

A Safety Sketch of China Civil Aviation after Rapid Development

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Abstract—Civil aviation of China experienced a continuous and rapid development in last decades. Aircraft fleets, flight activities and airlines increased at a high speed. A new safety record was achieved. The aim of this paper is to assess the risks after the rapid development. Industry development data and unsafe occurrences data of transport aviation and general aviation are collected. Rates, types, periods, victim numbers, and fluctuations of accident and incident are compared. A Series of relationship among accidents and incidents, accidents and fatal accidents, occurrences and human-factor occurrences, etc. are analyzed. Contributions to the risks from industry development and human factors are discussed. A quantitative model is developed and used in risk assessment. Based on the outputs of the quantitative model, it is concluded that China civil aviation is in a stage of high risks.

Keywords—development, safety, data analysis, risk assessment

I. INTRODUCTION

Since implementation of the reform and opening-up policy, China civil aviation achieved a continuous and rapid development. The aircraft fleet grew more than ten times in last decades and the total transport turnover has been ranking the second in the world in 2010s. Rapid developments usually bring high risks. Efforts were paid in risk assessment and prediction.

Since aircrafts operation is the main activities in civil aviation transportation, researchers focused on the safety of airlines operation first and gave certain findings and promotion advice. Analysis methods were applied and employed, such as the Analytic Hierarchy Process and the Object-Oriented Risk Assessment Method [1]-[2].

With the introduction and implementation of Safety Management System in the middle of 2010s, it was internationally accepted that safety was influenced by all related activities including maintenance, air traffic control, ground handling, airports operation, besides of airlines operations [3]. Research of safety assessment expanded from the area of airlines to all areas of civil aviation. Safety of the industry was assessed systematically [4].

In the analysis, assessment and prediction, more and more theories and methods were introduced, applied and compared. The Accimap, Systems Theoretic Accident Modeling and Process (STAMP) and neural network model

were applied in systematic assessments [5]-[7]. The Human Factors Analysis and Classification System (HFACS), Dempster's Combination Rule and inductive reasoning approach were applied in reason analysis [8]-[9]. The Multiple Linear Regression (MLR), Auto-regressive Integrated Moving Average (ARIMA) and Structural Equation Model (SEM) were applied in data processing and prediction [10]-[11].

With these mathematics, logics and management theories and methods, researches were conducted in both the whole industry and individual operation areas. Safety assessment of China civil aviation were conducted [12]. Contributions and influences to safety risks from organizational factors, human factors, economic factors were analyzed[13]. Fatigue of pilots, maintenance engineers, air traffic controllers were assessed [14]-[16]. Risks of airport operation, air traffic management, transport aviation and business aviation were evaluated [17]-[18].

Most research gave optimistic predictions to China civil aviation safety risks and contributions from the industry development were seldomly considered. This paper explores the safety situation of civil aviation of China based on development data and safety data.

II. INDUSTRY DEVELOPMENT DATA ANALYSIS

Since 2010, both of transport aviation and general aviation in China have been developing at a continuous speed. Numbers of aircraft, flight hour and airline experienced over 100% increases, except the number of transport aviation airline which increased 41%.

A. Fleet Growth

Transport aviation fleet and general aviation fleet doubled, shown in Table I [19]. Transport fleet grew from 1597 aircrafts in 2010 to 3638 aircrafts in 2018 by 127.8%. The rapidest increase happened in the period of 2015 to 2017 in which the annual increasing rates are 11.8%, 11.3% and 11.7% respectively. In 2017 and 2018, 688 aircrafts joined the fleet, i.e. 0.94 new-coming aircraft every day. General fleet grew from 1010 aircrafts in 2010 to 2415 aircrafts in 2018 by 139.1%. The rapidest increase happened in the period of 2012 to 2014 in which the annual increasing rates are 17.4%, 15.1% and 18.4% respectively.

TABLE I. 2010-2018 TRANSPORT AVIATION AND GENERAL AVIATION AIRCRAFT NUMBERS AND INCREASING RATES

Year	Transport aviation		General aviation	
	Aircraft	Increasing rate	Aircraft	Increasing rate
2010	1597	12.7%	1010	-
2011	1764	10.5%	1124	11.3%
2012	1941	10.0%	1320	17.4%
2013	2145	10.5%	1519	15.1%
2014	2370	10.5%	1798	18.4%
2015	2650	11.8%	1904	5.9%
2016	2950	11.3%	2096	10.1%
2017	3296	11.7%	2297	9.6%
2018	3638	10.4%	2415	5.1%

B. Flight Hours Increase

Flight hours doubled in both transport aviation and general aviation, shown in Table II [19]. Transport flight hours grew from 5.1 million in 2010 to 11.5 million in 2018 by 125.8%. The rapidest increase happened in the period of 2015 to 2017 in which the annual increasing rates are 11.5%, 11.5% and 11.6% respectively. This coincides with the rapidest increase period of transport aviation fleet. General flight hours grew from 406 thousand in 2010 to 996 thousand in 2018 by 145.6%. The rapidest increase happened in the period of 2013 to 2015 in which the annual increasing rates are 14.0%, 13.7% and 14.2% respectively. It is contemporary with the rapidest increase period of general aviation fleet.

