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Evaluation of food safety on traditional Chinese snacks based on system safety theory: The case study of Wuhan hot-dry noodles

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Abstract

Wuhan hot-dry noodles, as one of the traditional Chinese snacks, have been famous in most parts of China for nearly 100 years. Its characteristic, taste, and quick cooking method cater to the needs of many people. However, food safety has become an essential obstacle in developing Wuhan hot-dry noodles. The present work developed evaluation indicators, and selected an entropy method to analyse the food safety problems of Wuhan hot-dry noodles based on the system safety theory. Results showed that the score was 2.59 over 5.00, which meant the performance was below average. This could have been due to poor perception of employees on food safety, primary enterprise management, and less effective and authoritative standards within the industry. Based on the system theory, the present work suggested engineering, education, and enforcement, namely the "3E principle", to solve the above problems. The key to the "3E principle" is to focus on identifying, controlling, and evaluating hazards around the most critical issues, and solving them in order of importance and urgency. The "3E principle" also emphasises circular processing for better food safety.

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Introduction

The development of society and economy promotes the transformation of people's attention on food from "quantity" to "safety" (Hassaue and Roosen, 2020). In recent years, food safety incidents have emerged one after another, and every major food safety incident touched the nerves of the society. It can be seen that food safety is not only related to the health and safety of individuals, but also the development of society (Liu *et al.*, 2014). As one of the traditional Chinese snacks, Wuhan hot-dry noodles are closely related to the breakfast of Chinese people. The food safety of Wuhan hot-dry noodles is of great importance to personal health and social development.

Wuhan hot-dry noodles have a history of nearly 100 years. Together with sliced noodles from Shanxi Province, Zhajiang noodles from Beijing, Ramen noodles from Lanzhou, Dandan noodles from Sichuan, and Yifu noodles from Guangdong and Guangxi, Wuhan hot-dry noodles are known as "six famous noodles in China" (Zhang and Ma, 2016). The Wuhan hot-dry noodles are not only different from cold noodles, but also different from soup noodles. They have high quality, strong fragrance, chewy taste, and unique flavour. People in Wuhan pay more attention to breakfast than in other cities, and regard eating breakfast as the festival called "enjoying breakfast". Among their breakfast, the most famous early food is Wuhan hot-dry noodles. There has yet to be an official historical record about the emergence of Wuhan hot-dry noodles. Some stories describe its origin. One story is that in the early 1930s, a noodle merchant named Bao Li drained the noodles from the soup the night before. It happened to be stained with sesame oil, and an idea struck him to scour it out in boiling water the next day, and mix it with the seasonings of the noodle soup. The other is that Mingwei Cai, a pasta merchant in Wuhan, cooked the noodles 70% done the day before, next spread them on a chopping board, doused them with a small amount of sesame oil, and then cooled and dried them into semi-finished products. On the morning of the next day, he put the noodles in boiling water several times, and then put them in a bowl with seasoning

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(Wuhan Government, 2022). At present, the Wuhan hot-dry noodles have followed the footsteps of Wuhan people all over China. Their practices have become increasingly diverse, influenced by local tastes and *halal* customs. The Wuhan hot-dry noodles are becoming one of the most essentials for the Chinese people (Cai *et al.*, 2019), and also evolving into a symbol of China.

Based on data released by NetEase, an authoritative Chinese website, a survey was conducted on the sanitary conditions of 80 hot-dry noodle shops in Wuhan. Four hundred and sixteen samples of hot-dry noodles were tested, and the qualified rate of total bacteria was 63%, the qualified rate of coliform was 39.18%, the detection rate of intestinal toxic bacteria was 6.60%, and the detection rate of *Escherichia coli* in the ingredients was 63.33%. The total number of bacteria in unqualified samples exceeded the national health standard by 431 times on average, and the average coliform bacteria exceeded the standard by 230 times. The survey reported reasons for the food safety problems of Wuhan hot-dry noodles, including imperfect industry norms, high alkalinity of noodles, high bacterial loads in noodles left overnight, and insufficient hygiene knowledge of employees. These food safety issues not only prevented them from applying for the title of "China's National Intangible Cultural Heritage", and affected the spread of Wuhan hot-dry noodles around the world, but also easily led to significant food safety accidents (Li *et al.*, 2019). However, solving these problems cannot be isolated but distributed in the production system of Wuhan hot-dry noodles. Therefore, it is urgent to solve food safety problems from the system safety perspective.

