and how to avoid them. The five keys focus on food hygiene messages to avoid FBI mainly caused by dangerous microorganisms (World Health Organization, 2006). The core messages of the Five Keys to Safer Food are: 1º keep clean; 2º separate raw and cooked foods; 3º cook thoroughly; 4º keep food at safe temperatures; and 5º use safe water and raw materials (World Health Organization, 2006). Despite their simplicity, the five keys are the crux of any food safety system as they address the main active failures that lead to an outbreak of FBI. We included the five keys for safer food to extend Reason's model due to their simplicity and effectiveness in communicating evidence-based food safety messages (Fontannaz-Aujoulat, Frost & Schlundt, 2019).

Identifying hazards, understanding the significance of a risk, weighing its severity and the likelihood of its occurrence is not an easy task (Mortimore & Wallace, 1998). In this sense, unifying HACCP concepts based on SCM and the PAHO/WHO Five Keys to Safer Food can be a simple way to demonstrate the importance of management strategies in restaurants.

2.3 Proposed model

We believe that Reason's model, which is consistent with the HACCP rationale and the five keys to safer food from PAHO /WHO, could shed light on understanding how the layers of defence could be applied in food safety. In this model, the word 'defence' has been used on the basis of the SCM and not on the basis of the definition of food defence which represents countermeasures against intentional threats. Figure 1 shows the proposed theoretical model, which is inspired by the models and documents mentioned above. The layers act as barriers that prevent hazards from causing losses (blue arrow – Figure 1). Free hazard (red arrow) could potentially lead to losses or FBI due to inadequate latent conditions and active failures. In both cases, the hazard could be a microorganism. In the red arrow, the microorganism was able to breach through some or all of the layers and potentially cause an FBI incident. The losses could be health-related (e.g. unwellness, hospitalisation, death), economic (e.g. fines, closure of the restaurant, loss of customers), and other, affecting consumers, restaurant owners, society,administrative controls and the government. In the blue arrow, the microorganism was eliminated at the layer of environmental hygiene, e.g. by proper cleaning of equipment. The model was designed to prevent FBI incidents caused by contaminated food or beverages, by various bacteria or their toxins, viruses, and parasites.



[Figure 1]

This theoretical model is more general and has been developed to encourage discussion, adaptation and inspiration. Based on this model, to test hyphotesis against empirical data, we have developed a hyphotesis model (Figure 2) that differs slightly from the theoretical model. The hyphotesis model aimed to test how each layer of defence could affect the other. Since latent conditions can be disruptive by promoting error-prone conditions in the workplace, and they can also create gaps that create weaknesses in the environment's defence system (Reason, 2000).

Administrative controls are the first layers of defence on both models. We believe that latent conditions such as an inadequate facility (H1) and inadequate training process (H2) can have a negative impact on all behavioural controls. In the hyphotesis model, we have considered the presence of a properly trained person responsible for food handling to be sufficient, as this is required by the Brazilian food safety regulation for food services (Brasil, 2004). It is well known how important training and education are to improve food handling (Medeiros et al., 2011). However, the impact of trained manager can be limited and needs to be complemented by other administrative controls, education and a proactive culture (da Cunha, 2021; Zanin, Stedefeldt, da Silva, et al., 2021). An inadequate facility can have two negative effects on behavioural controls. The first is task-related. Without an adequate environment, many food safety practises are impossible or very difficult to implement (de Andrade et al., 2021). For example, the lack of handwashing facilities would impede hand hygiene practices. The second is based on the broken windows theory. This theory assumes that disorder precedes crime in time (Gau & Pratt, 2010). Yiannas (2016) applies this theory to food safety and argues that working in an inadequate structure and without organisational support leads to inappropriate practises and complacency. Based on HACCP principles, latent conditions should not exist due to the prerequisite program (Codex Alimentarius Commission, 2020).

Based on the HACCP concept and the third key, the last two layers of defence deal with controls and temperature. Adequate cooking or thermal processing is the most important CCP in meal production. Temperatures above 63°C (143°F) can eliminate or reduce a biological hazard to an acceptable level (*Food Code*, 2017). Also, according to the fourth key, temperature is necessary to keep ready-to-eat food safe to avoid or reduce microbiological growth during cold and heat storage (Wu et al., 2018). Food temperature errors are a major cause of FBI incidents worldwide (Chan & Chan, 2008; Da

Cunha et al., 2014; Lima et al., 2013). When temperature control fails, other behavioural controls can provide some protection for the consumer and minimise the hazard of a contaminated food. Each of the other behavioural control layers includes a set of food safety practises aimed at avoiding cross-contamination, unhygienic behaviours, and the use of unsafe food and water. Since microorganisms are very different in nature, it is important to emphasise that some barriers are more crucial or important for the defence against a particular hazard. This aspect highlights the importance of improving all barriers together.

Finally, the last hypothesis is the 'cascade effect' of latent conditions and active errors at each layer (H3). We believe that failures at the distal levels of defence can lead to errors at the proximal levels that affect the whole system. For example, human errors that seemed remote from food production (e.g. error in menu design) can have serious implications on consumer's health such as food allergies. We have chosen to organise behavioural controls aligned to the meal production process and CCP. This order follows the logical process of typical meal production within a restaurant setting i.e. receipt of raw materials and ingredients (safe ingredients), ensuring a clean and hygienic kitchen prior to starting work (environmental hygiene), safe food handling (personal and food hygiene) and temperature control (safe food temperature). The active failures (holes) could be strung together and cause an FBI incident (red arrow – Figure 1). For example, food processing equipment that are not cleaned appropriately may harbour microorganisms and bio-film leading to cross contamination of subsequent foods. The listeriosis outbreak traced back to Maple Leaf Foods, Canada in 2008 demonstrated that despite operating a comprehensive food safety plan with its own HACCP and environmental testing for *Listeria monocytogenes*, behavioural controls play an essential role in the outbreak. The company detected positive *Listeria monocytogenes* from production lines every 2 – 3 weeks, but the trend was overlooked. Furthermore, the areas were immediately cleansed and sanitized, however the meat slicers were not deep cleaned allowing food residues to accumulate over time and re-contaminate subsequent food leading to the outbreak (Manning, et al., 2016; Weatherill Report, 2009). This demonstrates the 'cascade effect' of the latent and active failures within each layer. However, it is important to note that the behavioural controls are likely to be highly correlated and a different layers sequence could be possible. Figure 2 shows the hypothesis model that will be tested with a structural equation model (SEM). In this model, both direct and indirect influences were considered.

