

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

38 66% nitrogen (Sharma and Paradakar, 2010) and melamine scrap was easily accessible in
39 the local open market and could be ground and dyed into any colour to match 'additives' colour
40 (NYTimes, 2007; Xiu and Klein, 2010). Milk samples taken from twenty-two major Chinese
41 domestic dairy companies tested positive for melamine. Sanlu samples were found to contain
42 the highest amount of melamine content, i.e., up to 2563 mg/kg (Lu, 2011). The incident
43 resulted in six deaths, over 50,000 hospitalisations and 300,000 children were affected by
44 kidney stones and renal failure due to melamine exposure (Gossner *et al.*, 2009; Pei *et al.*,
45 2011). On 24 December 2008, Sanlu was declared bankrupt, and a number of executives
46 were prosecuted. Very significant penalties resulted including lifetime prison sentences and
47 even executions (Xiu and Klein, 2010). The Chinese Government introduced a number of
48 additional policy interventions and the Health Ministry's Health Supervision Bureau issued
49 national standards for maximum melamine levels of 2.5 mg/kg in liquid milk, milk powder, and
50 any other food containing more than 15% milk (Li *et al.*, 2019). The melamine milk scandal
51 was one of the biggest public health and food fraud crises and raised global concerns about
52 milk and milk-based products from China, prompting global recalls. The incident did not 'come
53 out of the blue.' Between 2004 and 2007 there were multiple incidents across the world
54 concerned with kidney failure in animals, and the cause was associated with pet food and
55 animal feed (Li *et al.*, 2019). Thus, the vulnerability for wider use of melamine as an intentional
56 means to adulterate milk would not have been unexpected.

57

58 It is estimated that the impact of food fraud on the food industry exceeds US\$40 – 50 billion
59 annually (PwC, 2016; Spielman, 2020). Food fraud is defined as intentional deception
60 associated with food for economic gain (Spink *et al.*, 2019). Numerous factors influence the
61 degree of vulnerability of a given food supply chain, food business or food product to food
62 fraud. These factors include *economic and supply chain factors* (e.g., factors that influence
63 the dynamics of supply and demand for a given food), *national factors* (e.g., governance
64 structures, preventive structures and control measures that are in place) and specific *incident*
65 *related factors* (e.g., the likelihood of fraud detection, the level of deterrence and the
66 opportunity to perpetrate the crime) (Manning and Soon, 2019; Marvin *et al.*, 2016). Van Ruth
67 *et al.*, (2017) identified three main elements to consider when assessing food fraud
68 vulnerability i.e., *opportunities* (i.e., technical opportunities and opportunities in time and
69 place), *motivations* (i.e., economic and cultural & behavioural drivers) and *control measures*
70 (e.g., technical and managerial controls). Although previous studies have examined the
71 causes or factors leading to the melamine milk scandal (Gossner *et al.*, 2009; Yang *et al.*,
72 2009; Xiu and Klein, 2010; Yang *et al.*, 2020), the complex inter-relationships between the
73 social, technical, human, management and operational interactions operating across a multi-
74 level socio-technical system were not explored. Furthermore, the systemic failures associated

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

80

81 AcciMap is a systems-based technique used to analyse accidents that occurred within
82 complex socio-technical systems. AcciMap is useful in capturing and showing the inter-
83 relationships of contributing factors from different parts of the systems (Branford, 2011). The
84 term *causal factors* is used by Branford instead of *contributing factors* as has been used in
85 this paper (Diaz De Oleo *et al.*, 2022). Both terminologies are used in the context of
86 recognising a necessary factor of influence in an incident, but not to imply causality (Branford
87 *et al.*, 2009). The AcciMap was derived from the Risk Management Framework that consists
88 of six systemic levels (Figure 1). Each level is connected by a flow of information in a top-
89 down, bottom-up or horizontal approach that represents decisions made by different entities
90 leading to direct or indirect consequences. The framework also captures the interactions within
91 and between the system levels (Diaz De Oleo *et al.*, 2022; Igene *et al.*, 2022; Rasmussen,
92 1997). AcciMap analysis has been used to consider road safety more generally (Hamim *et al.*
93 2020; Salmon *et al.*, 2020; Igene *et al.*, 2022); transportation (Kee *et al.*, 2017; Salmon *et al.*,
94 2013), recreational incidents (McLean *et al.*, 2021), child labour in supply chains (Nayak and
95 Manning, 2021) and more recently food safety incidents and foodborne disease outbreaks.
96 AcciMaps have been used to analyse food safety incidents such as Bovine Spongiform
97 Encephalopathy (BSE) (Cassano-Piche *et al.*, 2009), norovirus (Diaz De Oleo *et al.*, 2022),
98 and *Escherichia coli* O157 outbreaks (Nayak and Waterson, 2016). Although the melamine
99 milk scandal was not considered an 'accident' per se, the incident represented a system failure
100 that arose within a complex socio-technical system (Liu, 2009). Thus, using the AcciMap
101 approach could be useful to establish how multiple factors in all parts of the socio-technical
102 system may have contributed to the failure. The aim of this study was to analyse the melamine
103 milk scandal using the AcciMap approach to assess the contributory factors to the incident.
104 Three food fraud vulnerability factors have been considered (i.e., opportunities, motivation and
105 control measures).

