The study to prevent runway incursions Based on analysis of real cases in China

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***Abstract*—the rapid development of civil aviation industry of China in recent years makes the increase of the number of flights in each airport, and the increase of total number of accidents also, such as runway incursion. Runway incursions are the consequence of multiple operational and environmental factors. In order to provide theoretical support and reduce operation risk, the author had analyzed the real runway incursions case happened in China, used the SHELL mode to get a deep look why the crew of Airlines lack of situational awareness during airport surface operations, why there were ATC issues, and airport factors including aerodrome lightings system and markings. The author found some practical methods to prevent runway incursions happening, such as by improving the training of crew, updating the hardware of the airport, and using SMS to share risk information, establishing Local Runway Safety Team. As a result, some of them have been improved can effectively reduce runway incursions.**

Keywords—Runway Incursion, Safety, SMS, Local Runway Safety Team, Human factors, Pilot

I. Introduction

A. Background

Transport in the People's Republic of China (P. R. China) has experienced major growth and expansion in recent years. Airports, roads, and railway construction provide a massive employment boost in China. In November 2012, as a result of the rapidly expanding of civil aviation, there were 182 commercial airports in P. R. China. Under China's 12th Five-Year Plan (2011-2015), 82 new commercial airports are to be constructed.

According to the information released from the working conference of the Civil Aviation Administration of China (CAAC (Civil Aviation Administrator of China)), the civil aviation passengers' traffic of the year 2011 has reached 9.5 percent year-on-year to total 621 millions. The speed of development of the civil aviation industry in China is rather fast. We have new airports, new airlines, new aircraft and new pilots all the time. Simultaneously, the total pilots in China increased enormously.

The rapid development of civil aviation industry of China in recent years results in the increasing of the number of flights in each airport. For illustration, the number of flights of Beijing capital airport ranked No.2 in the world in 2011.However, as the traffic went up, the total number of accidents increased at the same time.

Statistics show that 68% of the accidents involving Air Traffic Management (ATM) occurred during the ground phase of flight. One major safety issue of airport surface operations is the occurrence of runway incursions. In 2007, there were 4 cases of runway incursion in China. In 2008, the number increased to 11. In 2009, there were 26 cases, and in 2010, there were 25 cases. Runway incursion is a great threat that may occur at any airport in the world, and it does occur in the daytime as well as at night, under good as well as low visibility conditions [2, 3].

Runway incursions are the consequences of multiple operational and environmental factors. Although these events did not cause direct and serious consequences sometime, but they greatly affected our aviation safety.

B. Definition of runway incursion

Runway incursions sometimes cause serious accidents with significant loss of life. As we know, the famous Tenerife airport disaster occurred on Sunday, March 27, 1977. Two Boeing 747 passenger aircraft collided on the runway of Los Rodeos Airport (now known as Tenerife North Airport) on the Spanish island of Tenerife, one of the Canary Islands. With a total of 583 fatalities, the crash is the deadliest accident in aviation history.

Although runway incursions are not new problems, they have been on the rise with the increasing of air traffic. We now give the possible definitions of runway incursion as follows [4, 5].(1) The Procedures for Air Navigation Services — Air Traffic Management (PANS-ATM, Doc 4444) defines a runway incursion as:"Any occurrence at an aerodrome involving the incorrect presence of an aircraft, vehicle or person on the protected area of a surface designated for the landing and take-off of aircraft."(2) The European JAA defines a runway incursion as: "the unintended presence of an aircraft, vehicle or person on the runway or runway strip."(3) The US FAA defines a runway incursion as:"any occurrence at an airport involving an aircraft, vehicle, person or object on the ground that creates a collision hazard or results in the loss of separation with an aircraft taking off, intending to take off, landing or intending to land".

They define 4 categories of potential hazards associated with an urgency level of reaction required from the flight crew:

(1) Little or no risk of a collision, no need for corrective action, but this is an incursion or incident nonetheless;

(2) Decreasing separation, corrective action is advisable and there is time and room for corrective action;

(3) Separation decreases, time-critical action is essential to avoid a collision;

(4) Extreme danger, instantaneous action required to narrowly avoid catastrophe (near collisions and collisions).

And the nature of the reaction from the crew depends upon situations:

(1) Lateral evasive maneuver in case of potential collision;

(2) Rejected takeoff, possibly near or above 100kt, or maximum braking at landing, instructed by Air Traffic Control (ATC) or decided by flight crew;

(3)Go around at low altitude (DH or below) instructed by ATC or decided by flight crew;

(4) Emergency evacuation following a collision.

C. Purpose of the Thesis

The purpose of the thesis is to study on the prevention of runway incursions. According to the incursion cases which had happened in China and the working experience of the author, the thesis mainly focus on:

(1)Analyzing the runway incursion case which had happened in China;

(2)Analyzing the main reasons of the runway incursion cases;

(3)Making suggestions of how to prevent runway incursion in China, how to reduce the likelihood of the runway incursion by crew training, and improvement of ATC procedures, the safety risks management of runway incursions by SMS approach, and the Runway Safety Action Plan by the Local Runway Safety Team.

