An AcciMap approach to analyse the Chinese melamine milk scandal

Purpose: The 2008 Chinese melamine milk scandal resulted in six reported fatalities and affected around 300,000 children of which 54,000 were hospitalised. Previous studies have used linear approaches to examine the root causes of the melamine milk scandal.

Methodology: In the present study we applied a systems approach to the melamine milk scandal to identify the complex systems level failures across the supply chain leading to the incident and why food fraud incidents such as this occurred in the dairy sector. Additionally, systemic failures associated with food fraud vulnerability factors were considered (i.e., opportunities, motivation and control measures).

Findings: Forty-eight contributory factors of influence were identified and grouped across six sociotechnical levels across the Chinese dairy system from government to equipment and surroundings. Lack of vertical integration (processes and communication) contributed to the failure. When viewed in a broader perspective, the melamine milk scandal can be linked to a series of human error and organisational issues associated with government bodies, the dairy supply chain, individual organisations and management decisions and individual actions of staff or processes.

Originality: To the best of our knowledge, this is the first study to analyse a food fraud incident using the AcciMap approach and food fraud vulnerability assessment (FFVA) technique. Accimap analysis is applied to both unintentional and intentional aspects of the incident.

Practical Implication: This approach is of value to policy makers and the industry as it supports public health investigation of food fraud incidents and proactive food safety management.

Keywords: dairy supply chain; food fraud; systemic analysis; vulnerability assessment

Introduction

On 11 September 2008, a public recall of infant formula was conducted in China. The Health Ministry revealed that infant milk produced by Sanlu Dairy Company was tainted with melamine. Melamine is a chemical used to manufacture plastics, laminates, paints and fire-resistant additives (Pei *et al.,* 2011). Melamine is rich in nitrogen and was alleged to have been added to diluted milk to boost the apparent protein content in milk. Melamine contains

66% nitrogen (Sharma and Paradakar, 2010) and melamine scrap was easily accessible in the local open market and could be ground and dyed into any colour to match 'additives' colour (NYTimes, 2007; Xiu and Klein, 2010). Milk samples taken from twenty-two major Chinese domestic dairy companies tested positive for melamine. Sanlu samples were found to contain the highest amount of melamine content, i.e., up to 2563 mg/kg (Lu, 2011). The incident resulted in six deaths, over 50,000 hospitalisations and 300,000 children were affected by kidney stones and renal failure due to melamine exposure (Gossner *et al.,* 2009; Pei *et al.,* 2011). On 24 December 2008, Sanlu was declared bankrupt, and a number of executives were prosecuted. Very significant penalties resulted including lifetime prison sentences and even executions (Xiu and Klein, 2010). The Chinese Government introduced a number of additional policy interventions and the Health Ministry's Health Supervision Bureau issued national standards for maximum melamine levels of 2.5 mg/kg in liquid milk, milk powder, and any other food containing more than 15% milk (Li *et al.,* 2019). The melamine milk scandal was one of the biggest public health and food fraud crises and raised global concerns about milk and milk-based products from China, prompting global recalls. The incident did not 'come out of the blue.' Between 2004 and 2007 there were multiple incidents across the world concerned with kidney failure in animals, and the cause was associated with pet food and animal feed (Li *et al.,* 2019). Thus, the vulnerability for wider use of melamine as an intentional means to adulterate milk would not have been unexpected.

It is estimated that the impact of food fraud on the food industry exceeds US$40 – 50 billion annually (PwC, 2016; Spielman, 2020). Food fraud is defined as intentional deception associated with food for economic gain (Spink *et al.,* 2019). Numerous factors influence the degree of vulnerability of a given food supply chain, food business or food product to food fraud. These factors include *economic and supply chain factors* (e.g., factors that influence the dynamics of supply and demand for a given food), *national factors* (e.g., governance structures, preventive structures and control measures that are in place) and specific *incident related factors* (e.g., the likelihood of fraud detection, the level of deterrence and the opportunity to perpetrate the crime) (Manning and Soon, 2019; Marvin *et al.,* 2016). Van Ruth *et al.,* (2017) identified three main elements to consider when assessing food fraud vulnerability i.e., *opportunities* (i.e., technical opportunities and opportunities in time and place), *motivations* (i.e., economic and cultural & behavioural drivers) and *control measures* (e.g., technical and managerial controls). Although previous studies have examined the causes or factors leading to the melamine milk scandal (Gossner *et al.,* 2009; Yang *et al.,* 2009; Xiu and Klein, 2010; Yang *et al.,* 2020), the complex inter-relationships between the social, technical, human, management and operational interactions operating across a multi-level socio-technical system were not explored. Furthermore, the systemic failures associated

with the three main elements of food fraud vulnerabilities (Van Ruth *et al.,* 2017) in the melamine milk scandal have not been extensively examined. Therefore, a systems-based analysis that examines the complex inter-relationships and interdependencies between different stakeholders across the dairy supply chain that led to the melamine milk scandal is important to address this gap.

