

# Analysis of Causes of Fatal Accidents in Recreational Diving Based on the Reason Model and the Delphi Method

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**ABSTRACT.** *The Delphi method was used to investigate the causes of fatal accidents in recreational diving by three rounds of questionnaire surveys on six Chinese experts in recreational diving based on the four factors - unsafe acts that cause accident, preconditions for unsafe acts, unsafe supervision and organizational influences - in the REASON model in psychology. A retroactive analysis was carried out to investigate the causes of accidents, and corresponding suggestions were proposed. The research found that unsafe acts, including technical fault and intentional violation, are the direct causes of accidents. Therefore, it is necessary to develop a qualification system for recreational diving in China. In terms of preconditions for unsafe acts, though the objective factors are uncontrollable, news media and print media can be united to create a good environment to improve people's safety awareness. Unsafe supervision refers to inadequate supervision, failure in early-warning of known hazards and poor review of diving licenses by clubs; to address these problems, clubs should improve personnel management and the club registration association should take full charge in coordination and control. Organizational influences in recreational diving mainly refer to the absence of rules and regulations, failure of the top-level institutions in China to perform their duties, and the lack of management, so it is advisable that the top-level institutions of the recreational diving industry perform their duties and take better management measures to improve the safety management system and safety regulations for recreational diving as soon as possible.*

**KEYWORDS:** *Reason model, Delphi method, Recreational diving, Fatal accident, Cause analysis*

## 1. Introduction

Recreational diving is a recreational underwater or water sport (e.g., snorkeling) realized with diving equipment and an all-in-one sport that integrates sports, sightseeing, entertainment and tourism[1]. Snorkeling, scuba diving, recreational hose-fed diving and diving with minor submersibles in recreational diving allow the enjoyment of underwater creatures, underwater exploration and underwater shooting.

Recreational diving benefits the divers both physically and mentally, allow them to relax, socialize and learn more about the ocean. In these years, this sport has gained popularity in China and as PADI, the world's largest diving association, reveals, Chinese OW (open water diver) certificate owners have increased by about 50% per year[2]. As one of the most popular sports among tourists, recreational diving produces huge economic benefits. In 2016, Wuzhizhou Coral Island Tourist Destination in Sanya City received 2.6 million tourists and recorded a revenue of 960 million yuan, of which 40% came from recreational diving[3].

However, frequent reports of fatal accidents in recreational diving undermines the development of this industry. Absence of explanation of the causes of such accidents by organizations and institutions definitely arouses misunderstanding and fear among the public, resulting in fewer recreational divers and consumption in related industries, and fewer economic benefits from the training market and the tourism industry. To enhance the healthy development of the recreational diving industry, the research team interviewed six authoritative Chinese experts, including international referees and national instructors under the guidance of the Diving Division of Zhanjiang Diving School of General Administration of Sport of China. Thereafter, the research team carried out REASON-model-based factor screening with the Delphi method, so as to analyze the cause of a typical fatal accident in recreational diving in China and make advice.

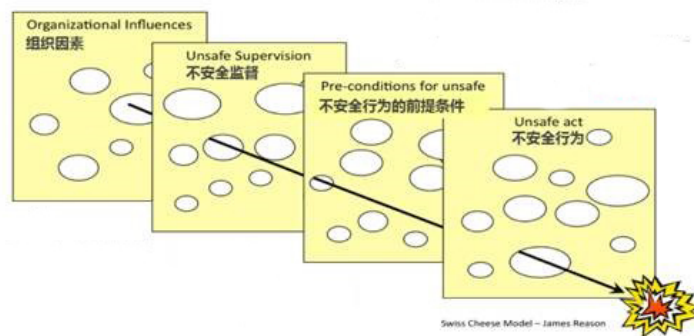
## 2. Description of the Fatal Incident in Recreational Diving

At around 18:00, May 2, 2019, Wu (male, 40 years old) and five of his friends (totaling 4 males and 2 females) rent equipment from Aishang Diving Club in Dapeng New Area, Zhenzhen City, for night diving. The club leased 6 air tanks, 2 BCDs and regulators and 6 weight balancers to them. After that, the club required them to fill out the PADI *Standard Safe Diving Practices Statement of Understand* and *Medical Statement* and recorded their diving licenses (including the electronic copies or ID photos). At around 21:00 that day, Wu's friends found something wrong with Wu, and called the ambulance and the police. Wu was identified to have no vital signs when the ambulance arrived. Wu died of drowning, as preliminarily judged by the forensic expert, though the final cause of death was still to be confirmed by the police after further investigation.