II. Factors Involved in Runway Incursions

A. Introduction

Aviation incidents and accidents investigations often lead to both cognitive and environmental contributing factors to these events. Environmental sources include a lot of factors such as flawed interface design, confusing automation, and unexpected weather conditions. Cognitive sources include many factors, for example, poor situation awareness, procedural noncompliance, and poor crew coordination.

Many, if not most, significant incidents and accidents are result from the combination of both cognitive and environmental factors. In fact, in a highly proceduralized domain such as aviation, with highly trained and motivated crews, accidents are rarely caused by either environmental or cognitive causes alone.

Runway incursions are the consequences of multiple operational and environmental factors. One major contributing factor is the lack of situational awareness during airport surface operations, induced by weather considerations and complex airport factors. Another contributing factor is caused by ATC issue, including radiotelephony phraseology and language proficiency. Other contributing factors include the aerodrome equipments, lighting and markings, aerodrome charts, airside vehicle drivers and so on.

For simplicity, the main reasons of runway incursions can be categorized as the following: Human Factors, Airport Factors, and Weather Factors.

We now deal with these factors respectively.

B. Human factors

Analysis of runway incursions can be executed using the SHELL Model, It should be noted that the SHELL Model does not draw attention to the different components independently, but to the interface between the human elements and the other factors.

SHELL Model is a conceptual framework proposed in ICAO Circular 216-AN31. The concept (the name being derived from the initial letters of its Components, Software, Hardware, Environment, and Liveware) was first developed by Edwards in 1972, with a modified diagram to illustrate the model developed by Hawkins in 1975 [6].

One practical diagram to illustrate this conceptual model uses blocks to represent the different components of Human Factors. This building block diagram does not cover the interfaces which are outside Human Factors (hardware-hardware; hardware-environment; software-hardware) and is only intended as a basic aid to understand Human Factors:

(1) Software - the rules, procedures, written documents etc., which are parts of the standard operating procedures.

(2) Hardware - the Air Traffic Control suites, their configuration, controls and surfaces, displays and functional systems.

(3) Environment - the situation in which the L-H-S system must function, the social and economic climate as well as the natural environment.

(4) Liveware-the controller with other controllers, flight Crews, engineers and maintenance personnel, management and administration people.

For example, the L-L interaction would include aspects of communication, cooperation and support; the L-H interaction would represent human-machine interface issues. For the ground operation, the Liveware of the runway incursions are the pilots, controllers and airside drivers. Mitigation strategies that address all three parties should be included in systemic solutions.

TABLE I. PILOT FACTORAND RISK LEVELS

Serial number	Description	Risk Level
1	pilots have not adequate preparation before flight	high
2	crew did not follow SOP and poor CRM, they did not do cross check	high
3	inability to see adequate signage and markings	high
4	controllers issue instructions when both pilot workload and cockpit noise are very high	medium
5	pilots performing mandatory head-down tasks, which reduces situational awareness	medium
6	taxing technique of crews or aircraft taxi with too high speed	medium
7	pilots have poor English	low
8	pilots have difficulty to read aerodrome charts, NOTAMs,	low

1) Pilot Factors

Pilot factors that may result in a runway incursion include inadvertent noncompliance with ATC clearances. Usually, these cases include runway incursion resulting from a breakdown in communications, loss of situational awareness, no cross check between two pilots, taxing technique of crews itself, non SOP and etc.

2) Air Traffic Control Factors

The most common controller-related factors identified in several studies are distraction, workload, experience level, inadequate training, and lack of a clear line of sight from the control tower, human-machine interface, and incorrect or inadequate handover between controllers. Consequently, the Common Controller-related Actions are:

TABLE II. ATC FACTORAND RISK LEVELS

Serial number	Description	Risk Level
1	momentarily forgetting about: an aircraft, the closure of a runway, a vehicle on the runway, or a clearance that had been issued;	high
2	failure to anticipate the required separation, or miscalculation of the impending separation;	high
3	a crossing clearance issued by a ground controller instead of a tower controller	high
4	inadequate coordination between controllers	medium
5	misidentification of an aircraft or its location	medium
6	failure of the controller to provide a correct read back of another controller's instruction	medium
7	failure of the controller to ensure that the read back by the pilot or the vehicle driver conforms with the clearance issued;	low
8	overlong or complex instructions	low
9	Poor English and using of non-standard phraseologies	low

3) Airside Vehicle Driver Factors

The most common driver-related factors identified in several studies are:

TABLE III. DRIVERS FACTOR AND RISK LEVELS

Serial number	Description	Risk Level
1	failure to obtain clearance to enter the runway	high
2	failure to comply with ATC instructions	high
3	inaccurate reporting of position to ATC	high
4	inadequate training	medium
5	absence of radiotelephony equipment	medium
6	absence of radiotelephony training	medium
7	lack of familiarization with the aerodrome	low
8	lack of knowledge of aerodrome signs and markings	low
9	communication errors	low