AcciMap is a systems-based technique used to analyse accidents that occurred within complex socio-technical systems. AcciMap is useful in capturing and showing the inter-relationships of contributing factors from different parts of the systems (Branford, 2011). The term *causal factors* is used by Branford instead of *contributing factor*s as has been used in this paper (Diaz De Oleo *et al.,* 2022). Both terminologies are used in the context of recognising a necessary factor of influence in an incident, but not to imply causality (Branford *et al.,* 2009). The AcciMap was derived from the Risk Management Framework that consists of six systemic levels (Figure 1). Each level is connected by a flow of information in a top-down, bottom-up or horizontal approach that represents decisions made by different entities leading to direct or indirect consequences. The framework also captures the interactions within and between the system levels (Diaz De Oleo *et al.,* 2022; Igene *et al.,* 2022; Rasmussen, 1997). AcciMap analysis has been used to consider road safety more generally (Hamim *et al.* 2020; Salmon *et al.,* 2020; Igene *et al.,* 2022); transportation (Kee *et al*., 2017; Salmon *et al.,* 2013), recreational incidents (McLean *et al.,* 2021), child labour in supply chains (Nayak and Manning, 2021) and more recently food safety incidents and foodborne disease outbreaks. AcciMaps have been used to analyse food safety incidents such as Bovine Spongiform Encephalopathy (BSE) (Cassano-Piche *et al.,* 2009), norovirus (Diaz De Oleo *et al.,* 2022), and *Escherichia coli* O157 outbreaks (Nayak and Waterson, 2016). Although the melamine milk scandal was not considered an 'accident' per se, the incident represented a system failure that arose within a complex socio-technical system (Liu, 2009). Thus, using the AcciMap approach could be useful to establish how multiple factors in all parts of the socio-technical system may have contributed to the failure. The aim of this study was to analyse the melamine milk scandal using the AcciMap approach to assess the contributory factors to the incident. Three food fraud vulnerability factors have been considered (i.e., opportunities, motivation and control measures).

Insert Figure 1 here

The structure of this paper is as follows: Section 1 provides an introduction and theoretical grounding of the paper. Section 2 explains the methodology and Section 3 the results. Section 4 presents the discussion and Section 5 the conclusion.

Methodology

Peer-reviewed journal articles, grey literature and media reports associated with the melamine milk scandal in China were reviewed. A systematic search and review of the melamine milk scandal was conducted. This method was selected as it combines the strength of a critical review with a comprehensive search approach (Grant & Booth, 2009). Five journal databases (i.e., Science Direct, Ingenta Connect, Emerald Insight, PubMed and Google Scholar) were reviewed for articles from 2008 to 2020. Search terms included 'melamine milk scandal', 'adulteration', 'food fraud', 'economically motivated', 'China', 'dairy supply chain', 'Sanlu', 'causes', 'contributing factors', 'investigation' and 'root cause'. References from the articles and reports were also reviewed for further information. Each relevant article were then read and re-read to identify potential contributing factors. Examples of human and organisational factors contributing to the incident were then extracted from the articles and reports. The list of sources used in the AcciMap analysis is listed in Supplementary Material 1. The timeframe of events (Supplementary Material 2) leading to the melamine crisis was established to provide an overview of the events and decisions made by stakeholders involved in the incident similar to the approach adopted in Diaz De Oleo *et al.* (2022) and Waterson (2009). The AcciMap was constructed based on Brandford *et al.* (2009). The initial AcciMap was created on a blank sheet of paper, divided into five systemic levels (i.e., external, government, organisations, processes/conditions and outcomes) adopted from Svedung and Rasmussen (2002). The list of contributory factors was placed at the bottom of the AcciMap sheet. The outcome(s) were identified and inserted into the 'Outcomes' level of the AcciMap. The contributing factors were allocated into appropriate AcciMap levels and inter-connections between factors were identified. Microsoft Visio was used to create the final AcciMap. Each of the contributing factors were assessed against van Ruth *et al.* (2017) food fraud vulnerability elements and detailed factors i.e., (i) opportunities (technical opportunities); (ii) opportunities (time and space); (iii) motivation (economic); (iv) motivation (culture and behaviour); (v) control measures (technical); and (vi) control measures (managerial). Control measures such as monitoring, detection methods and background screening could potentially reduce food fraud vulnerabilities associated with opportunities and motivation (van Ruth *et al.* 2017). However, in this study, we categorised them as 'lack of control measures' due to limited or non-existing food safety and food fraud control measures at various systemic levels. For example, lack of control measures (technical) include lack of or absence of 'hard controls' such as product authenticity testing, monitoring systems for raw materials and traceability. Lack of control measures (managerial) are associated with lack of or absence of lack of or absence of 'soft controls' such as ethical codes of conducts, background checks and weak enforcement (van Ruth et al., 2017).