System safety was first proposed in the 1950s as the application of system safety engineering and management methods (Johnson, 1973; Leveson, 2004). Following system safety, the system can achieve the best performance within the specified time and cost by identifying the source of danger, and taking control measures to minimise the risk (Johnson, 1973; Leveson, 2004). The background of system safety is related to the progress of science and technology. The progress of science and technology has caused the complexity of equipment, processes, and products. Minor errors may cause unexpected release of energy, and result in catastrophic accidents.

Based on the system safety theory's viewpoint, system hazards may cause safety accidents (Doménech *et al.*, 2009). Hazard is a potential unsafe factor that may lead to personal injury, property damage, or environmental pollution. Based on the two classification methods of hazards, the first type of hazard is mainly the energy or dangerous substances in the system that may be accidentally released, and the second type of hazard is mainly the unsafe factors that lead to the failure or destruction of energy-limiting measures. Different hazards may have different risks (Sui *et al.*, 2005). Risk refers to the possibility of safety accidents by specific hazards (Serra *et al.*, 1999). System safety theory considers that the first type of hazard is the root cause of safety accidents, and the second type is the direct cause (Aly *et al.*, 2021). Generally speaking, the occurrence of a safety accident results from the complex correlation and joint action of many human errors and object faults. Therefore, when preventing safety accidents, appropriate measures must be taken to clarify the relationship between factors rather than control each factor in isolation (Shi *et al.*, 2022). System safety theory believes that the focus of safety management is on the effective control of factors. To achieve effective control between factors, the most critical problems must be solved first, followed by the other issues. This order is to realise the linkage and optimisation of all factors of safety management. Since all hazards cannot be eliminated, there is no absolute safety. Therefore, the goal of system safety is not zero accidents but the best safety degree.

From the perspective of system safety theory, the food safety of Wuhan hot-dry noodles is the accidental release of hazards. These hazards include chemical energy produced by germs, mechanical energy produced by noodle-making machines, electrical energy within the production process, and heat energy from the power of boiling water. These energies have risks, such as chronic poisoning, cancers, and other diseases caused by chemical energy (Uçar *et al.*, 2016). These risks directly affect food quality, and result in many food safety issues. Based on the classification of hazards, we consider that the first type of hazards includes residual pesticides, herbicides, antioxidants, detergents, formaldehyde, and borax (Alaboudi, 2022), as well as smoke, steam, boiling water, and workshops for noodle making. The second type of hazards includes irregular disinfection, untimely disposal of chemical residues, broken wires, and pressure relief of pressure vessels. During the production of Wuhan hot-dry noodles, the accidental release of hazards is caused by various factors. These factors include unsafe behaviour of people, and unsafe state of things, such as employee behaviour and management system (Shenashen *et al.*, 2022). It can be seen that the system safety theory has important guiding significance to solve the food safety problems of Wuhan hot-dry noodles.

Food safety evaluation is mainly a scientific estimation of the probability and uncertainty of potential biological, chemical, or physical hazards (Chen *et al.*, 2021). Scholars' research on Wuhan hot-dry noodles focuses more on technology, history, culture, and art, and less on its food safety evaluation. However, Wuhan hot-dry noodles face tricky and difficult food safety problems, so it is urgent to conduct relevant research. Based on the system safety theory, the present work conducted a food safety evaluation of Wuhan hot-dry noodles using the entropy method (Wang and Guo, 2007; Yang, 2020). The assessment aimed to comprehensively analyse the current food safety situation, and effectually find appropriate solutions.

Materials and methods

Data sources

The data sources included primary and secondary data. The primary data came from the scores of experts in food nutrition, hygiene, and safety supervision. The secondary data came from the Wuhan Food and Drug Administration, the Bureau of Statistics, the Government Statistical Bulletin, and others.

Research sample

To carry out the food safety evaluation of Wuhan hot-dry noodles, top 50 hot-dry noodles shops in Wuhan were randomly selected based on review agencies such as Dianping.com, Koubei.com, Elema, and Meituan.

Evaluation indicators

Based on the system safety theory, China's National Food Safety Standards (GB), evaluation standards of related industries, and relevant research results (Zhao *et al.*, 2012; Moy, 2014; Hartmann *et al.*, 2018), a relevant indicator system was constructed (Table 1).