106

107 Insert Figure 1 here

108

109 The structure of this paper is as follows: Section 1 provides an introduction and theoretical
110 grounding of the paper. Section 2 explains the methodology and Section 3 the results. Section
111 4 presents the discussion and Section 5 the conclusion.

112

113 **Methodology**

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

149

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

161

162 **Results**

163 In the preliminary steps, fifteen academic sources were identified as being able to provide
164 evidence for the creation of the Accimp analysis of the incident. From these sources, the time
165 frame of events was developed from 2007 to 2009 (Table 1). The time frame reflects the
166 stages of the scandal. Scandals are described by Smith *et al.* (2022) as “a key mechanism
167 used by media, pressure groups and social movements to demand inquiries and investigations
168 into alleged corruption, incompetence and immorality.” The scandal narrative led to individuals
169 boycotting the product,with socio-economic and socio-political aspects then leading to
170 unravelling and revelation (Smith *et al.*, 2022) of the melamine in milk incident in China. Table
171 1 has been presented using the Storm and Wagner model (2015) 5-step model: 1)
172 transgression; 2) publicly observed dislocation destabilising the social order; 3) resulting in a
173 moral (and judgemental) communication; 4) an increase in environmental pressure for
174 appropriate action; and 5) calls for an institutional solution. The transgression, adulteration of
175 the milk, was a crime perpetrated both against the government and the individual and the
176 associated shaming, moral reckoning and retribution led to the loss of the business through
177 ceasing of trading, and personal penalties for individuals involved.

178

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

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

191

192 Insert Table 1

193

194 Insert Figure 2

195

196 **External contributory factors**

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

214

215 **Government (national and local)**

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

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

231

232 **Organisation**

233 *Dairy Supply Chain*

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

253

254 *Sanlu Dairy Company*

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

260 Other contributing factors include the lack of communication from local government and Sanlu.
261 Sanlu requested the local authorities to coordinate the media to minimise the reporting about
262 the tainted milk and used its advertising contracts to influence media coverage (Economist,
263 2008; Veil and Yang, 2012; Ye and Pang, 2011). The power dynamics between Sanlu and
264 Fonterra, the New Zealand based partner, were imbalanced and Fonterra's warning of the
265 need to recall non-compliant milk products went unheeded (Keck, 2009; Pavlovich *et al.*,
266 2014).

267

268 **Physical individual events, process and conditions**

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

284

285 **Discussion**

286 This is the first study to utilise the AcciMap framework to analyse the contributory factors of a
287 global food fraud scandal. It is also the first study to examine the contributory factors in relation
288 to food fraud vulnerability factors within the context of a scandal narrative. Although Sanlu
289 was identified as the main culprit in the fraudulent incident, the sources highlight adulteration
290 was an endemic practice across the dairy supply chain in a context of poor economic returns
291 in a market with a rising consumer demand. The AcciMap analysis demonstrates the
292 complexity and interconnectedness of human and organisational factors in a system. It also
293 shows there were very few feedback mechanisms from the business up through the socio-
294 technical levels. One of the advantages of AcciMap is the graphical representation of the
295 incident which provides a 'big picture' analysis of the contributing factors and the interactions
296 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