One of the major advantages of using the AcciMap approach is that it does not require a taxonomy of errors or failures modes to inform the analysis phase allowing the open identification of factors without methodological constraints (Hulme *et al.,* 2021). However to be consistent and methodological in applying the methodology requires a detailed understanding of how actions or decisions made at one system level influence activities, actions and decisions at another. Before an AcciMap can be constructed two preliminary steps must be followed (Brandford *et al.,* 2009): data collection and establishing an incident events and decisions time frame. The Accimap is then iteratively developed using Visio in Microsoft 365. Contributory factors are detailed [boxes] and grouped at a particular level and interconnections shown as arrows, colour coding at each level capturing the interactions and contributory factor across the system.

Results

In the preliminary steps, fifteen academic sources were identified as being able to provide evidence for the creation of the Accimp analysis of the incident. From these sources, the time frame of events was developed from 2007 to 2009 (Table 1). The time frame reflects the stages of the scandal. Scandals are described by Smith *et al*. (2022) as “a key mechanism used by media, pressure groups and social movements to demand inquiries and investigations into alleged corruption, incompetence and immorality.” The scandal narrative led to individuals boycotting the product,with socio-economic and socio-political aspects then leading to unravelling and revelation (Smith *et al.*, 2022) of the melamine in milk incident in China. Table 1 has been presented using the Storm and Wagner model (2015) 5-step model: 1) transgression; 2) publicly observed dislocation destabilising the social order; 3) resulting in a moral (and judgemental) communication; 4) an increase in environmental pressure for appropriate action; and 5) calls for an institutional solution. The transgression, adulteration of the milk, was a crime perpetrated both against the government and the individual and the associated shaming, moral reckoning and retribution led to the loss of the business through ceasing of trading, and personal penalties for individuals involved.

The AcciMap framework for the Chinese melamine milk scandal (Figure 2) identified 48 different factors and shows different levels of the socio-technical system being involved in the incident namely: 1. External, 2. Government (a) national and (b) local; 3. Organisational/workplace for (a) dairy supply chain and (b) Sanlu as an organisation; 4. Physical individual events, proesses and conditions; 5. Outcomes. The main difference between Figure 1 and 2 is that the latter’s organisational / workplace level is divided into two levels i.e., dairy supply chain and Sanlu to capture the interactions with other supply chain

actors. This is crucial as it helps to identify failures within/from the dairy supply chain and its interactions with Sanlu. The different contributing factors are identified at each level and their interrelationship. The factors have been characterised in terms of motivation (economic, culture and behaviour), technical opportunities and managerial and technical control measures. Each level is now considered in turn.

Insert Table 1

Insert Figure 2

External contributory factors

The increased demand for milk products drove the expansion of the Chinese dairy industry. The uncontrolled expansion of the dairy sector led to problems in operations and supply chain management that contributed to lack of food safety control (Chen *et al.*, 2014; Delman and Yang, 2012). The inequality of dairy demand especially between rural and urban consumers led to the production of milk in rural areas, where production lacked traceability and transparency so that the milk was produced without food safety oversight before it was transferred for processing (Lu, 2011; Pei *et al.,* 2011). This created an economic motivation for perpetrators to fill the void between high urban demand and low supply through dilution and adulteration with melamine. Economic pressure in 2006 of rising feed prices meant 40% of dairy farmers were making a loss and another 30% were barely breaking even so whilst some farmers were ceasing production the consumer, and thus processor, demand was increasing (Jia *et al.*, 2012; Manning and Soon, 2014). Another external cultural factor was the need to 'save face' (to maintain public respect) and to avoid uncertainty in the section by refraining from communicating about, or by diverting attention away, from the incident (Ye and Pang, 2011). These external factors created a favourable socio-economic environment for fraud to occur that impacted the day-to-day operation of government, dairy supply chain and Sanlu company.