Evaluation method

Each indicator was divided into five grades; I, II, III, IV, and V, and assigned 1, 2, 3, 4, and 5 points, respectively. The higher the score, the higher the grade, and the better the performance. Then, we invited ten experts to judge and score the indicators. The food safety indicators included five dimensions and 18 specific evaluation indicators. However, the influence of each dimension on the food safety of Wuhan hot-dry noodles was not the same. To improve the scientific and accuracy of the evaluation, it was necessary to determine the weight of each indicator. The entropy value method (EWM) was then used to calculate the weight of each indicator. Common methods to determine the weight of indicators include the Analytic Hierarchy Process (AHP) and weighted average method, but the subjectivity is too strong. The EWM relies on the original data to calculate the weight of indicators. Its main principle is to measure the amount of information based on information entropy, which is more objective (Wang and Guo, 2007; Yang, 2020). The calculation of the optimised EWM was as follows:

First, original data were collected to construct matrix C.

$$C = \begin{bmatrix} c11 & c12 & \cdots & c1n \\ c21 & c22 & \cdots & c2n \\ \cdots & \cdots & \cdots & \cdots \\ cn1 & cn2 & \cdots & cnn \end{bmatrix} \quad \text{(Eq. 1)}$$

Second, the data were standardised, and the information entropy R_i was calculated using the entropy formula.

$$R_i = -k\sum_{i=1}^{n} P\ln(P) \quad \text{(Eq. 2)}$$

$K = \frac{1}{ln(n)} > 0$, and P was the weight after standardisation.

Third, the weight coefficient g_i was calculated using the information entropy R_i.

$$g_i = \frac{1-R_i}{\sum_{i=1}^{n}(1-R_i)} \quad \text{(Eq. 3)}$$

Finally, the weight W was calculated based on g_i.

$$W = (g_1, g_2, g_3 \ldots g_n) \quad \text{(Eq. 4)}$$

Table 1. Evaluation indicators of food safety on Wuhan hot-dry noodles.

First-level indicator	Second-level indicator	Third-level indicator	Explanation
Food safety evaluation indicators of Wuhan hot-dry noodles	Employee factors S1	Skill S11	Skills in rolling, cooling, blanching, and making ingredients, *etc*.
		Morality S12	Job ethics
		Perception S13	Awareness and attitude towards food safety
	Material factors S2	Noodle S21	Moisture < 65%, alkalinity < 8%, others must follow GB 1355
		Water S22	No odour, 6.5 < PH < 8.5, $CaCO_3$ < 450 mg/L, others must follow GB 5749
		Ingredient S23	Edible alkali must follow GB 2760, edible salt GB5749, and other onions, garlic, *etc*. GB/T31121 standard
	Hygiene factors S3	Workshop S31	Adequate lighting, ventilation, smoke exhaust devices, effective fly-proof, dust-proof, rodent-proof facilities, *etc*.
		Storage S32	Food on shelves (at least 5 cm above the floor and 5 cm from the wall), dry floor, no odour, *etc*.
		Transportation S33	Container truck or tarpaulin in good condition, no peculiar smell such as oil, chemical, musty, *etc*.
		Appearance S34	Wearing work clothes, not painting nails, and sneezing on food
		Garbage S35	Waste containers with lids, solid and impermeable containers, garbage sorting
	Warranty factors S4	Production S41	Strict production node and time specifications
		Traceability S42	Traceability records of the relevant products
		Certification S43	OHSAS18001:2007
	Management factors S5	Organisation S51	Business model
		Produce S52	Regulation and personnel in the production process
		Finance S53	Regulation and personnel in finance
		Cooperation S54	Regulation and personnel in cooperation

In the calculation process, the score of third-level indicators was obtained by the arithmetic average method. Before obtaining the score of second-level indicators, we used EWM to calculate the weight of third-level indicators related to second-level indicators. Then, a matrix calculation was made with the weight of the third-level indicators to form the score of second-level indicators. In the same way, we obtained the weight of second-level indicators related to first-level indicators. Then, the score of the first-level indicators was calculated based on the second-level indicators and the weight.

Results and discussion

From the first-level indicators' perspective, the first-level indicators' score was 2.59, a medium score. This reflected that there were still many improvements needed for the food safety of Wuhan hot-dry noodles. The performance was far from the food safety of well-known noodles, such as curry noodles worldwide.