[Figure 2]

3. Methods

3.1 Data

We used a dataset (secondary data) of food safety ratings from 1,536 different restaurant establishments in Brazil. The dataset is based on assessments conducted by Brazil's National Health Surveillance Agency (*Agência Nacional de Vigilância Sanitária* in Portuguese), as well as local state and city health surveillance during 2013 and 2014. The data includes restaurant establishments from 27 different cities, including 12 large centres (capitals with more than one million inhabitants) and 15 smaller cities. Kyriazos

(2018) recommends a minimum sample of 200 for SEM studies. However, a larger sample was used to increase heterogeneity and reduce sampling error (Hair et al., 2019). Based on these assumptions, the sample is considered adequate.

The food safety assessment was carried out by trained health surveillance auditors. The dataset was first used to assess the results of a Brazillian policy to avoid FBI incidents during World Cup in 2014. It used a validated 51-item checklist (Da Cunha et al., 2014) (supplementary file). The descriptive results of this data are presented and discussed elsewhere (da Cunha et al., 2016). The dataset was coded as 1= for each error/violation and 0= for the corresponding condition. In this case, we tested the effect of errors on each construct.

The checklist items were organised into six constructs: adequate facilities (11 indicators); safe ingredients and water (6 indicators); environmental hygiene (8 indicators); personal and food hygiene (6 indicators); safe food temperature (15 indicators); and control (4 indicators). Manager training was included as an observed variable (1 indicator). Each indicator is described by two code numbers (e.g. 1.5). This is the same number for each indicator in the original instrument (Da Cunha et al., 2014).

3.2 Analysis

Partial least squares structural equation modelling (PLS-SEM) was chosen to analyse the data and test the hypotheses. The PLS-SEM was chosen because it makes no distributional assumptions and is suitable for exploratory research and studies with secondary data (Henseler et al., 2009). It could handle constructs measured with single- and multi-item (e.g. number of indicators) measures (Hair et al., 2021). The bias-corrected and accelerated bootstrap procedure with 5,000 samples was used to estimate the t-statistics (significance: $t > 1.96$) and the p-values (significance: $p < 0.05$) of the estimated loadings. The outer model (part of the model that describes the relationships among the constructs and their indicators) was assessed using factor loadings (> 0.40) and composite reliability (CR) > 0.70. CR is a measure of internal consistency in scale items. The heterotrait-monotrait ratio (HTMT) of correlations was used to assess discriminant validity (< 0.85) (Hair et al., 2016; Henseler et al., 2009); that is the average of the heterotrait-heteromethod correlations (i.e., the correlations of indicators across constructs), relative to the average of the monotrait-heteromethod correlations (i.e., the correlations of indicators within the same construct) (Henseler, Ringle & Sarstedt, 2015). Multicollinearity was assessed using the variance inflation factor (VIF) values (< 3.3). The inner model was assessed using the variance explanation of the constructs, effect sizes ($f^2 > 0.10$), and predictive relevance (Stone-Geisser's Q2 > 0.15). Effect size (f^2) was classified as small ($f^2 \geq 0.02$), medium ($f^2 \geq 0.15$), and large ($f^2 \geq 0.35$) (Cohen, 1988). The inner model (part of the model that describes the relationships among the constructs) explanatory power of the model was measured (R^2). Values of 0.26, 0.13, and 0.02 were considered as large, medium, and small effects, respectively (Cohen, 1988). There were no problems with missing data, as only complete assessments were included in the data set.

The PLS-SEM was performed using SmartPLS v.3.2.8 (SmartPLS GmbH. Bönningstedt - Germany) (Ringle et al., 2015).

4. Results

Table 1 shows each indicator of the constructs and CR. All constructs had adequate reliability, with a high CR (> 0.70) and factor loadings above 0.40. Some indicators were removed to increase reliability and validity. Personal and food hygiene had the highest median percentage of violations. In this case, it is the layer with the 'largest number of holes'. Safe ingredients and water, on the other hand, is the layer with the fewest violations.

[Table 1]

Table 2 shows the HTMT ratio of the correlations. All correlations ratios were adequate (< 0.85), indicating adequate discriminant validity. No collinearity problems were found as all VIF values were less than 2.13.

[Table 2]

Table 3 shows the Pearson correlation coefficient of the constructs. All constructs were positively correlated with weak ($r < 0.20$) to medium effect size ($r < 0.80$).

[Table 3]

As for the inner model, some constructs had a predictive relevance of less than 0.15, but none were less than 0.10, as follows: Control ($Q^2 = 0.22$); safe food temperature ($Q^2 = 0.13$); personal and food hygiene ($Q^2 = 0.18$); environmental hygiene ($Q^2 = 0.21$); safe ingredients and water ($Q^2 = 0.10$). All pathways showed a high effect size ($f^2 > 0.10$), except for the training variable. The observed variable training showed significant effects, but with low effect sizes ($f^2 < 0.06$) on all behavioural controls (H2a, H2b, H3c, and H2d).