Government (national and local)

One of the contributing factors at this level was the 'inspection-exempt' policy where national brands and products that met relevant state standards were exempted from inspection by the government regulators (Custance *et al.,* 2011; Liu, 2009). This created a lack of deterrence to prevent fraud and also an environment that increased fraud vulnerability, especially where there was a strong motive for economic gain by adulterating with melamine. The inspection exemption failed to prevent Sanlu and other dairy companies selling infant formula that was produced with reduced food safety and quality standards. At the national level, there was

overlapping of responsibilities and roles, and it was unclear which department was responsible for oversight. This contributed to weak enforcement and poor compliance in the regulatory system (Li, 2015). Additionally, China was the host for Olympics 2008 during the crisis, and this delayed further action as the government had issued orders to suppress bad news during that period (IRGC, 2010; Spencer, 2008). This was another reason why the local government did not report concerns to provincial authorities (Lyu, 2012). Local protectionism was also identified as a contributing factor to the incident (Li, 2015). Overall this demonstrated a lack of effective governance.

Organisation

Dairy Supply Chain

A catalogue of problems was associated with the dairy supply chain. The increased demand for milk intensified the competition for raw milk, resulting in less safety and quality checks (Custance, 2011) and an economic motivation to commit fraud. There were minimal services available to farmers and milk collection agents in rural areas. The lack of managerial and technical controls contributed to lack of sanitary conditions, lack of training and lack of technical and safety awareness in the dairy supply chain (Chen *et al.,* 2014). Sanlu utilised a decentralised milk supply model that relied on multiple, independent small-scale farms as raw milk suppliers to reduce operational costs. The fragmented supply chain made it more difficult to standardise the monitoring process (Delman and Yang, 2012; Pavlovich *et al.,* 2014). The local dairy supply chain had very little control over milk price and the feed price hike created pressure on the dairy industry to save costs through adulteration activities (DeLaurentis, 2009; Xiu and Klein, 2010). The use of poor quality feed and fragmented supply chain were caused by poor services available to milk suppliers. Small dairy farmers faced challenges in managing their dairy herd and better services should be provided by Sanlu or milk collection stations e.g., by offering technical advice on how to manage production and how to use technologies (Ma et al., 2007). The lack of inspection at higher levels and lack of documentation at lower levels led to minimal traceability of raw and processed milk making it difficult to identify the sources of adulteration (DeLaurentis, 2009). This highlights the lack of technical and managerial controls resulting in a failure to address food fraud.

Sanlu Dairy Company

As a result of higher-level contributing factors i.e., products being exempted from inspection, Sanlu was able to set its own standards and implement its own inspection systems (Xiu and Klein, 2010). The inconsistent communication from Sanlu exacerbated the crisis as Sanlu initially denied there were any problems and claimed the problematic products were counterfeit products (Lyu *et al.,* 2012; Ye and Pang, 2011) before finally making a recall announcement.

Other contributing factors include the lack of communication from local government and Sanlu. Sanlu requested the local authorities to coordinate the media to minimise the reporting about the tainted milk and used its advertising contracts to influence media coverage (Economist, 2008; Veil and Yang, 2012; Ye and Pang, 2011). The power dynamics between Sanlu and Fonterra, the New Zealand based partner, were imbalanced and Fonterra's warning of the need to recall non-compliant milk products went unheeded (Keck, 2009; Pavlovich *et al.,* 2014).

Physical individual events, process and conditions

Six physical individual events, process and/or conditions were identified as contributory factors to the incident. Firstly, melamine was considered an 'unknown' hazard and was not listed as an illegal additive. It was also believed to be non-toxic as it was used as an additive in the feed industry (Chen *et al.,* 2014; IRGC, 2010; Yang *et al.,* 2009). The protein test used was ineffective in detecting the fraud since Kjedahl protein test measured the amount of nitrogen, including the nitrogen-rich melamine (Pei *et al.,* 2011). Since the method determines total nitrogen and not protein nitrogen, this created a technical opportunity for milk adulteration to increase the protein content (Finete *et al.,* 2013). Sanlu also did not test the milk products when it received initial complaints, further delaying the product recall (Custance *et al.,* 2011). This was linked to actions from the higher level as the government did not want bad news to tarnish the Olympic games (IRGC, 2010; Spencer, 2008). The product recall was further delayed by higher level actions (i.e., cover-up from government and Sanlu) by replacing the tainted products with milk products with 'lower' level of melamine content (Ye and Pang, 2011). This highlights the consequences of actions made at higher levels resulting in a failure to address the food fraud.