C. Airport factors

Complex or inadequate aerodrome design significantly increases the probability of a runway incursion. The frequency of runway incursions has been shown in many researches to be related to the number of runway crossings and the characteristics of the aerodrome layout. Common factors include:

(1) The complexity of the airport layout including roads and taxiways adjacent to the runway;

(2) Insufficient spacing between parallel runways;

(3) The marking of taxiway and runway is too small or not clear;

(4) Light of taxi or runway is too dim at night;

(5) The taxiway is named unreasonable;

(6) The entrance of runway has not clear alert equipments: stop bar, holding point line, etc.

Various airport factors may affect pilot situational awareness, distract the crew, or lead to crew confusion. Surface ground radar may fail in case of low visibility, construction works involving people and vehicles on the airport surface. There may be abnormal airport configuration: closed taxiways or runways (see Fig. 1.), which will increase the risk of runway incursion too [7].

Fig. 1. Identification of a closed runway

D. Weatherfactors

The weather will reduce the ability of the pilots to see the taxiway and runway markings, and it may affect pilot situational awareness too. Particularly, the following factors will be very troublesome: the low visibility conditions or the visibility on taxiway lower than expected, position of the sun versus pilot's eyes, reflection of the sun on wet surfaces. Snow and icing over surfaces covering airport surface markings, and the night time operations [8].

So we know the main reasons of runway incursions: human factors, airport factors and weather factors, we will do the runway incursions cases study from those aspects.

III. ANALYSIS OF THE RUNWAY INCURSION CASES IN CHINA

A. Introduction

As mentioned above, runway incursions are the consequences of multiple operational and environmental factors. In this chapter, the emphasis is put on the Wenzhou Yongqiang International Airport and the runway incursions happened there, especially the cases investigated by the author.

B. A Panorama of Wenzhou Airport

Wenzhou is a big city in the southeastern of Zhejiangprovince, P. R. China. According to the census in 2010, the population of the Wenzhou city proper is about 3,039,500, the area under its jurisdiction, which includes two satellite cities and six counties, had a population of

9,122,100. The prefectural area borders Lishui to the west, Taizhou to the north, and looks out to the East China Sea on its eastern coast.

The Wenzhou Yongqiang International Airport serves the Wenzhou area, with scheduled flights to major cities in China and popular cities for traveling in Asia. The Airport is situated on the southeast of Wenzhou city proper, 20 kilometers away from the city center, it started opening up in 1995, and it ranked 1st in terms of passenger transit among cities of same level in China. In 2010, the Airport handled 49,854 landings, a passenger transit of 5.3 million, cargo throughput of 50,024 tons. There was a 2,400 meters' runway without parallel taxiway(see Fig.2 and Fig. 3.)at that time, and ILS approach on the runway 03 side, VOR/DME approach on the other side [9].

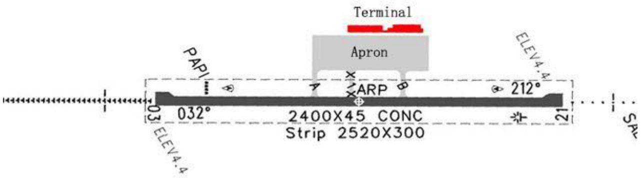

Fig. 2. The Layout of Wenzhou International Airport

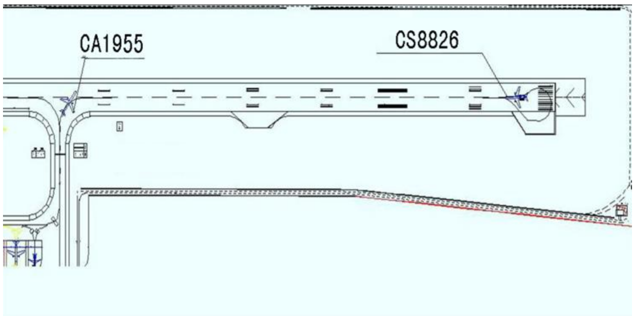

Fig. 3. The position of the two aircraft

C. Runway incursions at ZSWZ

From 1999 to 2010, the growth of flight in Wenzhou Yongqiang International Airport was more than 10% each year. There are 180 flights taking off and landing today by a 2,400 meters' runway without parallel taxiway. Since aircraft go from the apron into the runway every day, the risk of runway incursions has greatly increased.

At the day of September 19, 2010, one Airport vehicle got into the runway by mistake, the Airchina flight on short final went around. It was caused by the bad coordination between the airport authorities and the ATC. Short after that, November 08, 2010, one flight got into the runway when the other flight was cleared for takeoff, which aborted in seconds, and one flight in the approach went to the alternate airport.

Let's see what happened at November 08 2010 with detail:

20:29:00, CA1955 /B737-800, was cleared to taxi and hold short of runway 03 at A, and CS8826 A320 was on the runway ready for takeoff.