Hypotheses H1 (a, b, c and d), H2 (a, b and d), and H3 (a, b, c and d) were confirmed (figure 3). Hypothesis H2c was not confirmed. Failures in facilities led to failures in the behavioural controls. With small effects, lack of training also contributed to failures in ingredient handling, environmental hygiene and temperature control. A 'cascade effect' was observed, where distal behavioural controls impacted proximal controls and system control. High explanatory power ($R^2 > 0.26$) was found for all dependent variables (Cohen, 1988).

[Figure 3]

5. Discussion

5.1 Model discussion

The aim of this study was to discuss the use of multiple layers of defence to prevent FBI in restaurants. Our hypotheses are that administrative layers (facilities and manager training) could influence all other behavioural controls. We also hypothesise a 'cascade effect' of errors where distal layers could impact proximal layers. The hypotheses were confirmed and the Swiss Cheese Food Safety Model is proposed as a new perspective for food safety. One of the main criticisms of the SCM is its simplicity. Some authors consider the model too general and not sufficiently specified (Larouzee & Le Coze, 2020). However, we see a great opportunity in the SCM to highlight the importance of organisational culture, staff engagement and appropriate facilities, and their interdependence to improve food safety. As with the five keys to safer food, a simple and straightforward message can be an excellent tool for risk communication. Fontannaz-Aujoulata, Frostb and Schlundt (2019) report that the Five Keys communication strategy is characterised by evidence-based, clear and simple messages that link core messages to specific instructions and are easy to understand. Food handlers and managers are often optimistic about food-related hazards (da Cunha et al., 2015). A clear and transparent system where responsibilities are shared is therefore very useful, as the public prefers a clear message regarding risks and related uncertainties (Frewer, 2004).

In this study, we observed how failures in the facilities affected all active failures in behavioural controls. Considering that the physical structure in food establishments is often inadequate (de Andrade et al., 2020; Zanetta et al., 2022), its improvement is extremely important for an efficient control system and consequently for the reduction of FBI. An adequate facility is able to influence food safety practises (de Andrade et al., 2021) by providing greater support for activities relevant to a food service (Ahuja, 2017; Faille et al., 2018). For example, proper facilities to avoid cross-contamination through the presence of sinks in strategic locations, the presence of appropriate places for hygiene of food handlers, and proper work surfaces for each type of preparation (raw and cooked). Mihalache et al. (2022) found that sink placement in kitchen is correlated with observed cross contamination events. The lack of or poor accessibility to handwashing facilities led to lower hand hygiene practices. Therefore, it is considered as one of the first layers of defence. The food handlers uses shortcuts to make their work easier (da Cunha, 2021). Shortcuts are less safe but quicker practises such as not washing hands prior to putting on new gloves or after handling unsanitary objects or body parts (Soon, 2019). In an inadequate structure, these shortcuts may be more frequent. Also, in a previous study, the positive effect of physical structure on food safety climate has already been observed (de Andrade et al., 2021). The authors discuss this effect as a driver of positive attitudes and behaviours aligned to the broken windows theory.

Training had an effect on behavioural control, but with a weak effect size. This result was expected for two reasons. First, the checklist used does not describe denser educational processes, but only whether the manager is trained in food safety, as required by Brazilian legislation (Brasil, 2004). Secondly, the limitations of training to change practise are well known (da Cunha, 2021). Although studies found an increase in food safety knowledge after training, this does not translate into behaviour change (Harris et al., 2017; Reynolds & Dolasinski, 2019). Hence, it would be important to evaluate in future studies the impact of the constructs that make up a continuous education system.

The lack of administrative controls can trigger demotivation and food handlers wonder *"If they (managers) do not care about the restaurant, why should I?"* This was evidenced by Harris et al. (2017) and Pivarnik et al. (2013) who found that employees were more motivated if managers listen to their issues and food safety culture is an organisational priority. Thus, failure in administrative controls (inadequate facilities and education) could lead to a cascade effect of demotivating appropriate food safety behaviour. Active errors in the beginning of food production can align with errors in other layers of defence, increasing risk or setting the stage for new active failures to occur. With appropriate latent and behavioural controls, each layer is a form of defence, reducing the risk of FBI. The first behavioural control is the 'layer of safe ingredients'. One contaminated and unsafe ingredient can put the whole chain at risk (World Health Organization, 2006). Thermal processes and disinfection of raw materials can reduce the number of microorganisms to safe levels (Jay et al., 2005). However, these procedures are not sufficient to control some toxins, sporulating microorganisms and food with high numbers of microorganisms (Jay et al., 2005). A similar effect occurs with environmental hygiene. A safe ingredient or ready-to-eat food can be contaminated by cross-contamination, as shown in the example of Maple Leaf Foods above. Cross-contamination is a recurrent active failure (Carrasco et al., 2012), with Salmonella Enteritidis and *Campylobacter jejuni* organisms generally associated with FBI incidents (McCabe-Sellers & Beattie, 2004; Medus et al., 2006).

Environmental hygiene failures have implications for the third behavioural control, personal hygiene and food hygiene. Poor personal hygiene is associated with the presence of many microorganisms on food, e.g. viruses from the Calciviridae family such as norovirus and *Staphylococcus aureus.* People who handle food can carry such viruses and contaminate suitable ingredients and ready-to-eat food through faecal-oral route (Moe, 2009). On the other hand, *Staphylococcus aureus* is one of the leading cause of food poisoning due to inadequate food handling and storage temperature (Soares et al., 2012). It is important to emphasise the importance of food hygiene and appropriate storage temperature, since there is no 'killing step' or CCP applied to salads and many ready-to-eat raw or minimally processed food products (Codex Alimentarius Commission, 2020). Finally, environmental hygiene also affects the safe temperature of food. Improper temperature is mainly associated with the leading cause of FBI (Da Cunha et al., 2014; McCabe-Sellers & Beattie, 2004). *Clostridium perfringens*, *Bacillus cereus* and Salmonella Enteritidis are organisms often associated with temperature abuse (McCabe-Sellers & Beattie, 2004; Medus et al., 2006). The latter is the main cause of FBI in Brazil (Finger et al., 2019) mainly due to undercooked poultry and egg products (Carneiro et al., 2015; Gomes et al., 2013). The risk of salmonellosis is even higher in the warmer months of the year (Boore et al., 2015). So, in addition to the correct temperature, it is also important to highlight the importance of maintaining the temperature after cooking (*Food Code*, 2017). In this sense, controls and systems that support management are necessary. Controls help to identify active errors and are also a motivator for appropriate practises.