Dilemma between poor perception of food safety and skilled cook experience among employees

Among third-level indicators (Figure 1), the score of perception (S13) was 2.1, the lowest. This represents their inner attitude (Morya *et al.*, 2020). From the score, it can be seen that employees' attention to the food safety of Wuhan hot-dry noodles had to be improved. From investigation, we found that most employees were 40 - 60 years old, most of whom were women around 55. They have relatively skilled cooking experience, able to expertly complete the rolling and boiling of noodles, and even quickly add more than ten ingredients. However, their understanding of the food safety of Wuhan hot-dry noodles could be more evasive. Some employees consider food safety issues only related to diners' tastes. Therefore, insufficient attention was paid to intestinal diseases such as diarrhoea and dysentery caused by foodborne pathogens (Ahmad *et al.*, 2018). There was also a lack of long-term cognition of the crisis of corporate trust and the sustainable development of products caused by food safety (Doménech *et al.*, 2010).

For instance, based on the results of ten hot-dry noodles restaurants randomly sampled by the food supervision department, the lowest pH was 8.3, half were over 9.0, and the highest was 9.2. In general, pH is a number that measures the acidity and alkalinity of a substance, and the pH of food suitable for the human body should be around 7.0. Based on this calculation, the alkalinity of this batch of hot-dry noodles was 19 - 31% higher than the normal pH. Every increase in the number by one means the alkalinity increases by ten times. The pH of Wuhan hot-dry noodles reaches 9.2, meaning the alkalinity is more than 100 times that of ordinary pure water. The misuse of the food additive noodle alkali causes the problem of noodles being too alkaline. To prevent the noodles from going bad or make the noodles firmer, some employees use excessive amounts of baking soda (sodium bicarbonate). Baking soda is non-toxic but strongly alkaline. In a survey of religious groups, we also found that some employees did not pay more attention to the dietary safety of Muslim groups. The lack of attention may cause harm to these groups, reduce the purchase desire of such people, and lose the opportunity to develop the potential of the *halal* market (Pradana *et al.*, 2020).

Primary enterprise management and lack of a standardised storage system

In further interview, we found that most Wuhan hot-dry noodles workers were self-employed. The proportion of formal enterprise management was relatively low. The management method of self-employed was still mainly based on personal experience, and lacked a relatively sustainable management system. The management method was contrary to the principle of step-by-step and node-by-node advocated by the system safety principle. The organisation's score (S51) (Figure 1) was only 2.3, further confirming the problem. All of this led to unsafe behaviours of people or unsafe conditions of things, thus generating hazards and further producing risks. For example, due to the lack of strict operating procedures and management systems, novice employees could not achieve the purpose of disinfection when processing raw noodles (half-cooked) under low water temperatures and short cooking time. Unclean ingredients and tableware are easy to cause secondary contamination. In the follow-up investigation, we found that storing the raw materials of Wuhan hot-dry noodles was highly unsafe. Some employees even dried raw noodles on the hall floor with heavy dust, or places where mice and beetles could easily reach. These unsanitary practices have also become the annual hot list news. The storage (S32) (Figure 1) also performed poorly in food safety, scoring only 2.2. The low score further