Shenzhen Dapeng New Area Dive Association led the investigation of the accident. The direct cause of the fatal accident in recreational diving was unsafe acts, according to the investigation report. Wu and his five friends were all PADI divers. Five of them, including Wu, were PADI's AOW divers (advanced open water divers) and one was OW diver (open water diver not qualified for night diving). Aishang Diving Club that leased the diving equipment was neither registered with Dapeng New Area Dive Association nor in any diving systems (e.g., CMAS, PADI, NUAI or SSI). Its registered scope of business covered diving training, diving services and diving tourism, and its legal person was the only PADI diving coach in the club.

### 3. Basic Structure and Principles of the Reason Model

Prof. James Reason from the University of Manchester, the U.K., put forward the REASON model, also known as the “Swiss Cheese” model, in his famous psychological monograph, *Human Error*, in 1990, based on previous studies. It is a model that analyzes causes of accidents. The analysis with this model reveals systematically that the occurrence of safety accidents relates not only to the (currently invalid) acts of actors directly concerned in the accidents, but also to the (potentially invalid) activities and persons at other levels far away from accidents. According to the REASON model[4], organizational influences, unsafe supervision, preconditions for unsafe acts and unsafe acts are the four factors in an accident of an organization. Defense layers for the four factors are like four slices of cheese, and flaws in them resemble holes in the cheese slices, which are constantly changing with time, space and position. Holes in different slices of cheese may overlap with each other at a certain moment, indicating that a fatal accident is caused not by a single factor, but by multiple factors that cut through a dangerous pathway with overlapped holes. Such cutting through the defense layers acts on the event and leads to an accident.



组织因素	Organizational influences
不安全监督	Unsafe supervision
不安全行为的前提条件	Preconditions for unsafe acts
不安全行为	Unsafe acts

Fig.1 Reason Model

### 4. Four Factors in Screening with the Delphi Method

The Delphi method collects the estimates or projections of individual experts and yields a quantified result with the mean or median. By collecting and analyzing the feedback on the three rounds of questionnaire surveys on six Chinese authoritative experts in recreational diving, the research team sought the main causes of fatal accidents among the four factors of the REASON theory.

**5. Retroactive Analysis of Accident Causes Based on the Four Factors in the Reason Model**

Through retroactive analysis of the accident causes based on the REASON model, holes in the four slices of cheese were identified through the vulnerabilities observed from the end of the accident, i.e. to analyze the main factors on the four defense layers with hindsight[5].

**5.1 Unsafe Acts**

*Table 1 Feedback from Experts on Unsafe Acts*

E N	First judgment					Second judgment					Third judgment				
	T e c h n i c a l f a u l t	D e c i s i o n f a u l t	P e r c e p t i o n f a u l t	I n t e r n a l v i o l a t i o n	U n i n t e r n a l v i o l a t i o n	T e c h n i c a l f a u l t	D e c i s i o n f a u l t	P e r c e p t i o n f a u l t	I n t e r n a l v i o l a t i o n	U n i n t e r n a l v i o l a t i o n	T e c h n i c a l f a u l t	D e c i s i o n f a u l t	P e r c e p t i o n f a u l t	I n t e r n a l v i o l a t i o n	U n i n t e r n a l v i o l a t i o n
1	1	1	0	1	1	1	1	0	1	0	1	1	0	0	0
2	1	1	1	0	1	1	1	1	0	1	1	1	0	1	0
3	1	0	1	1	0	1	0	1	1	0	1	0	0	1	0
4	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1
5	0	1	1	1	0	0	1	1	1	0	1	1	0	1	0
6	1	0	0	0	0	1	1	1	0	0	1	0	0	0	0
N	0.83	0.67	0.67	0.67	0.5	0.83	0.83	0.83	0.67	0.33	0.83	0.67	0.17	0.67	0.