20:31:19, CS8826 was cleared to take off, then ATC found the Runway Incursion —CA1955 was getting into the runway by taxiway A, CS8826 was forced to abort take off immediately, both of them stopped, there was only 900M between the two captains(see Fig.2).

The passengers could feel the acceleration of the Flight CS8826, it can be calculated by the formula of the aircraft performance also:

$$a = (F - f)/m \tag{1}$$

$$S = V_0 t + 1/2at^2 \tag{2}$$

F= Thrust come from the engines (CFM56 26400 lb)

f = (ground friction + drag of air), at low speed, the drag of air can be ignored

f =μN, if the runway condition is dry, μ=0.3

Used all the mathematics, we can see the 900 meters is too dangerous for the runway incursion, they will collide in less than 15 seconds if the ATC did not make the call.

For better understanding, let's have a look at the QAR data of the aborted take-off flight CS8826 (shown as Fig. 4.).

Time	FLIGHT_PHASE	GS (knot)	HEAD (deg)	GW (10kg)	N21C (%)	N22C (%)	N11 (%)	N12 (%)	EPR_CMD_1	EPR_CMD_2	EPR1	EPR2	EGT1C (deg C)	EGT2C (deg C)	TLA1 (deg)	TLA2 (deg)	TLA1C	TLA2C
20:30:06	TAXI OUT	6	205.664	6575	60.6	60.4	21.9	21.8	1.000	1.000	1.004	1.004	511	504	-2.81	-2.81	IDLE	IDLE
20:30:07	TAXI OUT	6	196.523		60.6	60.4	21.9	21.8	1.000	1.000	1.004	1.004	511	504	-2.81	-2.81	IDLE	IDLE
20:30:08	TAXI OUT	6	187.383	6575	60.6	60.4	21.9	21.8	1.000	1.000	1.004	1.004	511	505	-2.81	-2.81	IDLE	IDLE
20:30:09	TAXI OUT	6	177.891		60.6	60.5	21.9	21.8	1.000	1.000	1.004	1.004	511	504	-2.81	-2.81	IDLE	IDLE
20:30:10	TAXI OUT	6	168.398	6577	60.6	60.5	21.9	21.8	1.000	1.000	1.004	1.004	511	505	-2.81	-2.81	IDLE	IDLE
20:30:11	TAXI OUT	6	158.203		60.6	60.5	21.9	21.8	1.000	1.000	1.004	1.004	511	505	-2.81	-2.81	IDLE	IDLE
20:30:12	TAXI OUT	5	147.305	6577	60.6	60.5	22.0	21.8	1.000	1.000	1.004	1.004	511	505	-2.81	-2.81	IDLE	IDLE
20:30:13	TAXI OUT	5	135.000		60.6	60.5	21.9	21.6	1.000	1.000	1.004	1.004	511	505	-2.81	-2.81	IDLE	IDLE
20:30:14	TAXI OUT	5	122.344	6575	60.6	60.5	21.9	21.6	1.000	1.000	1.004	1.004	511	505	-2.81	-2.81	IDLE	IDLE
20:30:15	TAXI OUT	5	110.391		60.6	60.5	21.9	21.5	1.000	1.000	1.004	1.004	511	505	-2.81	-2.81	IDLE	IDLE
20:30:16	TAXI OUT	5	99.141	6575	60.6	60.4	21.9	21.6	1.000	1.000	1.004	1.004	511	505	-2.81	-2.81	IDLE	IDLE
20:30:17	TAXI OUT	5	89.648		60.6	60.5	21.9	21.8	1.000	1.000	1.004	1.004	511	505	-2.81	-2.81	IDLE	IDLE
20:30:18	TAXI OUT	5	80.859	6575	60.6	60.5	21.9	21.8	1.000	1.000	1.004	1.004	511	505	-2.81	-2.81	IDLE	IDLE
20:30:19	TAXI OUT	5	72.070		60.6	60.5	21.9	21.9	1.000	1.000	1.004	1.004	511	505	-2.81	-2.81	IDLE	IDLE
20:30:20	TAXI OUT	5	63.984	6575	60.8	60.5	21.9	21.9	1.000	1.000	1.004	1.004	511	504	-2.81	-2.81	IDLE	IDLE
20:30:21	TAXI OUT	5	56.250		60.6	60.5	21.9	21.9	1.000	1.000	1.004	1.004	511	504	-2.81	-2.81	IDLE	IDLE
20:30:22	TAXI OUT	5	48.516	6577	60.8	60.5	21.9	21.9	1.000	1.000	1.004	1.004	511	504	-2.81	-2.81	IDLE	IDLE
20:30:23	TAXI OUT	5	41.484		60.8	60.5	21.9	21.9	1.000	1.000	1.004	1.004	511	504	-2.81	-2.81	IDLE	IDLE
20:30:24	TAXI OUT	5	36.211	6577	60.8	60.5	21.9	21.9	1.000	1.000	1.004	1.004	511	504	0.00	0.00	IDLE	IDLE
20:30:25	TAXI OUT	5	33.047		60.9	60.6	22.0	22.0	1.031	1.000	1.004	1.004	511	504	5.63	5.63	IDLE	IDLE
20:30:26	TAXI OUT	5	31.289	6577	62.3	62.1	22.8	22.8	1.031	1.031	1.006	1.006	512	505	8.44	8.44	IDLE	IDLE
20:30:27	TAXI OUT	6	30.234		64.4	64.1	24.0	24.0	1.031	1.031	1.006	1.008	514	507	11.25	11.25	IDLE	IDLE
20:30:28	TAXI OUT	6	30.234	6577	66.8	66.5	25.6	25.8	1.031	1.031	1.008	1.010	518	511	11.25	11.25	IDLE	IDLE
20:30:29	TAXI OUT	6	30.586		69.4	69.1	27.8	27.8	1.031	1.031	1.012	1.014	522	515	11.25	11.25	IDLE	IDLE