Discussion

This is the first study to utilise the AcciMap framework to analyse the contributory factors of a global food fraud scandal. It is also the first study to examine the contributory factors in relation to food fraud vulnerability factors within the context of a scandal narrative. Although Sanlu was identified as the main culprit in the fraudulent incident, the sources highlight adulteration was an endemic practice across the dairy supply chain in a context of poor economic returns in a market with a rising consumer demand. The AcciMap analysis demonstrates the complexity and interconnectedness of human and organisational factors in a system. It also shows there were very few feedback mechanisms from the business up through the socio-technical levels. One of the advantages of AcciMap is the graphical representation of the incident which provides a 'big picture' analysis of the contributing factors and the interactions within and between systemic levels. When viewed in a broader perspective, the melamine milk

297 scandal occurred due to a series of policy gaps, failures and vulnerabilities for public health
298 across different levels of government (national and local), the dairy supply chain, and
299 individual organisations such as Sanlu. At each socio-technical system level there should have
300 been stringent managerial and technical controls involving food safety management via the
301 control of processes through laws, regulations and industry policies (Rasmussen, 1997). Our
302 AcciMap analysis demonstrates a lack of vertical integration of technical and managerial
303 controls. For the system to work, Cassano-Piche *et al.* (2009) reported that the decisions made
304 at higher levels (e.g., national and local government) should have filtered downwards to the
305 lower levels while information from lower levels (e.g., staff, processes, environment) should
306 have informed the decisions and actions at higher levels. Local government and Sanlu were
307 aware of the incident but did not convey the information to decision makers at higher level
308 (Parry, 2008; Wang *et al.,* 2020). Following the incident, the Chinese government responded
309 to ensure the safety and quality of Chinese food products through the implementation of food
310 safety laws, increasing penalties for illegal practice, and implementing a risk evaluation
311 (Manning and Soon, 2014) with the legislation changing focus from food sanitation to food
312 safety (Xiu and Klein, 2010). The lack of vertical integration shown in the AcciMap resulted in
313 uncertainty, instability and loss of control thus creating more vulnerabilities in the system
314 (Grant et al., 2018). Food fraud vulnerability factors were characterised in the AcciMap
315 analysis as opportunities, motivations and presence or lack of control measures (van Ruth et
316 al., 2017).
317
318 Technical opportunities to conduct fraud were identified at national, dairy supply chain and
319 process levels. For example, inspection exemption led to reduced monitoring, and this created
320 the opportunity within the supply chain for fraudsters to adulterate milk with little surveillance.
321 At the process level, the inherent characteristics of nitrogen rich melamine coupled with
322 ineffective protein tests provided technical opportunities for fraud to occur. The reliance on
323 multiple and fragmented milk suppliers created opportunities in time and space for adulteration
324 to occur and for adulterated milk to enter the market, as fraudsters had legitimate access to
325 milk collection stations to commit the fraud.
326
327 Motivation due to economic, cultural and behavioural factors were identified across all
328 systemic levels. Demand for milk in a difficult economic market, increased costs of inputs
329 including feed, and a need to save costs whilst boosting profit and tax revenues were
330 economic drivers to commit fraud. Poor quality and diluted milk that led to dairy suppliers who
331 boosted the 'apparent protein content' by adding melamine was also an economical motivation
332 driver for fraud (Sharma and Paradakar, 2010; van Ruth et al., 2017; Xiu and Klein, 2010).
333 Cultural and behavioural factors were identified in overarching external factors that influenced

the scandal narrative and how the incident was shaped by internal and cultural factors especially the need to protect social stability and to 'save face' during the Beijing Olympics. According to Ye and Pang (2011), Sanlu's management and leadership were influenced by political and cultural factors. Sanlu placed an emphasis on using government relationships and relied on local government to influence the media. Sanlu's chairperson, Tian Wenhua was a local government official and thus, had close affiliation with local government (Li, 2015). The imbalanced power dynamics between Sanlu and Fonterra created further cultural and behavioural vulnerabilities. Although Fonterra owned 43% of the shares, Sanlu was the dominant local partner in China (Pavlovich *et al.,* 2014). Scandal narratives will often include scripted aspects of denial of wrongdoing, even whilst wrongdoing is still being perpetrated, often dissociated from admitting responsibility (Smith *et al.* 2022). These external factors created an environment where undisclosed fraud could occur despite the responsibilities of government, dairy supply chain and the Sanlu company, among others to ensure safe food. With twenty-two organisations being identified with melamine contaminated infant formula products (Gossner *et al.,* 2009) this demonstrates the large scale of the perpetration of the fraud across the industry. More widely melamine was found globally in powdered and liquid milk, protein powders, yogurts, frozen desserts, cereal products, confectionary, cakes and biscuits, and processed foodstuffs through the global trade in milk powder (Gossner *et al.,* 2019). The problem was exacerbated by the carryover from feed to animal related food products. For a similar case where the incident had a complex impact see the systematic analysis of the Fipronil incident (Nayak *et al.,* 2022).