Unsafe acts include faults and violations. As Table 1 shows, known faults in recreational diving are divided by type into technical fault (83%), decision fault (67%) and perception fault (17%) in recreational diving based on the Delphi method. Technical faults are unsafe acts resulting from failure in mastering necessary skills, including swimming skills, mask dewatering, neutral buoyancy, backhand air tank unscrewing and other technical movements. Technical faults also encompass skills that can only become automated actions through repeated practices that are required to be learned during the training for diving licenses of different grades. Decision faults, in this case, refer to the divers' failure to judge accurately and objectively the diving environment. As for the abovementioned case of accident, it is evident that the weather and time at the time of diving (with visibility less than 1 meter and wave height of about 1 meter, as well as showers, and at 21:00) were totally unsuitable for night diving. However, due to lack of experience, decision faults led to the fatal

accident. Perception faults refer to the faults resulting from the difference between one's perception and the actual situation. For example, when diving 30 meters under water, a diver is prone to nitrogen narcosis, which makes people feel like drunk and causes dizziness and slow loss of judgment. This is similar to the loss of control in drunk driving.

Violations, including intentional violations (67%) and unintentional violations (17%), refer to all violations of safety regulations by divers. By intentional violations, a diver continues ignoring safety regulations and explicit prohibitions since he/she always believes that everything is under control. Wu and his five friends were PAID divers, and their violations of basic PADI safety regulations were the direct cause of the accident. Their violations included: 1) They dived forward even when they knew one of them was not qualified for night diving; 2) They knew little about the waters where they dived, had no diving coaches or instructors who knew about the water accompanying them, and had no diving plans or emergency responses; 3) They didn't insure for diving, so they had no remedies after the accident. Intentional violations are irrational acts by persons concerned due to unawareness of rules and regulations or misunderstanding of safety regulations.

#### ***5.1.1 Establishing and Implementing a Qualification System for Recreational Diving in China***

China Water Ski, Underwater & Powerboat Federation should, step by step, strictly standardize and systematically carry out reviews on recreational diving qualifications as directed and supported by Water Sports Management Center of General Administration of Sport of China. Diving licenses in China mainly include the following. First, technical diving licenses for coaches and athletes of recreational diving. The approval of these licenses is organized by China Water Ski, Underwater & Powerboat Federation, who guides local sports authorities to rate coaches and athletes of all grades. Second, recreational diving licenses for the public. The evaluation of this kind of license mainly refers to technical movement regulations and standards of different grades stipulated in the *Textbook for Recreational Diving* (to be compiled). Recreational diving practitioners (instructors and coaches) should give lessons in accordance with technical movement regulations and standards of different grades stipulated in the *Textbook for Recreational Diving*, and offer and manage different grades of training as per unified appraisal standards. Diving certificates of each grade should be issued according to the *Standard Safe Diving Practices Statement of Understand* when corresponding preconditions are met. On the one hand, a coach responsible for issuing the certificates of a grade is required to strictly implement the appraisal standards, and should not issue one to a diver failing to meet technical diving requirements of the grade. All qualification certificates should bear the legal signature of the coach. On the other hand, divers with certificates of a specific grade are not allowed to dive if they are in violation of their diving qualifications of the said grade.