20:30:30	TAXI OUT	7	30.938	6577	72.9	72.5	32.6	32.6	1.031	1.031	1.025	1.025	526	519	11.25	11.25	IDLE	IDLE
20:30:31	TAXI OUT	8	31.641		76.3	75.6	41.0	40.1	1.031	1.031	1.041	1.041	529	522	11.25	11.25	IDLE	IDLE
20:30:32	TAXI OUT	9	32.344	6579	78.1	77.5	46.9	45.9	1.031	1.031	1.055	1.053	529	522	11.25	11.25	IDLE	IDLE
20:30:33	TAXI OUT	10	33.047		78.6	78.1	49.8	48.5	1.031	1.031	1.061	1.059	526	520	11.25	11.25	IDLE	IDLE
20:30:34	TAXI OUT	12	33.398	6577	79.5	79.1	51.3	50.4	1.031	1.250	1.068	1.066	521	515	22.50	22.50	CLIMB	CLIMB
20:30:35	TAXI OUT	14	33.398		83.9	83.3	59.3	58.3	1.187	1.250	1.113	1.111	514	509	14.06	11.25	IDLE	IDLE
20:30:36	TAXI OUT	17	33.398	6579	83.8	83.1	65.6	64.4	1.187	1.031	1.135	1.129	503	499	5.63	5.63	IDLE	IDLE
20:30:37	TAXI OUT	19	33.750		81.6	81.1	60.1	58.6	1.031	1.031	1.094	1.090	490	488	0.00	0.00	IDLE	IDLE
20:30:38	TAXI OUT	21	33.750	6575	79.9	79.1	53.6	52.4	1.031	1.031	1.064	1.061	482	480	-2.81	-2.81	IDLE	IDLE
20:30:39	TAXI OUT	21	33.398		77.1	76.6	47.3	46.4	1.031	1.031	1.045	1.041	476	474	-2.81	-2.81	IDLE	IDLE
20:30:40	TAXI OUT	20	33.047	6573	75.0	74.4	42.4	41.9	1.031	1.000	1.031	1.029	470	468	-2.81	-2.81	IDLE	IDLE
20:30:41	TAXI OUT	18	32.695		72.8	72.4	37.9	37.3	1.000	1.000	1.021	1.020	464	462	-2.81	-2.81	IDLE	IDLE
20:30:42	TAXI OUT	15	32.344	6573	71.3	71.0	34.1	33.6	1.000	1.000	1.016	1.014	459	456	-2.81	-2.81	IDLE	IDLE
20:30:43	TAXI OUT	11	31.992		70.1	69.9	31.1	30.8	1.000	1.000	1.012	1.012	455	453	-2.81	-2.81	IDLE	IDLE
20:30:44	TAXI OUT	8	31.289	6573	69.3	69.0	29.1	28.9	1.000	1.000	1.010	1.010	452	450	-2.81	-2.81	IDLE	IDLE
20:30:45	TAXI OUT	5	31.289		68.4	68.3	27.6	27.5	1.000	1.000	1.010	1.008	451	449	-2.81	-2.81	IDLE	IDLE
20:30:46	TAXI OUT	3	31.289	6575	67.6	67.4	26.6	26.5	1.000	1.000	1.008	1.008	452	449	-2.81	-2.81	IDLE	IDLE
20:30:47	TAXI OUT	1	31.289		66.6	66.4	25.8	25.8	1.000	1.000	1.008	1.008	452	450	-2.81	-2.81	IDLE	IDLE
20:30:48	TAXI OUT	0	31.289	6577	65.8	65.5	25.1	25.0	1.000	1.000	1.006	1.006	453	450	-2.81	-2.81	IDLE	IDLE
20:30:49	TAXI OUT	0	31.289		65.1	64.9	24.5	24.5	1.000	1.000	1.006	1.006	454	451	-2.81	-2.81	IDLE	IDLE
20:30:50	TAXI OUT	0	31.289	6577	64.6	64.3	24.1	24.0	1.000	1.000	1.006	1.006	456	452	-2.81	-2.81	IDLE	IDLE
20:30:51	TAXI OUT	0	31.289		64.0	63.6	23.8	23.6	1.000	1.000	1.006	1.006	457	453	-2.81	-2.81	IDLE	IDLE
20:30:52	TAXI OUT	0	31.289	6579	63.4	63.0	23.4	23.3	1.000	1.000	1.006	1.004	459	455	-2.81	-2.81	IDLE	IDLE
20:30:53	TAXI OUT	0	31.289		62.6	62.4	22.9	22.8	1.000	1.000	1.004	1.004	462	457	-2.81	-2.81	IDLE	IDLE
20:30:54	TAXI OUT	0	31.289	6579	62.1	61.8	22.4	22.4	1.000	1.000	1.004	1.004	463	458	-2.81	-2.81	IDLE	IDLE
20:30:55	TAXI OUT	0	31.289		61.5	61.3	22.0	22.0	1.000	1.000	1.004	1.004	465	460	-2.81	-2.81	IDLE	IDLE
20:30:56	TAXI OUT	0	31.289	6577	61.0	60.8	21.8	21.6	1.000	1.000	1.004	1.004	467	462	-2.81	-2.81	IDLE	IDLE
20:30:57	TAXI OUT	0	31.289		60.6	60.5	21.5	21.4	1.000	1.000	1.004	1.004	469	464	-2.81	-2.81	IDLE	IDLE
20:30:58	TAXI OUT	0	31.289	6575	60.4	60.3	21.3	21.3	1.000	1.000	1.004	1.004	471	466	-2.81	-2.81	IDLE	IDLE
20:30:59	TAXI OUT	0	31.289		60.3	60.1	21.3	21.1	1.000	1.000	1.004	1.004	473	468	-2.81	-2.81	IDLE	IDLE
20:31:00	TAXI OUT	0	31.289	6575	60.3	60.1	21.3	21.1	1.000	1.000	1.004	1.004	476	471	-2.81	-2.81	IDLE	IDLE
20:31:01	TAXI OUT	0	31.289		60.3	60.3	21.3	21.1	1.000	1.000	1.004	1.004	479	474	-2.81	-2.81	IDLE	IDLE
20:31:02	TAXI OUT	0	31.289	6573	60.4	60.4	21.3	21.3	1.000	1.000	1.004	1.004	482	477	-2.81	-2.81	IDLE	IDLE
20:31:03	TAXI OUT	0	31.289		60.6	60.5	21.4	21.4	1.000	1.000	1.004	1.004	486	480	-2.81	-2.81	IDLE	IDLE