Finally, the five keys to safer food were included in the model because they address the most important causal factors for FBI incidents (World Health Organization, 2006). Although they do not address risk and causality, the five keys are barriers at different stages of food processing. In SCM, the keys have been aligned as sequential barriers that provide defences and prevent errors from lining up and leading to losses. Layers with the highest number of holes should be carefully addressed, in our case 'personal and food hygiene'. Anecdotally, we can also say that the largest holes are the errors related to the five keys to safer food, as they address important aspects related to FBI incidents. This symbolism can be used to communicate to consumers and managers that a safety system is easier to understand. Therefore, SCM applied to food safety is a new way to show and discuss the relationship between hazards, risks, active failures and latent conditions.

5.2 Limitations and future research

The study has some limitations. First, it is acknowledged that it is difficult to design empirical studies in the context of SCM. Active errors and latent conditions can be distant in time and space from an incident, making it difficult to characterise them (Reason, 1997). Therefore, we decided to combine the original model with HACCP and the five keys for safer food. To simulate a cascade effect through SEM, behavioural controls were aligned to the meal production process and the CCP. Similar to HACCP, the SCM model is specific for each meal and handling process by a restaurant since different raw materials, ingredients and tasks pose different hazards. Although failures in latent and behavioural controls may increase the risk of FBI, it can be difficult to characterise or identify the root causes of human errors. This may potentially limit the empirical nature of the study. However, this could be mitigated with root cause analyses and investigation of FBI in depth from a qualitative perspective (Soon et al., 2020).

The database used assessed only one aspect of training, i.e., the presence of a manager trained in food safety. Understanding the role of denser educational actions as a layer of protection is necessary to better discuss the latent conditions promoted by its absence.

Different order of defence layers could be tested for different types of food. For future research, theoretical studies that evaluate the production chain of different foods, in the light of the model, can be interesting. Nevertheless, it is important to assess the public perception of food safety specialists, professionals and restaurant managers in terms of understanding and practicability of the model.

We believe that the model can be generalised to different countries and cultures because of the use of internationally accepted principles and models. Therefore, the SCM, applied to food safety, can be used as a theoretical basis for understanding failures and layers of defence for FBI incidents, foucusing on biological hazards. We hope that the model can be used to develop tools, self-assessments instruments, education and communication strategies.

6. Conclusion

The use of multiple layers of defence for food safety was presented. It could be seen that SCM, enhanced by HACCP and the five keys for safer food, can be used for food safety management and education. As hypothesized, inadequate facility and education (administrative controls) could lead to negative latent conditions that affect all behavioural controls. Active failures in the distal defence layers of behavioural control could affect the proximal layers and lead to a cascade effect. It was discussed how latent conditions and active errors could be strung together and cause an FBI incident. All these aspects underline the importance of improving all layers of food safety defences.

Acknowledgments

We thank the *Agência Nacional de Vigilância Sanitária* (ANVISA) and all the professionals and researchers involved in the pilot project for the 2014 World Cup. We thank Humberto Thimoteo da Cunha for the artwork. This study was partially funded by CAPES – *Coordenação de Aperfeiçoamento de Pessoal de Nível Superior* (Coordination for the Improvement of Higher Education Personnel), financial code 001. DTC is thanks Cnpq – Conselho Nacional de Desenvolvimento Científico e Tecnológico for his productivity grant 310450/2021-7.

References

Ahuja, P. K. (2017). Design and construction of eating establishments for ensuring food safety. *Food Safety in the 21st Century: Public Health Perspective*, 355–369. https://doi.org/10.1016/B978-0-12-801773-9.00028-5

Aini, M. S., & Fakhru'l-Razi, A. (2013). Latent errors of socio-technical disasters: A Malaysian case study. *Safety Science*, *51*(1), 284–292. https://doi.org/10.1016/j.ssci.2012.07.004

Boore, A. L., Hoekstra, R. M., Iwamoto, M., Fields, P. I., Bishop, R. D., & Swerdlow, D. L. (2015). Salmonella enterica Infections in the United States and Assessment of Coefficients of Variation: A Novel Approach to Identify Epidemiologic Characteristics of Individual Serotypes, 1996–2011. *PLOS ONE*, *10*(12), e0145416. https://doi.org/10.1371/journal.pone.0145416

Brasil. (2004). Resolução – RDC Nº 216, de 15 de setembro de 2004 - Procedimentos de boas Práticas para serviço de alimentação, garantindo as condições higiênico-sanitárias do alimento preparado. *Agencia Nacional de Vigilancia Sanitária - ANVISA*, 1–14.