#### ***5.2 Preconditions for Unsafe Acts***

Table 2 Feedback from Experts on Preconditions for Unsafe Acts

Expert No.	First judgment				Second judgment				Third judgment			
	Personal status	Environmental factors	Equipment	Others	Personal status	Environmental factors	Equipment	Others	Personal status	Environmental factors	Equipment	Others
1	0	1	0	1	0	1	0	0	1	1	0	0
2	1	1	1	0	1	1	1	0	1	1	0	0
3	1	0	1	1	1	0	1	1	1	1	0	1
4	1	1	1	1	1	1	1	1	1	1	0	1
5	0	0	1	0	0	1	1	0	1	1	0	0
6	1	1	0	0	1	1	0	0	1	0	0	0
Mean	0.67	0.67	0.67	0.50	0.67	0.83	0.67	0.33	1.00	0.83	0.00	0.33

As shown in Table 2, unsafe acts occur for reasons, usually under subjective and objective conditions. As shown in the above table, subjective and objective conditions are mainly personal status of divers (100%), environmental factors (83%) and equipment (0%) when preconditions for unsafe acts were screened with the Delphi method. In the abovementioned case of accident, the divers dived at 21:00 with poor visibility amid heavy waves and showers, all of which were preconditions for unsafe acts in the accident. Personal physical status of divers refers to their mental and physiological status. This includes the physical examination report at the time of attending the diving license examination, physical discomfort - such as dizziness and cold - at the time of diving, and mental status when facing an unfamiliar diving environment. All of these factors would be hidden safety risks.

Generally, the three safety defenses for diving are skills, training and regulations. Defenses are often the last safety guard against hidden hazards and human mistakes, so the most common way to reduce safety risks is to strengthen existing defenses or to develop new ones<sup>[6]</sup>. In the May 23 accident, there were two defense defects. Technically, one among the six divers was not qualified for night diving, and all six of them were unfamiliar with the waters where they dived. By rules, the six divers failed to comply with the basic PADI diving requirements to have themselves accompanied by diving coaches or instructors familiar with the waters during the whole process when they knew little about the waters. Such hidden hazards broke the systematic defenses, suggesting that the persons concerned in the accident had unintentionally departed from the conditions for safe diving.

### ***5.2.1 Encouraging Joint Publicity and Education by News Media and Print Media to Improve Safety Awareness of the Public***

Development of all industries benefits from the publicity by the media. Creating

a sound safety environment for divers and recreational diving practitioners requires the joint efforts of news media and print media in communication and publicity, despite the uncontrollable environments among the preconditions for unsafe acts. A sound environment for safety allows all practitioners in the industry to better judge the personal status, environmental factors and equipment of every diver. However, China Water Ski, Underwater & Powerboat Federation offers outdated information on its official website, and fails to disclose adequate details. The official website is the largest open platform for the public to learn about water sports, so we urgently need prompt solutions to improve operation of the website. In this regard, redwhaledc.com may be a good example. Sports event operators and domestic cultural communication companies should join hands to build reputation of China Water Ski, Underwater & Powerboat Federation. News media should make diving precautions well known to the public so that fatal accidents would not drive away those who are fond of recreational diving.

**5.3 Unsafe Supervision**

*Table 3 Feedback from Experts on Unsafe Supervision*

Expert No.	First judgment				Second judgment				Third judgment			
	Club's inadequate supervision	Club's failure to warn known hazards	Club's failure to strictly review diving licenses	Others	Club's inadequate supervision	Club's failure to warn known hazards	Club's failure to strictly review diving licenses	Others	Club's inadequate supervision	Club's failure to warn known hazards	Club's failure to strictly review diving licenses	Others
1	1	1	1	1	1	1	0	0	1	1	0	0
2	1	1	1	1	1	1	1	1	1	1	1	0
3	0	0	1	0	1	0	1	0	1	0	1	0
4	0	1	1	1	0	1	1	1	0	1	1	1
5	0	1	1	0	0	1	1	0	1	1	1	0
6	1	0	0	0	1	1	0	0	1	1	1	0
Mean	0.50	0.67	0.83	0.50	0.67	0.83	0.67	0.33	0.83	0.83	0.83	0.17

As Table 3 shows, unsafe supervision includes club's inadequate supervision

(83%), club's failure to warn known hazards (83%) and club's failure to strictly review diving licenses (83%) when unsafe supervision factors are screened with the Delphi method. Practices proved that well-trained and adequately-supervising operators effectively reduce mistakes and improve work efficiency[7]. Club employees leased the diving equipment though they knew about the bad weather, unqualified diver and absence of insurance, and failed to introduce in detail the waters of diving and arrange diving coaches or instructors familiar with the waters to accompany the six divers during the whole process.