Fig. 4. the QAR data of the CS8826

From the QAR, we can see the captain of the CS8826 had excellent reaction time that day, and it was good that the controller on the tower is watching them although it's in the night. Otherwise, it might be a tragic accident.

Obviously, it's the mistake of the crew of the flight CA1955, but, it was not that easy to conclude, let's see the crew first. The captain of CA1955, total flight time of 11,800 hours. The first officer, total flight time of 800 hours. Let's have a look of the air traffic controllers: Two qualified controllers on duty, one chief monitor on the tower. Let's have a look of the Airport: there are no taxiway lights at that time, no waiting lights at the runway entrance of Taxiway A.

D. Analysis by the human factors

(1) Pilots

It looked like that was the air china crew's big mistake during the taxi, so we will do some research from them first.

1) The preparation of the crew's before that flight was not good enough, the captain's last flight here was three years ago, and it's the first time for the F/O.

2) The cockpit authority gradient is too steep, compared with the F/O, the captain is too experienced, so when the captain was doing wrong, the young F/O failed to advise him.

3) It's a small airport, and sometimes the pilots believe it's easy to taxi.

4) During the talk with them, they believed that the lack of holding lights and taxiway lights is the main reason, and there's no information to let the pilots know it's highly risky to get runway incursion since it's happened several times, especially during night.

(2) Air traffic controllers

The air traffic controller found the runway incursion at a perfect moment. But let's think about the system, the B737 was at stand 15 which was facing to the terminal building. When it's cleared to taxi, they must turn 180 degrees before they can see the runway. However, there was no holding light at A. Although the ATC know the local airport very well, they didn't issue some NOTAM or give some advice to the crew. If they did that, things might be better.

E. Analysis by the airport factors and weather factors

Since the crew said the main reason of the runway incursion was the lack of holding lights and taxiway lights, we'll see what happened to the airport.

As a small airport, there were not so many flights at the beginning, even no night operation at all, so they did not take the whole lighting system into consideration at the airport designing period, but not so long after that, the airport authorities found it's developing so fast that the terminal building, the runway and taxiways, the navigation system and the lighting systems could not match the development at all. Then they started to do the plan to expand the airport, and they believed the old system will be all right since it was good before.