Bustos, J., Gonzales, I., Saavedra, H., Handali, S., & Garcia, H. H. (2021). Neurocysticercosis. A frequent cause of seizures, epilepsy, and other neurological morbidity in most of the world. Journal of the Neurological Sciences, 427, 117527. https://doi.org/10.1016/J.JNS.2021.117527

Carneiro, M. R. P., Cabello, P. H., Albuquerque-Junior, R. L. C., Jain, S., & Candido, A. L. (2015). Characterization of a foodborne outbreak caused by *Salmonella enteritidis* in Aracaju, State of Sergipe, Brazil. *Revista Da Sociedade Brasileira de Medicina Tropical*, *48*(3), 334–337. https://doi.org/10.1590/0037-8682-0260-2014

Carrasco, E., Morales-Rueda, A., & García-Gimeno, R. M. (2012). Cross-contamination and recontamination by Salmonella in foods: A review. *Food Research International*, *45*(2), 545–556. https://doi.org/10.1016/j.foodres.2011.11.004

Centers for Disease Control and Prevention (CDC) (2018). Surveillance Resource Center. Estimates of Foodborne Illness in the United States. Available at <https://www.cdc.gov/foodborneburden/2011-foodborne-estimates.html> (accessed on 08 March 2022).

Chan, S. F., & Chan, Z. C. Y. (2008). A review of foodborne disease outbreaks from 1996 to 2005 in hong kong and its implications on food safety promotion. *Journal of Food Safety*, *28*(2), 276–299. https://doi.org/10.1111/j.1745-4565.2008.00120.x

Chang, S., Pierson, E., Koh, P. W., Gerardin, J., Redbird, B., Grusky, D., & Leskovec, J. (2021). Mobility network models of COVID-19 explain inequities and inform reopening. *Nature*, *589*(7840), 82–87. https://doi.org/10.1038/s41586-020-2923-3

Codex Alimentarius Commission. (2020). *Codex Alimentarius*.

Cohen, J. (1988). *Statistical Power Analysis for the Behavioral Sciences* (2nd edition). Academic Press.

Di Cola, G., Fantilli, A. C., Pisano, M. B., & Ré, V. E. (2021). Foodborne transmission of hepatitis A and hepatitis E viruses: A literature review. International Journal of Food Microbiology, 338, 108986. https://doi.org/10.1016/J.IJFOODMICRO.2020.108986

da Cunha, D.T., Braga, A. R. C., Passos, E. D. C., Stedefeldt, E., & de Rosso, V. V. (2015). The existence of optimistic bias about foodborne disease by food handlers and its association with training participation and food safety performance. *Food Research International*, *75*. https://doi.org/10.1016/j.foodres.2015.05.035

da Cunha, D.T., Saccol, A. L. F., Tondo, E. C., de Oliveira, A. B. A., Ginani, V. C., Araújo, C. V., Lima, T. A. S., de Castro, A. K. F., & Stedefeldt, E. (2016). Inspection score and grading system for food services in Brazil: The results of a food safety strategy to reduce the risk of foodborne diseases during the 2014 FIFA World Cup. *Frontiers in Microbiology*, *7*(APR). https://doi.org/10.3389/fmicb.2016.00614

da Cunha, D.T. (2021). Improving food safety practices in the foodservice industry. *Current Opinion in Food Science*, *42*, 127–133. https://doi.org/https://doi.org/10.1016/j.cofs.2021.05.010

da Cunha, D.T., de Oliveira, A. B. A., Saccol, A. L. de F., Tondo, E. C., Silva, E. A., Ginani, V. C., Montesano, F. T., de Castro, A. K. F., & Stedefeldt, E. (2014). Food safety of food services within the destinations of the 2014 FIFA World Cup in Brazil: Development and reliability assessment of the official evaluation instrument. *Food Research*

International, *57*, 95–103. https://doi.org/10.1016/j.foodres.2014.01.021

de Andrade, M. L., Stedefeldt, E., Zanin, L. M., & da Cunha, D. T. (2020). Food safety culture in food services with different degrees of risk for foodborne diseases in Brazil. *Food Control*, *112*, 107152. https://doi.org/10.1016/J.FOODCONT.2020.107152

de Andrade, M. L., Stedefeldt, E., Zanin, L. M., Zanetta, L. D., & da Cunha, D. T. (2021). Unveiling the food safety climate's paths to adequate food handling in the hospitality industry in Brazil. *International Journal of Contemporary Hospitality Management*, *33*(3), 873–892. https://doi.org/10.1108/IJCHM-09-2020-1030

de Freitas, R. S. G., da Cunha, D. T., & Stedefeldt, E. (2020). Work Conditions, Social Incorporations, and Foodborne Diseases Risk: Reflections About the (Non)Compliance of Food Safety Practices. *Risk Analysis, 40(5), 926-938*. https://doi.org/10.1111/risa.13453

Dzwolak, W. (2019). Assessment of HACCP plans in standardized food safety management systems – The case of small-sized Polish food businesses. *Food Control*, *106*, 106716. https://doi.org/10.1016/j.foodcont.2019.106716

Eves, A., & Dervisi, P. (2005). Experiences of the implementation and operation of hazard analysis critical control points in the food service sector. *International Journal of Hospitality Management*, *24*(1), 3–19. https://doi.org/10.1016/J.IJHM.2004.04.005

Faille, C., Cunault, C., Dubois, T., & Bénézech, T. (2018). Hygienic design of food processing lines to mitigate the risk of bacterial food contamination with respect to environmental concerns. In *Innovative Food Science and Emerging Technologies*, 46(Apr), 65–73. https://doi.org/10.1016/j.ifset.2017.10.002

Finger, J. A. F. F., Baroni, W. S. G. V, Maffei, D. F., Bastos, D. H. M., & Pinto, U. M. (2019). Overview of Foodborne Disease Outbreaks in Brazil from 2000 to 2018. *Foods, 8* (10), 434. https://doi.org/10.3390/foods8100434

Focker, M., & van der Fels-Klerx, H. J. (2020). Economics applied to Food Safety. *Current Opinion in Food Science, 36 (Dec), 18-23*. https://doi.org/10.1016/j.cofs.2020.10.018

Fontannaz-Aujoulat, F., Frost, M., & Schlundt, J. (2019). WHO Five Keys to Safer Food communication campaign - Evidence-based simple messages with a global impact. *Food Control*, *101*, 53–57. https://doi.org/10.1016/j.foodcont.2019.02.016