**5.3.1 Establishing District-Based Diving Associations to Strengthen Management and Collaboration of Diving Clubs**

District diving associations should be established for unified organization and standardized management of local registered clubs, so as to realize the overall management from the district level to the municipal level, and then to the provincial level and finally by Chinese Underwater Association or China Water Ski, Underwater & Powerboat Federation. District associations should carry out routine reviews and random inspections on registered clubs. Besides, clubs should review the qualifications of their coaches, divers and practitioners according to rules and regulations and improve the staff's work ethics and enhance safety awareness. They should also timely identify their hidden hazards and correct their mistakes in routine reviews and random inspections. However, domestic diving organizations have failed to establish such level-by-level district, municipal or provincial associations for some reasons, according to interviews with the experts. China Water Ski, Underwater & Powerboat Federation, Fujian Recreational Diving Association and Shenzhen Dapeng New Area Dive Association now are the only registered recreational diving organizations in China. District, municipal and provincial diving or recreational diving associations may be established by the public in coastal cities in China, given the particularity of recreational diving, to enhance level by level the "pilot-to-generalization" management of diving organizations in China.

**5.4 Organizational Influences**

*Table 4 Feedback from Experts on Organizational Influences*

	First judgment				Second judgment				Third judgment			
	Abs	Chin	Lac	O	Abs	Chin	Lac	O	Abs	Chin	Lac	O
Expert N o.	ence of rule s and regulation s	Chin ese divin g organiza tions' failure to perf	Lac k of man age men t of Chin ese divi ng	Other s	ence of rule s and regulation s	Chin ese divin g organiza tions' failure to perf	Lac k of man age men t of Chin ese divi ng	Other s	ence of rule s and regulation s	Chin ese divin g organiza tions' failure to perf	Lac k of man age men t of Chin ese divi ng	Other s



		orm dutie s	orga nizat ions			orm dutie s	orga nizat ions			orm dutie s	orga nizat ions	
1	0	1	0	0	0	1	0	0	1	1	0	0
2	1	1	1	1	1	1	1	1	1	1	1	0
3	1	0	1	0	1	0	1	0	1	0	1	0
4	1	1	1	1	1	1	1	1	1	1	1	1
5	0	1	1	0	0	1	1	0	1	1	1	0
6	1	0	0	0	1	1	0	0	1	1	1	0
M ea n	0.6 7	0.67	0.67	0. 3 3	0.6 7	0.83	0.67	0. 3 3	1.0 0	0.83	0.83	0. 1 7

As Table 4 shows, organizational influences on recreational diving mainly consist of the absence of rules and regulations (100%), Chinese diving organizations' failure to perform duties (83%) and lack of management of Chinese diving organizations (83%) when organizational influences were screened with the Delphi method. Decision faults of the senior management have direct impacts on acts of supervisors and attitudes and behaviors of operators, while organizational faults, the root causes of accidents, are often ignored[6]. In this case, Shenzhen Dapeng New Area Dive Association, the first district diving association in China established in November 2018, has given 36 risk warnings on weather conditions to clubs registered with it and its member units since its establishment in compliance with the requirements of government agencies. With its safety management, the association has ensured zero safety accidents of registered clubs to this date. Neither registered with any diving associations nor in any diving systems, Aishang Diving Club did not have the senior management, and it was operating without valid supervision. The vulnerability of unsafe acts in the fourth layer cut through a hazardous pathway of vulnerabilities in all four layers, making organizational defects the hidden root cause of the accident.