334 the scandal narrative and how the incident was shaped by internal and cultural factors
335 especially the need to protect social stability and to 'save face' during the Beijing Olympics.
336 According to Ye and Pang (2011), Sanlu's management and leadership were influenced by
337 political and cultural factors. Sanlu placed an emphasis on using government relationships
338 and relied on local government to influence the media. Sanlu's chairperson, Tian Wenhua was
339 a local government official and thus, had close affiliation with local government (Li, 2015). The
340 imbalanced power dynamics between Sanlu and Fonterra created further cultural and
341 behavioural vulnerabilities. Although Fonterra owned 43% of the shares, Sanlu was the
342 dominant local partner in China (Pavlovich *et al.*, 2014). Scandal narratives will often include
343 scripted aspects of denial of wrongdoing, even whilst wrongdoing is still being perpetrated,
344 often dissociated from admitting responsibility (Smith *et al.* 2022). These external factors
345 created an environment where undisclosed fraud could occur despite the responsibilities of
346 government, dairy supply chain and the Sanlu company, among others to ensure safe food.
347 With twenty-two organisations being identified with melamine contaminated infant formula
348 products (Gossner *et al.*, 2009) this demonstrates the large scale of the perpetration of the
349 fraud across the industry. More widely melamine was found globally in powdered and liquid
350 milk, protein powders, yogurts, frozen desserts, cereal products, confectionary, cakes and
351 biscuits, and processed foodstuffs through the global trade in milk powder (Gossner *et al.*,
352 2019). The problem was exacerbated by the carryover from feed to animal related food
353 products. For a similar case where the incident had a complex impact see the systematic
354 analysis of the Fipronil incident (Nayak *et al.*, 2022).

355

356 As shown in Figure 2, motivations driven by economic, cultural and behavioural factors were
357 present at all sociotechnical levels. The lack of government and business strategies and
358 ethical culture resulted in denials and thus delaying product recall, but this is a common modus
359 operandi in some scandals (Smith *et al.*, 2022). The industry also had a culture where
360 adulteration and sub-standard milk products were widespread. The lack of technical and
361 managerial measures was evident across government, organisations and process levels.
362 Ineffective governance, overlapping government departments and lack of food safety and
363 quality control measures contributed to increased vulnerability. The food fraud vulnerability
364 factors identified in this study from analysis of the melamine milk scandal support Yang *et al.*'s
365 (2020) findings where farmers were identified as more vulnerable to food fraud due to their
366 rural location, lack of guardians and hurdles and thus the increased opportunities and
367 motivation to commit fraud and a lack of control measures to prevent their occurrence or
368 identify fraud where it had taken place. Some contributory failures were associated with two
369 or more vulnerable factors. For example, local protectionism was partly motivated by
370 economic, cultural and behavioural factors. Sanlu was a major source of tax revenue for local

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

376

377 **Limitations**

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

386

387 **Conclusion**

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

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

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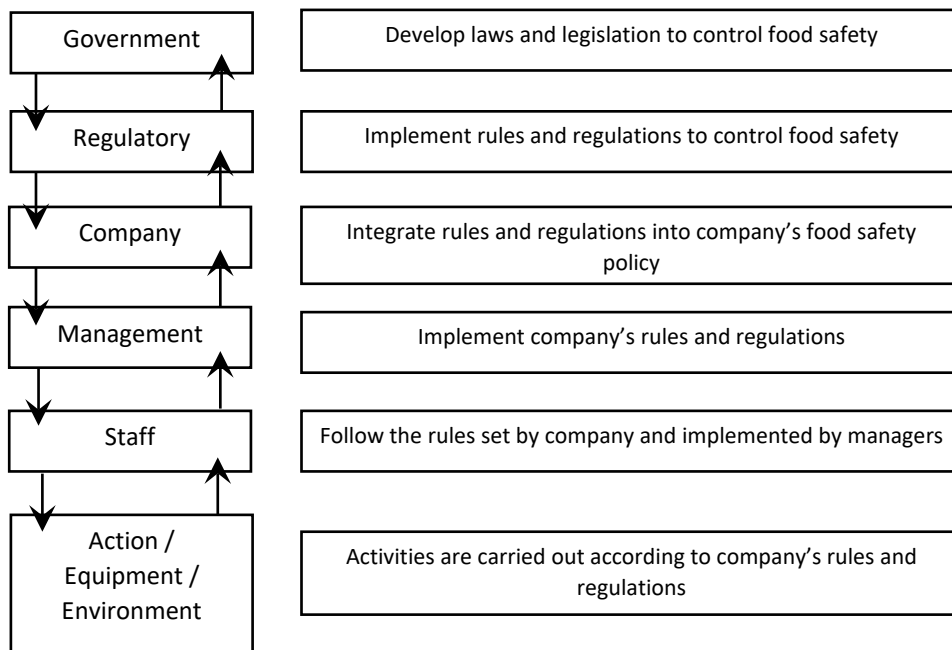