Frewer, L. (2004). The public and effective risk communication. *Toxicology Letters*, *149*(1), 391–397. https://doi.org/https://doi.org/10.1016/j.toxlet.2003.12.049

Garfield, S., & Franklin, B. D. (2016). Understanding models of error and how they apply in clinical practice. *Pharmaceutical Journal*, *296*(7890). https://doi.org/10.1211/PJ.2016.20201110

Gau, J. M., & Pratt, T. C. (2010). Revisiting Broken Windows Theory: Examining the Sources of the Discriminant Validity of Perceived Disorder and Crime. *Journal of Criminal Justice*, *38*(4), 758–766.

https://doi.org/https://doi.org/10.1016/j.jcrimjus.2010.05.002

Gomes, B. C., De Melo Franco, B. D. G., & De Martinis, E. C. P. (2013). Microbiological Food Safety Issues in Brazil: Bacterial Pathogens. *Foodborne Pathogens and Disease*, *10*(3), 197–205. https://doi.org/10.1089/FPD.2012.1222

Hair, J. F., Hult, G. T. M., Ringle, C. M., & Sarstedt, M. (2016). *A primer on partial least squares structural equation modeling (PLS-SEM)* (1st ed.). Sage.

Hair, J. F., Hult, G. T. M., Ringle, C. M., Sarstedt, M., Danks, N. P., & Ray, S. (2021). An Introduction to Structural Equation Modeling. 1–29. https://doi.org/10.1007/978-3-030-80519-7_1

Hair, J. F., Risher, J. J., Sarstedt, M., & Ringle, C. M. (2019). When to use and how to report the results of PLS-SEM. *European Business Review*, *31*(1), 2–24. https://doi.org/10.1108/EBR-11-2018-0203

Hakim, M. P., Zanetta, L. D., & da Cunha, D. T. (2021). Should I stay, or should I go? Consumers' perceived risk and intention to visit restaurants during the COVID-19 pandemic in Brazil. *Food Research International*, *141*(March), 110152. https://doi.org/10.1016/j.foodres.2021.110152

Harris, K. J., Murphy, K. S., DiPietro, R. B., & Line, N. D. (2017). The antecedents and outcomes of food safety motivators for restaurant workers: An expectancy framework. *International Journal of Hospitality Management*, *63*, 53–62. https://doi.org/10.1016/j.ijhm.2017.02.004

Henseler, J., Ringle, C. M., & Sinkovics, R. R. (2009). The use of partial least squares path modeling in international marketing. *Advances in International Marketing*, *20*, 277–319. https://doi.org/10.1108/S1474-7979(2009)0000020014

Henseler, J., Ringle, C. M., & Sarstedt, M. (2015). A new criterion for assessing discriminant validity in variance-based structural equation modeling. *Journal of the Academy of Marketing Science*, *43*(1), 115–135. https://doi.org/10.1007/s11747-014-0403-8

Jaffee, S., Henson, S., Unnevehr, L., Grace, D., & Cassou, E. (2018). *The safe Food Imperative: Accelerating Progress in Low- and Middle-income countries*. World Bank. Agriculture and Food Series; Washington, DC: World Bank. https://openknowledge.worldbank.org/handle/10986/30568

Jay, J. M., Loessener, M. J., & Golden, D. A. (2005). Food Protection with High Temperatures, and Characteristics of Thermophilic Microorganisms. In J. M. Jay, M. J. Loessener, & D. A. Golden (Eds.), *Modern Food Microbiology* (7th edition, pp. 415–441). Springer.

Jespersen, L., Butts, J., Holler, G., Taylor, J., Harlan, D., Griffiths, M., & Wallace, C. A. (2019). The impact of maturing food safety culture and a pathway to economic gain. *Food Control*, *98*, 367–379. https://doi.org/10.1016/j.foodcont.2018.11.041

Kyriazos, T. A. (2018). Applied Psychometrics: Sample Size and Sample Power Considerations in Factor Analysis (EFA, CFA) and SEM in General. *Psychology*, *09*(08), 2207–2230. https://doi.org/10.4236/psych.2018.98126

Larouzee, J., & Le Coze, J.-C. (2020). Good and bad reasons: The Swiss cheese model and its critics. *Safety Science*, *126*, 104660. https://doi.org/10.1016/j.ssci.2020.104660

Lima, G. C., Loiko, M. R., Casarin, L. S., & Tondo, E. C. (2013). Assessing the epidemiological data of Staphylococcus aureus food poisoning occurred in the State of Rio Grande do Sul, Southern Brazil. *Brazilian Journal of Microbiology*, *44*(3), 759–763. https://doi.org/10.1590/S1517-83822013005000063

Liu, F., Rhim, H., Park, K., Xu, J., & Lo, C. K. Y. (2021). HACCP certification in food industry: Trade-offs in product safety and firm performance. *International Journal of Production Economics*, *231*, 107838. https://doi.org/10.1016/J.IJPE.2020.107838

Manning, L., Wallace, C. A., & Soon, J. M. (2016). Chapter 13: Foodborne disease outbreaks in complex manufacturing establishments. In J. M. Soon, L. Manning, & C. A. Wallace (Eds.), *Foodborne Diseases: Case Studies of Outbreaks in the Agri-Food Industries* (pp. 287–311). CRC Press.