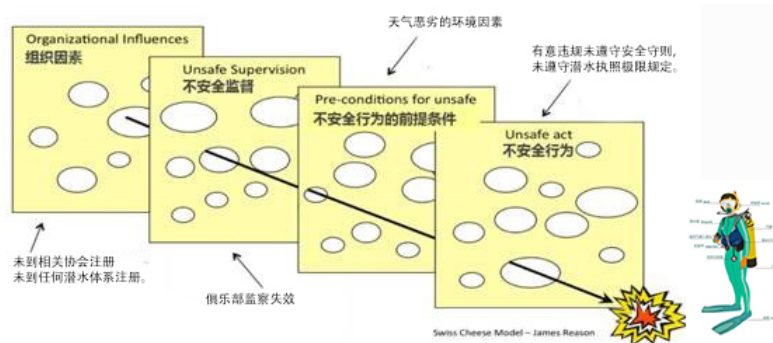
From the perspective of formulation of rules and regulations, the recreational diving industry is not legally restricted due to the absence of legally effective safety management systems and management regulations in China. Performance of duties by diving organizations and associations in China will change the “unmanaged diving” situation in this country. Level-by-level management, communication and guidance, as well as other high-level management and supervision by municipal and provincial diving associations will be enabled under the joint supervision of Water Sports Management Center of General Administration of Sport of China and China Water Ski, Underwater & Powerboat Federation. In view of organizational influences, developing a safety management system and safety regulations should be the first step in the process of organization and management.

**5.4.1 Developing a Safety Management System and Safety Regulations for Recreational Diving**

A safety management system for recreational diving should include at least the following aspects. First, it is necessary to intensify the development of standardized coaching. That is, functional departments of diving in China should develop a standardized coaching system with unified and standardized educational materials and contents, which should be promoted nationwide after recognized by authorities. Second, it is necessary to set up coaching quality supervision departments based on standardized courses. Meanwhile, safety regulations should define in detail the violations and penalties, and be circulated throughout the diving industry by announcement of public documents. As learned, Zhanjiang Diving School of General Administration of Sport of China, as well as experts in the field, supervised by Water Sports Management Center of General Administration of Sport of China and China Water Ski, Underwater & Powerboat Federation, are the developers of specific diving rules and regulations. But top talents are still expected in the field to formulate a safety management system and safety regulations for recreational diving, which is one of the greatest difficulties in the development of the diving industry. Given the absence of talents and incapability to timely add new posts, it is the most effective way to actively seek solutions from foreign experts to solve the problem. For example, we can try to seek solutions from French or American experts, who are at least 20 years ahead of us in diving.

### 6. Formation of the Event Chain of Fatal Accidents

A retroactive accident investigation based on the REASON model completely restores the event chain (Fig. 2). Unsafe acts break the last defense layer in an accident, and their preconditions intensify the risk of unsafe acts, while clubs' failure to supervise doubles the safety risks. Defective rules and regulations for recreational diving, incapability of Chinese diving organizations or associations to perform their duties and poor safety education in management are the hidden causes of diving accidents.



组织因素	Organizational influences
不安全监督	Unsafe supervision
不安全行为的前提条件	Preconditions for unsafe acts
不安全行为	Unsafe acts

未到相关协会注册	Failure to register with relevant associations
未到任何潜水体系注册	Failure to register in any diving system
俱乐部监察失效	Clubs' failure to supervise
天气恶劣的环境因素	Bad weather
有意违规未遵守安全守则, 未遵守潜水执照极限规定	Intentional violations of safety rules Violations of diving license limits

*Fig.2 Reason-Model-Based Case Restoration*

## 7. Conclusion

In the present study, analysis based on the REASON model reveal that organizational influences are the main causes of fatal accidents, while organizational defects are the hidden causes of faults and violations. The frequency and number of fatal accidents should be minimized so that recreational diving can enjoy sustainable development in China and attract overseas tourists as a popular sport among tourists. Targeted measures should be taken to remedy defects and vulnerabilities in the four defense layers to strengthen the defense capability of each layer. Penalties on individuals or clubs are not effective solutions. Regarding organizational influences, rules and regulations for recreational diving should be developed to strengthen the safety awareness of and safety education for diving practitioners, and clubs that supervise unsafe acts should adopt a safety accountability mechanism to ensure the safety of recreational diving.

## 8. Acknowledgment

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