As shown in Figure 2, motivations driven by economic, cultural and behavioural factors were present at all sociotechnical levels. The lack of government and business strategies and ethical culture resulted in denials and thus delaying product recall, but this is a common modus operandi in some scandals (Smith *et al.,* 2022). The industry also had a culture where adulteration and sub-standard milk products were widespread. The lack of technical and managerial measures was evident across government, organisations and process levels. Ineffective governance, overlapping government departments and lack of food safety and quality control measures contributed to increased vulnerability. The food fraud vulnerability factors identified in this study from analysis of the melamine milk scandal support Yang *et al.*'s (2020) findings where farmers were identified as more vulnerable to food fraud due to their rural location, lack of guardians and hurdles and thus the increased opportunities and motivation to commit fraud and a lack of control measures to prevent their occurrence or identify fraud where it had taken place. Some contributory failures were associated with two or more vulnerable factors. For example, local protectionism was partly motivated by economic, cultural and behavioural factors. Sanlu was a major source of tax revenue for local

governments and authorities rely on state or private enterprises to grow the economy. To protect the local economy, the local government did not report the incident to the provincial government (Fu and Nicoll, 2010; Li, 2015). Additionally, an increase in local Gross Domestic Product (GDP) boosted local officials' social status through re-appointments and career progression.

Limitations

There are limitations associated with AcciMap framework. The analysis is dependent on the expertise and subjective judgement of the analyst as it does not have a classification scheme to guide the analysis (Salmon *et al.,* 2012; Underwood and Waterson, 2013). A 'bottom-up' approach is required to identify contributing factors and there must be sufficient literature or data to describe the socio-technical system and interacting events. Although AcciMap is potentially highly comprehensive in identifying all contributory factors, it does not identify the most dominant contributory factors (Goode *et al.,* 2017; Salmon *et al.,* 2012), so cannot be used to prioritise the factors identified.

Conclusion

This study analysed the melamine milk scandal using an AcciMap approach. More than 40 contributory factors were identified at all systemic levels (i.e., external, government, organisation and physical events / process). The AcciMap method was useful in depicting the complexity of human and organisational factors in a system, in particular a food fraud incident that was not considered an 'unintentional'. The lack of vertical integration resulted in loss of control which created food fraud vulnerabilities in the system. The decisions made at the top of the socio-technical system influenced those at the lower level whilst information from lower levels did not translate into actions at higher levels. This shows that the factors interacted in a non-linear systematic way. Over time, these contributory factors came together resulting in the melamine milk crisis. In this study, we also explored the food fraud vulnerability elements associated with each contributory factors, specifically opportunities, motivations and lack of control measures. These findings are of interest when considering food supply chains operating under difficult economic and supply conditions. It demonstrates the importance of effective and transparent communication at and between all systemic levels. Decisions made by regulatory bodies should have filtered downwards to the industry while information from lower levels should have informed the decisions and actions at higher levels. The combination of AcciMap analysis and food fraud vulnerability factors (FFVA) is practical for future public health investigations of food fraud incidents. Further studies are recommended to explore the potential application of AcciMap and food fraud vulnerability assessment in assessing complex

food fraud incidents and to then identify appropriate changes to extant policy and regulation to reduce vulnerability.