McCabe-Sellers, B. J., & Beattie, S. E. (2004). Food safety: Emerging trends in foodborne illness surveillance and prevention. *Journal of the American Dietetic Association*, *104*(11), 1708–1717. https://doi.org/10.1016/j.jada.2004.08.028

Medeiros, C. O., Cavalli, S. B., Salay, E., & Proença, R. P. C. (2011). Assessment of the methodological strategies adopted by food safety training programmes for food service workers: A systematic review. *Food Control*, *22*(8), 1136–1144. https://doi.org/10.1016/j.foodcont.2011.02.008

Medus, C., Smith, K. E., Bender, J. B., Besser, J. M., & Hedberg, C. W. (2006). Salmonella Outbreaks in Restaurants in Minnesota, 1995 through 2003: Evaluation of the Role of Infected Foodworkers. *Journal of Food Protection*, *69*(8), 1870–1878. https://doi.org/10.4315/0362-028X-69.8.1870

Mihalache, O. A., Møretrø, T., Borda, D., Dumitraşcu, L., Neagu, C., Nguyen-The, C., Maître, I., Didier, P., Teixeira, P., Lopes Junqueira, L. O., Truninger, M., Izsó, T., Kasza, G., Skuland, S. E., Langsrud, S., & Nicolau, A. I. (2022). Kitchen layouts and consumers' food hygiene practices: Ergonomics versus safety. *Food Control*, *131*, 108433. https://doi.org/10.1016/J.FOODCONT.2021.108433

Moe, C. L. (2009). Preventing Norovirus Transmission: How Should We Handle Food Handlers? *Clinical Infectious Diseases*, *48*(1), 38–40. https://doi.org/10.1086/594119

Mortimore, S. E., & Wallace, C. A. (1998). *HACCP - A practical approach* (2nd ed.). USA: Aspen Publishers Inc.

Murray-Gibbons, R., & Gibbons, C. (2007). Occupational stress in the chef profession. *International Journal of Contemporary Hospitality Management*, *19*(1), 32–42. https://doi.org/10.1108/09596110710724143/FULL/PDF

Pereira, M. B., de Freitas, R. S. G., Stedefeldt, E., & da Cunha, D. T. (2021). Conflicts, informality and risk perception about foodborne diseases in small family and non-family run restaurants. *Journal of Foodservice Business Research*, 1–27. https://doi.org/10.1080/15378020.2021.1883796

Pivarnik, L. F., Patnoad, M. S., Nyachuba, D., McLandsborough, L., Couto, S., Hagan, E. E., & Breau, M. (2013). Development and Pilot Testing of a Food Safety Curriculum for Managers and Staff of Residential Childcare Institutions (RCCIs). *Journal of Food Science Education*, *12*(4), 67–74. https://doi.org/https://doi.org/10.1111/1541-4329.12011

Pizam, A. (2021). The aftermath of the corona virus pandemic. *International Journal of Hospitality Management*, *95*, 102909. https://doi.org/https://doi.org/10.1016/j.ijhm.2021.102909

Reason, J. (1990). The contribution of latent human failures to the breakdown of complex systems. *Philosophical Transactions of the Royal Society of London. B, Biological Sciences*, *327*(1241), 475–484. https://doi.org/10.1098/rstb.1990.0090

Reason, J. (1997). *Managing the Risks of Organisational Accidents*. Ashgate Publishing Limited.

Reason, J. (2000). Human error: models and management. *BMJ (Clinical Research Ed.)*, *320*(7237), 768–770. https://doi.org/10.1136/bmj.320.7237.768

Reason, J., Hollnagel, E., & Paries, J. (2006). *Accidents in complex system occur through the accumulation of multiple factors and failures*. https://www.eurocontrol.int/sites/default/files/library/017_Swiss_Cheese_Model.pdf

Reynolds, J., & Dolasinski, M. J. (2019). Systematic review of industry food safety training topics & modalities. *Food Control*, *105*, 1–7. https://doi.org/10.1016/J.FOODCONT.2019.05.015

Ringle, C., Wende, S., & Becker, J. (2015). *SmartPLS 3*. Bönningstedt: SmartPLS.

Scallan, E., Hoekstra, R. M., Angulo, F. J., Tauxe, R. V, Widdowson, M.-A., Roy, S. L., Jones, J. L., & Griffin, P. M. (2011). Foodborne illness acquired in the United States--major pathogens. *Emerging Infectious Diseases*, *17*(1), 7–15. https://doi.org/10.3201/eid1701.p11101

Soares, L. S., Almeida, R. C. C., Cerqueira, E. S., Carvalho, J. S., & Nunes, I. L. (2012). Knowledge, attitudes and practices in food safety and the presence of coagulase-positive staphylococci on hands of food handlers in the schools of Camaçari, Brazil. *Food Control*, *27*(1), 206–213. https://doi.org/10.1016/j.foodcont.2012.03.016

Soon, J. M. (2019). Finger licking good? An observational study of hand hygiene practices of fast food restaurant employees and consumers. *British Food Journal*, *121*(3), 697–710. https://doi.org/10.1108/BFJ-07-2018-0420/FULL/PDF

Soon, J. M., Brazier, A. K. M., & Wallace, C. A. (2020). Determining common contributory factors in food safety incidents – A review of global outbreaks and recalls 2008–2018. *Trends in Food Science & Technology*, *97*, 76–87. https://doi.org/https://doi.org/10.1016/j.tifs.2019.12.030

Statista. (2021). *Industry revenue of “restaurants and mobile food service activities” in the United Kingdom 2012-2025*.