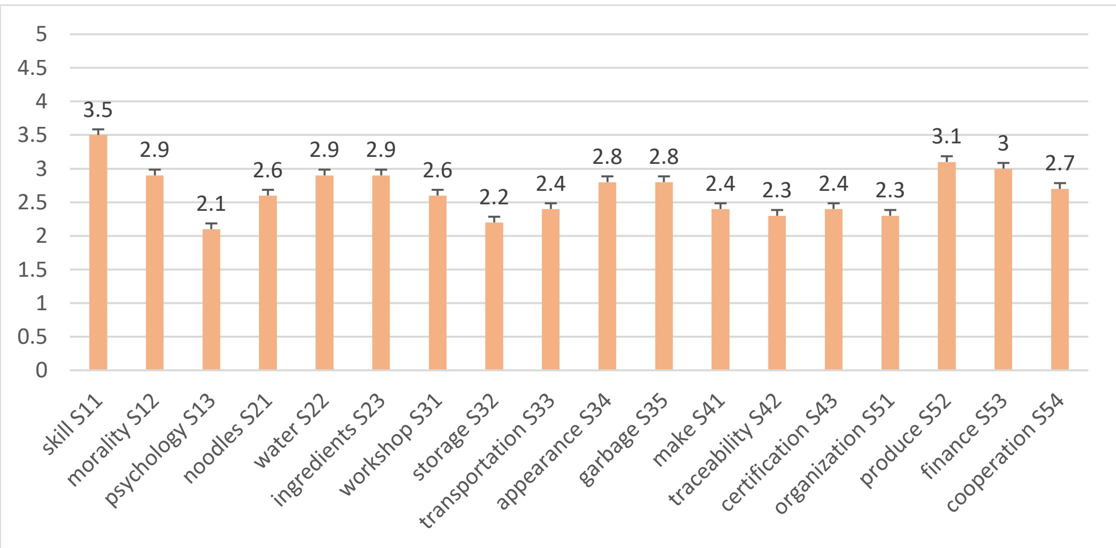

Figure 1. Level of third-level indicators.

confirmed the storage system's problems. The main reason behind the problem was that there had to be a sustainable restriction of enterprise management systems rather than relying mainly on personal experience and emotions. In the interview, some employees and employers thought the relationship between Wuhan hot-dry noodle production and major food safety accidents must be improved. It was believed that the occurrence of accidents was a small probability, and one or more times cannot cause significant harm (da Cunha *et al.*, 2015). So, they further believed that there was no need to establish a sustainable management system, and carry out standardised enterprise management.

Imperfect warranty system resulting in lots of hazards

Among the second-level indicators (Figure 2), the warranty factors (S4) yielded the lowest score of 2.37. The warranty factors are the standard and regulation of food safety (Liu *et al.*, 2021). The lower score reflected that the current Wuhan hot-dry noodles association still needed to form a unified standard and an effective industry norm. The poor production (S41) and certification (S43) (Figure 1) led to the diverse production paradigms of Wuhan hot-dry noodles. The lack of traceability (S42) (Figure 1) might bring management difficulties to the food management department (Jansomboon *et al.*, 2018). As a result, there were many first and second types of hazards. For instance, the score of hygiene (S3) was 2.52, which was closely related to the warranty factors. Since there was no professional standard, hygiene was only referred to other standards in general. However, other standards may not be suitable for Wuhan hot-dry noodles. The lack of professional standards resulted in hygienic problems such as mould, dirty water, and odour, and further causes excess pathogenic flora such as aflatoxin, *Salmonella*, *Shigella*, *Staphylococcus*, and *Streptococcus* (Walsh and Leva, 2019; Altomare *et al.*, 2021).

Another example was that the raw flour of Wuhan hot-dry noodles was mainly soft white wheat. The processing quality becomes inauthentic once it is replaced with hard white wheat or others. Such behaviour results in neither whiteness nor gluten in the product. Due to the lack of an industry restraint system for raw flour, the raw flour of Wuhan hot-dry Noodles often had inconsistent standards. These unconventional standards resulted in heterogeneous tastes of Wuhan hot-dry noodles in different stores and regions. In addition, the low score of warranty factors (S4) also reflected the current difficulties of Wuhan hot-dry noodles going global. Because there was no corresponding standard, it became difficult for some countries to acquire the skills of Wuhan hot-dry noodles. With the help of investigation and analysis, we found that the warranty factors (S4) could be better because there were too many restaurant or food associations related to Wuhan hot-dry noodles. However, these associations had differing views on practical and authoritative standards.