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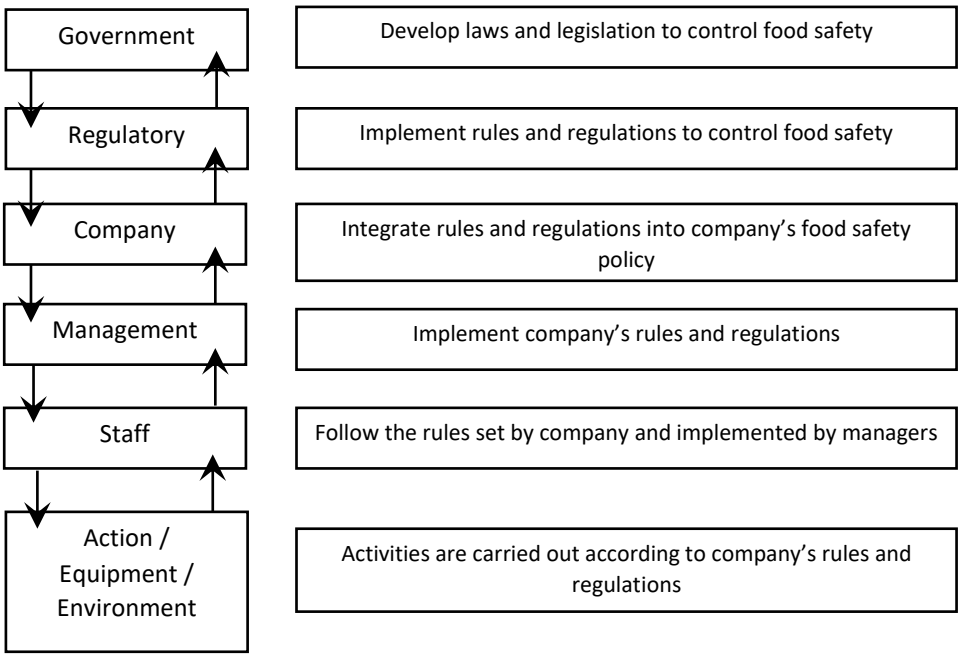

Figure 1. Systemic levels in AcciMap framework (Adapted from Diaz De Oleo et al., 2022; Igene et al., 2022; Rasmussen, 1997)