When the airport got 80 take-off and landings each day, there were few night flights operated by the based airlines, the pilots of theirs know the airport very well, it's not a problem at all. When the airport got 100 take-off and landings each day, the other airlines started to operate the night flight to Wenzhou, the pilots of those airlines have no idea what's it looked like at night at all.

At some point between 2007 and 2008, the ATC of Wenzhou had suggested the airport authorities to do something about the lighting system but with no responding. As the traffic went up, the risk of the runway incursion went up too, if you know the Murphy's Law, "Anything that can go wrong will go wrong". So that happened at one day.

It's easy to see by the Swiss cheese model. The Swiss Cheese model of accident causation is used in the risk analysis and risk management of human systems, general aviation, engineering, and healthcare. It likens human systems to multiple slices of Swiss cheese, stacked together, side by side. It was originally propounded by British psychologist James T. Reason of the University of Manchester in 1990 (Reason 1990), and has been accepted and used widely in healthcare, aviation safety industry, and emergency service organizations. It is sometimes called the cumulative act effect. An organization's defenses against failure are modeled as a series of barriers, represented as slices of the cheese. The holes in the cheese slices represent individual weaknesses in individual parts of the system, and are continually varying in size and position in all slices. The system as a whole produces failures when holes in all of the slices momentarily align, permitting "a trajectory of accident opportunity", so that a hazard passes through holes in all of the defenses, leading to an accident [10]. (See Fig. 5.)

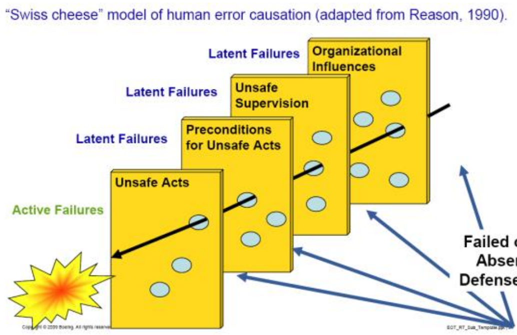

Fig. 5. Swiss cheese model

IV. PREVENTION STRATEGIES AND SOLUTIONS

A. Introduction

As we discussed before, if we want to reduce the probability of a runway incursion, we need to begin several initiatives to reduce the incursion rate including education, training, to improve the airfield infrastructure and procedures.

We need to do lots of work to avoid human errors, such as the pilot's training, the crew's SOP and CRM, making the ATC's procedure to improve their situation awareness, using new technology, such as EGWPS system on the aircraft, adding more training on the airside vehicle driver and other operation personnel related [11,12].

Moreover, for the whole system, we need to apply the SMS method, share and manage the safety risks, set up the Runway Safety Teams, and make it works. We'll see all of these in this chapter.

B. Training and Procedures

(1) Pilots

As mentioned above, many runway incursions are caused by flight crew's inability to correctly taxi by the ATC's clearance because of improperly visualize the cleared taxi path, inaccurately materialize on airport surface charts the cleared taxi routing with outstanding elements, or unfamiliarity with the airport, and unsuccessfully to advise controller when a loss of position awareness occurs.

In trying to prevent runway incursions, we need to train pilots in the following aspects:

1) Knowledge of airport surface markings, lights and signs;

2) Let them do a thorough briefing of expected taxi routing;

3) Sterile cockpit rule: Public address or operational calls on the airline frequency are to be avoided while taxiing;

4) Plan timing and execution of check lists to increase

attention when approaching intersections and runway crossings;

5) Taxi at adequate speed to avoid high taxi speed;

6) Performing a line-up check before onto the departure runway, identification of runway markings.

(2) ATC

As we know, runway incursions may also be due to ATC: controller degraded situational awareness; controller's failure to see and track airport activity from the tower, failure to provide separation on ground; incorrect or inadequate clearance, improper TWR / GND controllers' coordination; use of non-standard phraseology, or pilots' readback-error not detected by controller.

In summary, by the SHELL model mentioned above, the L-L interface between ATC and pilot is very important for the system, and the practical way to cooperate between them, is the Communication.

The following communication guidelines should be implemented to address the factors involved in runway incursions:

1) ATC should use aviation English in international airports, and adhere to established standard ICAO phraseologies in order to keep situational awareness for all participants associated with runway operations.

2) When using Chinese Mandarin, the ATC must use the standard phraseologies too and the full call sighs are needed all time. If there are crews that cannot speak Chinese, the ATC should speak English.

3) The ACT must check the read back of all the clearances and instructions from pilots, including call sign and runway designator, especially full read back of any holding position instructions. If they are not clear, do not hesitate to request clarification.

4) The ACT must avoid giving instructions at a bad timing, especially when the aircraft just landed on the runway or you just cleared a flight for take-off, the pilot is highly concentrating on the control of the aircraft.