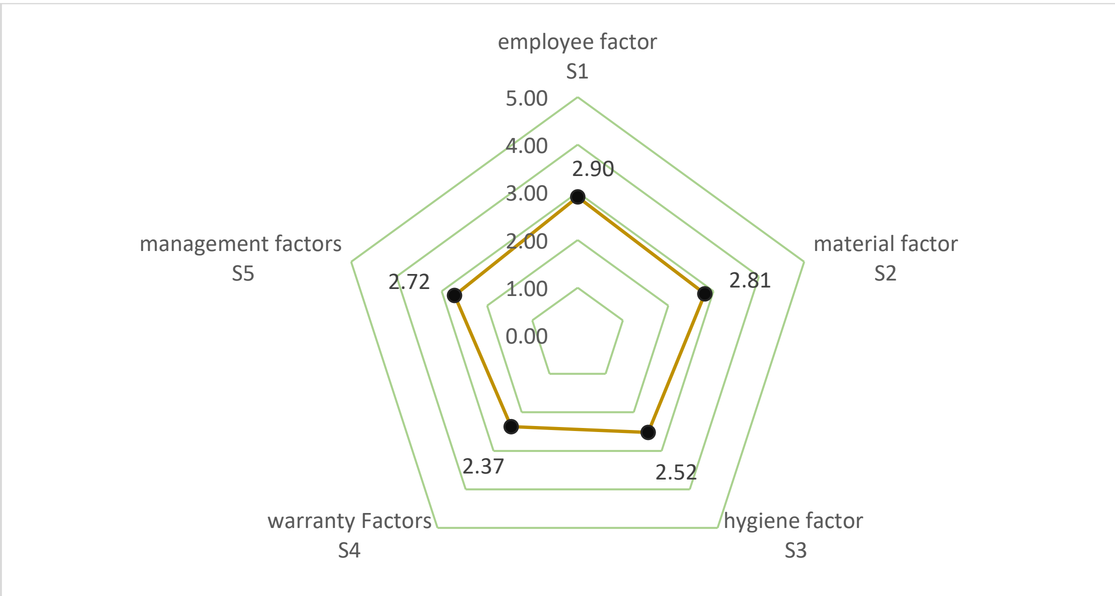

Figure 2. Level of second-level indicators.

Suggestions on food safety of Wuhan hot-dry noodles based on system safety theory

Based on the system theory, the present work suggested the "3E principle" (engineering, education, and enforcement). Engineering means using engineering technology to eliminate the unsafe state of things. The main methods include controlling the first type of hazards, such as bacteria generated by food spoilage (Bleotu *et al.*, 2018), and preventing the second type of hazards, such as operational errors, damaged wires, and vessel pressure relief. Education means using various forms of education to improve the perception of food safety. The main methods include establishing the idea of "safety-first" among employees, and mastering the necessary knowledge and functions for safe production, especially providing Muslim groups with safe food. Enforcement means that industry associations, enterprises, and individuals should establish systematic regulations to restrain unsafe behaviour (Kurbanoglu *et al.*, 2018), and gradually explore a mature and replicable enterprise management model. The key to the "3E principle" is to focus on identifying, controlling, and evaluating hazards around the most critical problems (Koutsoumanis and Aspridou, 2016). Then, these critical problems should be solved in order of importance and urgency (Chen *et al.*, 2018). Since hazards cannot be eradicated, there is always food safety risk. The long-term existence of food safety risks means absolute safety does not exist. Therefore, after achieving the phased goal of food safety, we should continue to carry out food safety management by the "3E principle". The purpose of continued implementation is to further remove relevant hazards, and promote the development of a higher food safety state. In addition, it is worth noting that accomplishing the identification, control, and evaluation of hazards also requires the support of high technology. With the development of current popular digital technologies, it has become a trend to adopt technologies such as block chain and big data in food safety (Hong *et al.*, 2021). These digital technologies are crucial for identifying some chemical toxic substances and controlling the implementation process. At the same time, dealing with food safety will inevitably trigger the interests of relevant people, so the implementation of norms and anti-corruption are also crucial.

Conclusion

The present work evaluated the food safety of Wuhan hot-dry noodles, and found that the score was 2.59 over 5.00. This showed that the performance could be improved, and there were still many problems in food safety for Wuhan hot-dry noodles. Among them, the score of perception (S13), organisation (S51), and warranty factors (S4) were 2.1, 2.3, and 2.37, respectively. This indicated the problems of poor perception of food safety, primary enterprise management, and lack of warranty system. The main reasons for these problems included insufficient attention to safety, and less effective and authoritative standards within the industry. It is also worth noting that focusing on Wuhan hot-dry noodles' food safety and consumption needs within the *halal* group needs to be optimised. Following the system safety theory, the present work suggested the "3E" principle. This principle focuses on solving the food safety problems of Wuhan hot-dry noodles by identifying, controlling, and evaluating hazards around the most critical problems. However, it should be noted that food safety problems cannot be avoided or eliminated. We should constantly strive to reach the highest state of food safety. As one of the traditional Chinese snacks, the food safety problems of Wuhan hot-dry noodles should be addressed and solved. Addressing and solving the food safety of Wuhan hot-dry noodles is not only helpful for personal health, but also significant for Wuhan hot-dry noodles to apply for "Intangible Cultural Heritage", as well as beneficial for creating sustainable cultural symbols.

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