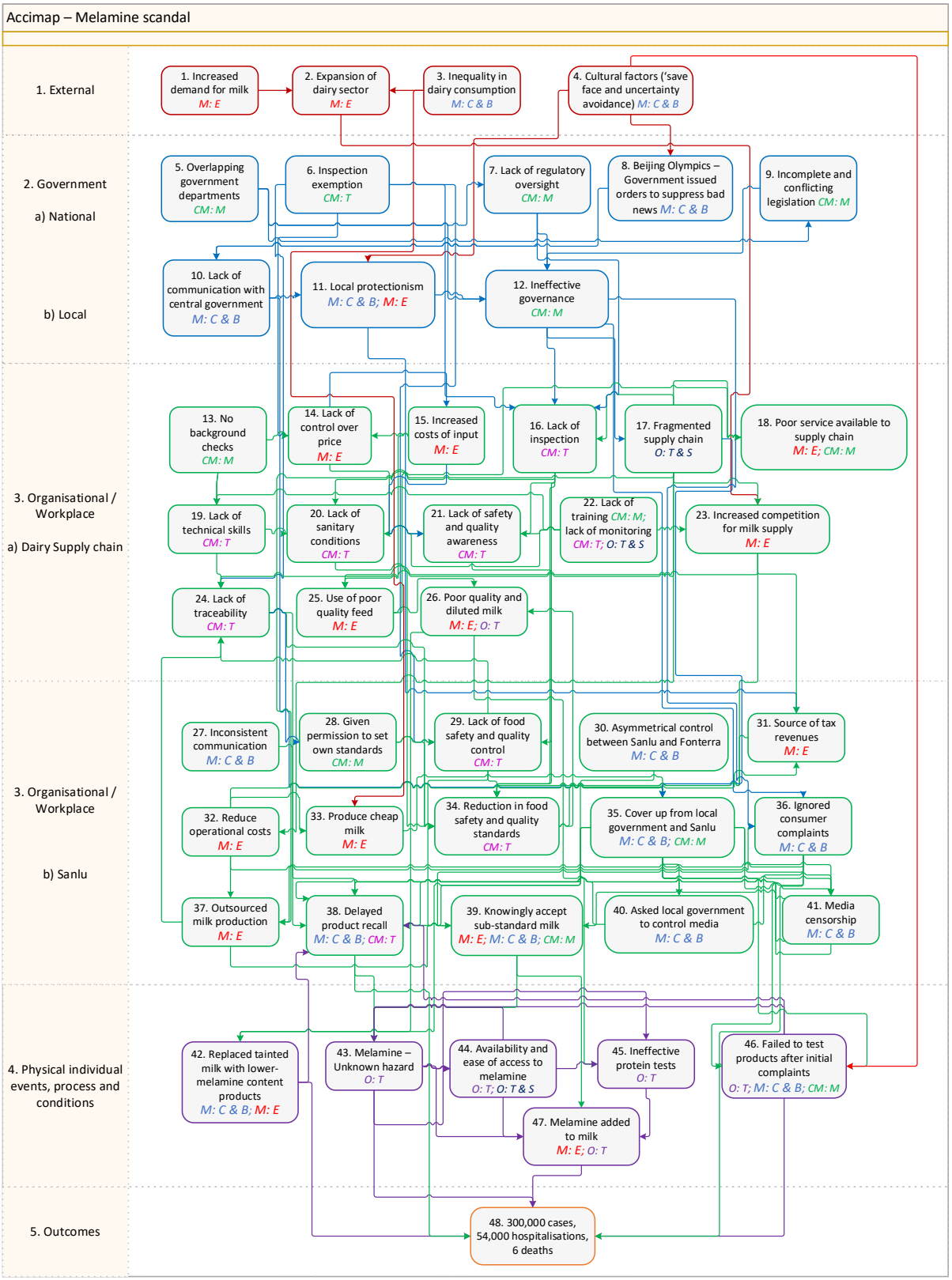

Figure 2. AcciMap analysis of the 2008 melamine milk scandal (Notes: M:E = Motivation: Economic; M:C&B = Motivation: Culture & Behaviour; CM:M = Control measures: Managerial; CM:T = Control Measures: Technical; O:T = Opportunities: Technical; O:T&S = Opportunities: Time & Space)

Table 1. Time frame of melamine milk scandal (Adapted from: Chen et al. 2014; Custance et al. 2011; Fu & Nicoll 2011; Gossner et al. 2008; Jia et al. 2012; Hubbard, 2010; Keck, 2009; Li, 2015; Lu, 2011; Manning & Soon, 2014; Pavlovich et al. 2014; Qiao et al. 2012; Rushworth, 2009; Veil & Yang, 2012; Wang et al. 2020; Xiu & Klein, 2010; Ye & Pang, 2011; Zeng et al. 2018)

Time period	Event
Phase 1 Transgression	
	Perpetration of the adulteration and associated criminal activities occurred. In 2006, dairy production in China faced rising feed prices with 40% of dairy farmers losing money and further 30% just breaking even
Phase 2 Dislocation	
December 2007	Sanlu received complaints but did not take any action
May 2008	First baby died.
June 2008	Increased number of reports of kidney stones associated with milk formula. Complaints about Sanlu's milk powders appeared in the General Administration of Quality Supervision and Quarantine of China (AQSIQ) website.
July 2008	20 babies were hospitalised and the cases were linked to Sanlu's formula milk. Limited communication of information.
Phase 3 Moral communication	
1 August 2008	Inspectors found melamine in milk powder from Sanlu.
2 August 2008	Sanlu reported to local government and asked local government to coordinate media information. Fonterra became aware of Sanlu melamine contamination and warned the need to recall the products.
13 August 2008	Sanlu initiated product market response where finished products with melamine < 10ppm could still be sold while products with > 10ppm were held in storage.
Phase 4 Environmental pressure/Phase 5 Calls for institutional solution	
22 August 2008	Fonterra reported to New Zealand Foreign Affairs Department.
9 September 2008	New Zealand Prime Minister informed Chinese Central Government. Hebei authorities (provincial level) were informed. Shanghai Daily reported 14 infants sick after drinking infant formula.
11 September 2008	China's Health Ministry announced infant formula produced by Sanlu was contaminated by melamine; public recall of infant formula.
12 September 2008	Sanlu admitted infant formula contained melamine. 432 cases reported and 1 death.
13 September 2008	Central Government initiated Level I Food Safety Reaction, an urgent crisis handling step. All hospitals across country provided free examinations to all babies.
17 September 2008	Milk samples from 22 organisations were confirmed as testing positive for melamine. First melamine findings reported outside of China in Singapore.
18 September 2008	China's General Bureau of Quality Inspection announced the abrogation of exemption of quality inspection of food.
1 December 2008	6 deaths and 300,000 cases associated with consumption of melamine-contaminated milk and milk products were announced.
24 December 2008	Sanlu declared bankrupt.
22 January 2009	Tian Wenhua, chairwoman of Sanlu sentenced to life imprisonment, three former executives sentenced to between 5 and 15 years in prison, and two other 3rd party milk supplier sentenced to death
1 June 2009	New food safety law adopted in China