5) Military pilots and ground personnel may not be familiar with ICAO flight rules, phraseology, aerodrome signs, lights and markings. They will also be unfamiliar with local aerodrome procedures. Special attention must be paid and ATC should let other traffic know the information with the help of the tower frequency.

It's significant to introduce formal communications training and assessment for drivers and other personnel who operate on or near the runway too. They need to know how to communicate with ACT and they must know where they are. The vehicle must be equipped with GPS when they are checking the runway and taxiways. The communications between ACT and drivers must be clearly established [13].

The aerodrome operator should ensure that a procedure exists and maneuvering area vehicle drivers are trained for those occasions where they become uncertain of their position on the maneuvering area. Regularly review the operational use of aeronautical runway, taxiway signs and markings, and runway warning light, (Shown as Fig. 6.), to ensure a robust policy to protect the runway [8, 14, 15].

Fig. 6. Runway warning light

C. Local Runway Safety Teams

(1) General

A Local Runway Safety Team (LRST) is a key element in an aerodrome runway safety program and should ensure that a strong focus is maintained on runway safety across all parties creating, in fact, an aerodrome level safety management function [16, 17].

The establishment of a Local Runway Safety Team is intended to facilitate effective local implementation of the recommendations from the CAAC level for the prevention of Runway Incursions and Runway Excursions and to stimulate proactive management of runway safety.

Specific objectives include:

1) Identify potential runway safety issues by reviewing aerodrome practices regularly, and when relevant information is available, from incident investigation findings;

2) Develop appropriate safety risk prevention measures and creation of awareness of potential solutions;

3) Advise management on runway safety issues and recommend mitigation measures;

4) Create a plan containing action items for mitigating runway safety deficiencies. Action items should be aerodrome specific and linked to a runway safety concern, issue or problem at that aerodrome.

5) Monitor the number, type and, the severity of runway incursions;

6) Work as a cohesive team to better understand the operating difficulties of personnel who work in other areas and recommend areas for improvement;

7) Conduct a runway safety awareness campaign that focuses on local issues, e.g. produce and distribute local hot spot maps or other guidance material as considered necessary; and

8) Review the airfield to ensure it is adequate and compliant with ICAO Standards and recommended practices regularly.

The LRST should consist of, as a minimum, representatives from the main groups associated with takeoff and landing operations, namely the Aerodrome Operator (which could include navigation aids engineers, infrastructure maintenance etc.) Meteorological Offices and Aeronautical Information Service Providers, representatives from the Air Navigation Service Provider, local Air Traffic Controller associations and pilots from Aircraft Operators, local pilot associations that operate at the aerodrome and other relevant organizations that operate on the maneuvering area.

Let's use the case of ZSWZ airport again. The Aerodrome Operator is the Wenzhou Airport Company, owned by the government of the city. Air Traffic Control Service and Aeronautical Information Service are provided by the Wenzhou ATC center, they get the Meteorological Offices too. And there are two based airlines, Air China and China Eastern. Both of them have finished the audit of SMS. To prepare a Runway Safety Program for the Aerodrome, in China, the leader of the LRST will always be the Aerodrome Operator, i.e., the Wenzhou Airport Company. And we'll see how the Local Runway Safety Team Meeting works and how they can share the safety risk data.

(2) Local Runway Safety Team Meeting

A runway safety program should demonstrate consideration of runway and taxiway layout, traffic intensity and mix, and both visual and non-visual aids such as markings (Shown as Fig. 7.), lights, signs, radar, taxiway designations, ATS procedures, AIP (Aeronautical Information Publication) information, etc.

Fig. 7. Taxiway markings of runway entrance

V. CONCLUSIONS

How to reduce the likelihood of runway incursions are one major safety concerns for all operators, as we have studied above, by the human factor approach, we can do lots of work, such as the pilot's training, the crew's SOP and CRM, keeping good situation awareness when operating on the ground. The ATC's training and procedures are important, the using of standard phraseologies is a must when the instructions given by Chinese. The manufacturers have supplied some new technologies, which designed to break the chain of events leading to these runway incidents effectively. For example, Honeywell's Smart Runway product can increase flight safety by improving situational awareness for pilots during approach, landing, taxi and take-off[18]. For small airports, the full size runway lighting system may be very helpful, the enhanced taxiway markings are even cheaper to get help at daytime operation. LRST can get all kinds of view for the runway safety, they can find lots to do on the markings, lights, signs, radar, AIP information, and even the apron design, the push-out and starting engine procedures to help the safety level by reduce runway incursions.

VI. ABBREVIATIONS

AIP: Aeronautical Information Publication

ATC: Air Traffic Control

CAAC: Civil Aviation Administrator of China

CAUC: Civil Aviation University of China

CCAR: China Civil Aviation Regulations

LRST: Local Runway Safety Team

ICAO: International Civil Aviation Organization

NOTAM: Notice to airmen

PF: Pilot Flying

PNF: Pilot Not Flying

SOP: Standard operating procedure

SMS Safety management system(s)

RSAP: Runway Safety Action Plan

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