Figure 1. Systemic levels in AcciMap framework (Adapted from Diaz De Oleo et al., 2022; Igene et al., 2022; Rasmussen, 1997)

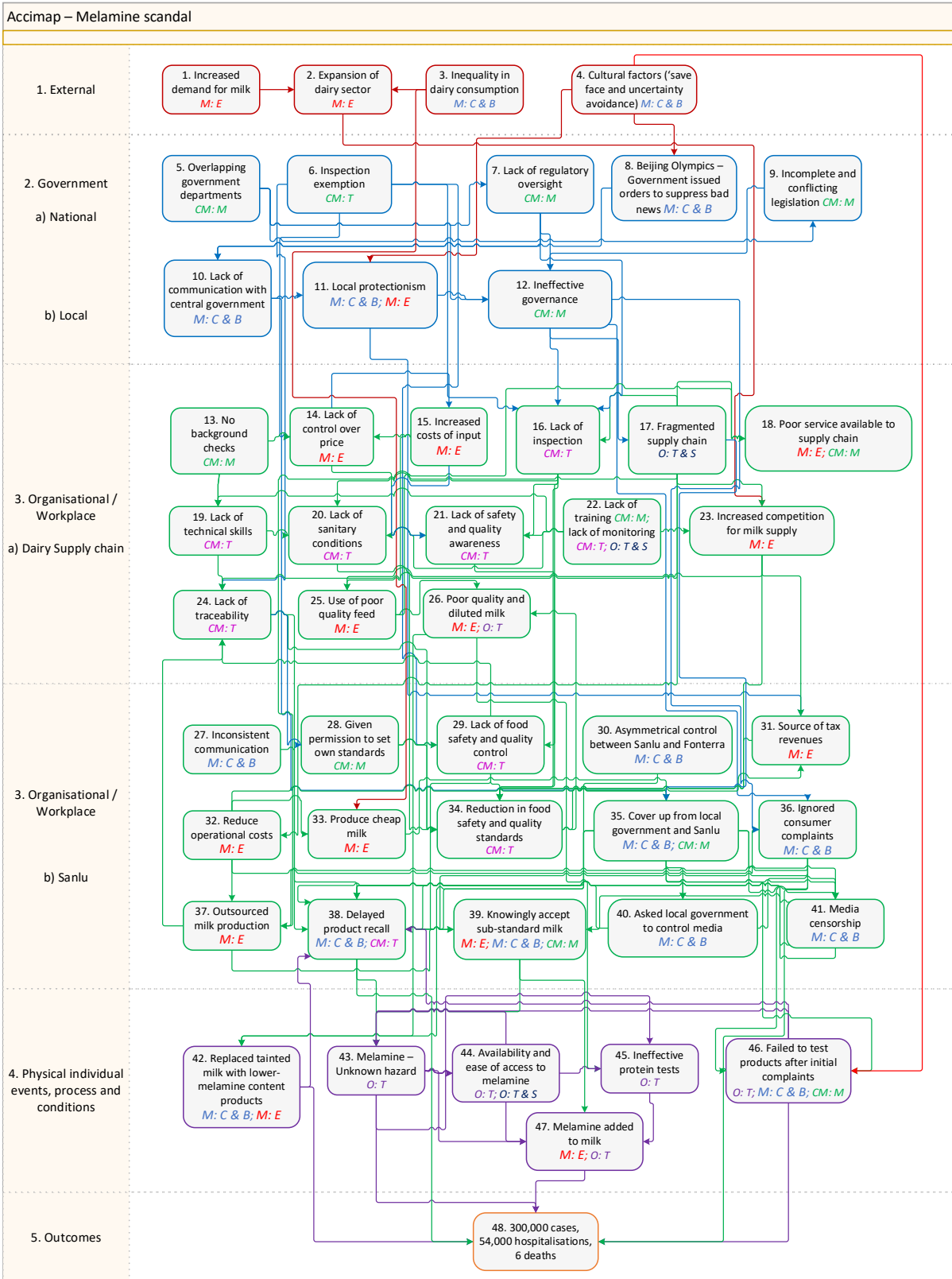


Figure 2. AcciMap analysis of the 2008 melamine milk scandal (Notes: *M:E* = Motivation: Economic; *M:C&B* = Motivation: Culture & Behaviour; *CM:M* = Control measures: Managerial; *CM:T* = Control Measures: Technical; *O:T* = Opportunities: Technical; *O:T&S* = Opportunities: Time & Space)

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 3 rd party milk supplier sentenced to death |
| 1 June 2009 | New food safety law adopted in China |