Todd, E. C. D., Greig, J. D., Bartleson, C. A., & Michaels, B. S. (2007). Outbreaks where food workers have been implicated in the spread of foodborne disease. Part 3. Factors contributing to outbreaks and description of outbreak categories. *Journal of Food Protection*, *70*(9), 2199–2217. https://doi.org/10.4315/0362-028X-70.9.2199

Tongchaiprasit, P., & Ariyabuddhiphongs, V. (2016). Creativity and turnover intention among hotel chefs: The mediating effects of job satisfaction and job stress. *International Journal of Hospitality Management*, *55*, 33–40. https://doi.org/10.1016/J.IJHM.2016.02.009

Food Code, 767 (2017) (testimony of U.S. Food and Drug Administration). https://www.fda.gov/Food/ResourcesForYou/Consumers/ucm239035.htm

Wallace, C. A., Holyoak, L., Powell, S. C., & Dykes, F. C. (2014). HACCP – The difficulty with Hazard Analysis. *Food Control*, *35*(1), 233–240. https://doi.org/10.1016/J.FOODCONT.2013.07.012

Weatherill Report. (2009). *Report of the independent investigator into the 2008 listeriosis outbreak*. https://www.cpha.ca/

Weinroth, M. D., Belk, A. D., & Belk, K. E. (2018). History, development, and current status of food safety systems worldwide. *Animal Frontiers : The Review Magazine of Animal Agriculture*, *8*(4), 9–15. https://doi.org/10.1093/af/vfy016

Wiśniewska, M., Czernyszewicz, E. & Kałuża, A. (2019), "The assessment of food safety culture in small franchise restaurant in Poland: The case study", *British Food Journal,* 121(10), 2365-2378. https://doi.org/10.1108/BFJ-03-2019-0152

Wiśniewska, M. (2022), "Just culture and the reporting of food safety incidents", *British Food Journal*, ahead-of-print. https://doi.org/10.1108/BFJ-12-2021-1316

World Health Organization. (2006). *Five Keys for Safer Food Manual*. WHO Press.

World Health Organization. (2019). *Estimating the burden of foodborne diseases*.

Wu, Y., Liu, X., Chen, Q., Liu, H., Dai, Y., Zhou, Y., Wen, J., Tang, Z., & Chen, Y. (2018). Surveillance for foodborne disease outbreaks in China, 2003 to 2008. *Food Control*, *84*, 382–388. https://doi.org/10.1016/j.foodcont.2017.08.010

Yiannas, F. (2016). *Food safety = behavior* (2nd ed.). Springer New York LLC.

Zanetta, L. D., Hakim, M. P., Stedefeldt, E., de Rosso, V. V., Cunha, L. M., Redmond, E. C., & da Cunha, D. T. (2022). Consumer risk perceptions concerning different consequences of foodborne disease acquired from food consumed away from home: A case study in Brazil. *Food Control*, *133*, 108602. https://doi.org/10.1016/j.foodcont.2021.108602

Zanin, L. M., Stedefeldt, E., da Silva, S. M., da Cunha, D. T., & Luning, P. A. (2021). Influence of educational actions on transitioning of food safety culture in a food service context: Part 2 - Effectiveness of educational actions in a longitudinal study. *Food Control*, *120*, 107542. https://doi.org/10.1016/j.foodcont.2020.107542

Zanin, L. M., Stedefeldt, E., & Luning, P. A. (2021). The evolvement of food safety culture assessment: A mixed-methods systematic review. *Trends in Food Science & Technology*, *118(Dec)*, 125–142. https://doi.org/https://doi.org/10.1016/j.tifs.2021.08.013

Swiss cheese slices are layers of defence; holes are active failures or latent conditions; the red arrow is a free hazard; the blue arrow is a hazard blocked by controls; FSMS = Food safety Management Systems. Source: Authors.

Figure 1 – The proposed model (Swiss Cheese Model of food safety incidents) inspired by SCM, HACCP, and PAHO/WHO five keys to safer food.

Ellipses are constructs; Rectangle is an observed variable

Figure 2 – The hypothesis model

*p<0.001; **p<0.01; n.s. = non-significant.

Figure 3 – Final inner model

Table 1 – Indicators and composite reliability of each construct

Constructs	Indicators (code number)	Removed indicators	CR	Median percentage of violations
Adequate facilities	1.1, 1.4, 1.5, 1.6, 1.7, 2.1, 2.2, 4.3, 7.1	1.2, 1.3	0.811	24.4
Trained manager	9.1	None	-	54.9
Safe ingredients and water	6.1, 6.2, 6.3, 6.4, 6.6, 6.7	None	0.788	13.9
Environmental hygiene	3.1, 3.2, 3.3, 3.4, 3.6, 4.1, 4.2	3.5	0.845	27.0
Personal and food hygiene	5.1, 5.2, 5.3, 7.11, 7.2, 8.3	None	0.804	65.0
Safe food temperature	7.10, 7.12, 7.3, 7.4, 7.5, 7.6, 7.7, 7.8, 7.9, 8.2, 8.4, 8.5, 8.6, 8.9	8.8	0.883	33.5
Control	6.5, 8.1, 8.7, 9.2	None	0.841	25.5

CR = Composite reliability.

Table 2 – Discriminant validity - Hetero-trait mono-trait ratio of correlations.

Constructs	(1)	(2)	(3)	(4)	(5)	(6)
Environmental hygiene (1)	-					
Adequate facilities (2)	0.747					
Safe ingredients and water (3)	0.778	0.601				
Personal and food hygiene (4)	0.812	0.697	0.740			
Safe food temperature (5)	0.722	0.582	0.788	0.697		
Trained manager (6)	0.355	0.335	0.341	0.309	0.383	
Control (7)	0.698	0.626	0.745	0.658	0.745	0.452

Table 3 – Pearson's correlation coefficient of the constructs

Constructs	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Environmental hygiene (1)	1.000						
Adequate facilities (2)	0.614	1.000					
Safe ingredients and water (3)	0.572	0.487	1.000				
Personal and food hygiene (4)	0.615	0.592	0.526	1.000			
Safe food temperature (5)	0.593	0.522	0.627	0.557	1.000		
Trained manager (6)*	0.307	0.314	0.300	0.260	0.366	1.000	
Control (7)	0.541	0.519	0.550	0.499	0.626	0.392	1.000

All with $p < 0.001$; *Correlations with training were made through bi-serial correlation.