TABLE II. 2010-2018 TRANSPORT AVIATION AND GENERAL AVIATION FLIGHT HOURS AND INCREASING RATES

Year	Transport aviation		General aviation	
	Flight hour	Increasing rate	Flight hour	Increasing rate
2010	5107542	14.8%	405714	-
2011	5593355	9.5%	531776	31.1%
2012	6251969	11.8%	554770	4.3%
2013	6912539	10.6%	632325	14.0%
2014	7640737	10.5%	718710	13.7%
2015	8515605	11.5%	821024	14.2%
2016	9494159	11.5%	803732	-2.1%
2017	10596911	11.6%	900455	12.0%
2018	11535235	8.9%	996425	10.7%

C. Airlines Increase

A difference can be observed between increases of transport aviation airlines and general aviation airlines, shown in Table III [19]. General aviation airlines grew from 111 in 2010 to 422 in 2018 by 280.2%. The rapidest increase happened in the period of 2012 to 2015 in which the annual increasing rates are 18.7%, 29.5%, 26.5% and 17.6% respectively. This coincides with the rapidest increase period of general aviation fleet and flight hours. Such rapid increase did not happen in transport aviation industry. Transport aviation airlines grew from 43 in 2010 to 61 in 2018 by 41.9%. There was no increase in 2013 and two decreases in

2012 and 2017. Compared to general aviation airlines, it needs ten times money, staffs, resources and strict government certification to register and operate a transport aviation airline. This contributes to the lower increase rate of transport aviation airlines.

TABLE III. 2010-2018 TRANSPORT AVIATION AND GENERAL AVIATION AIRLINE NUMBERS AND INCREASING RATES

Year	Transport aviation		General aviation	
	Airline	Increasing rate	Airline	Increasing rate
2010	43	2.4%	111	-
2011	47	9.3%	123	10.8%
2012	46	-2.1%	146	18.7%
2013	46	0.0%	189	29.5%
2014	51	10.9%	239	26.5%
2015	55	7.8%	281	17.6%
2016	59	7.3%	320	13.9%
2017	58	-1.7%	365	14.1%
2018	61	5.2%	422	15.6%

D. Airlines Growth

It is hard to conclude that transport aviation industry grew slowly according to the lower increase rate of airlines. In transport aviation, aircrafts increased 127.8% and airlines increased 41.9% from 2010 to 2018, which means that airlines owned more aircrafts, i.e. airlines became bigger. At the end of 2018, two more transport aviation airlines grew their fleets to and over 50 aircrafts and became the 14th and 15th biggest airline in China, the list shown in Table IV. These 15 biggest airlines owned 3021 aircrafts, i.e. 83% of the whole country's transport aviation fleet, and consumed 273 of 342 new-coming aircrafts in 2018 [19].

TABLE IV. 2018 THE BIGGEST AIRLINES AND FLEETS

Airline	Aircraft at end of 2018	Aircraft at end of 2017
Southern Airline	628	565
Eastern Airline	537	504
Air China	447	429
Xiamen Airline	209	164
Hainan Airline	195	168
Shenzhen Airline	187	177
Sichuan Airline	148	132
Shandong Airline	122	113
Tianjin Airline	104	99
Shanghai Airline	103	93
Capital Airline	85	75
Spring Airline	81	76
Juneyao Airline	71	67
Lucky Air	54	46
Shunfeng Airline	50	40

III. TRANSPORT AVIATION SAFETY SKETCH

No indicator can accurately indicate the real situation of safety solely. It is internationally recognized to describe the safety level by accidents, incidents and victims. The less accidents and incidents happen or the less victims are, the higher safety level is.

A. Transport Aviation Accidents and Victims

It can be observed that the transport aviation safety level has been promoted in Fig. 1. Only 5 transport aviation accidents happened in the new century. The number of transport aviation accident decreases from 12 in 1990-1994 to 0 in 2005-2009. In this decade, only 2 transport aviation accidents happened. The latest transport aviation accident happened on May 10th, 2015, in which an Modern Ark 60 aircraft of Joy Air was damaged by heavy landing and no one was fatally or seriously injured. The latest fatal transport aviation accident happened on August 24th, 2010, in which an Embraer190 aircraft of Henan Airline was crushed and burned by landing out of runway and 41 passengers and 3 air crew were fatally injured. After that, no fatal accident happened in 106 months from September 2010 to June 2019. A new transport aviation safety record of 74.4 million flight hours is achieved.

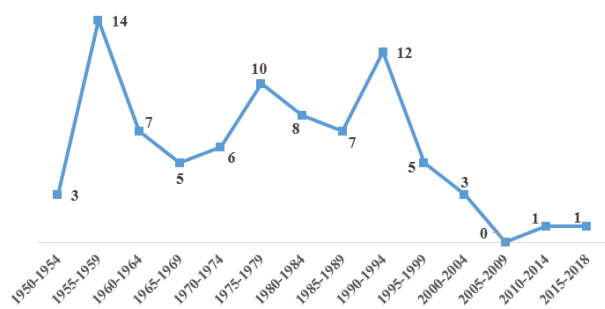


Fig. 1. 1950-2018 Transport aviation accidents

B. Transport Aviation Incidents

TABLE V. 2010-2018 TRANSPORT AVIATION INCIDENTS STATISTIC

Year	Transport aviation serious incident			Transport aviation common incident		
	Total	Human-factor serious incident	Percent of human-factor serious incident	Total	Human-factor common incident	Percent of human-factor common incident
2010	18	15	83.3%	178	8	4.5%
2011	11	9	81.8%	197	8	4.1%
2012	12	6	50.0%	254	12	4.7%
2013	7	3	42.9%	259	11	4.2%
2014	11	7	63.6%	295	16	5.4%
2015	8	2	25.0%	357	23	6.4%
2016	17	8	47.1%	496	24	4.8%
2017	20	7	35.0%	553	17	3.1%
2018	16	11	68.8%	552	19	3.4%

The numbers of transport aviation serious incident, the numbers of the serious incidents caused by human factors,

and the percentages of the human-factor serious incidents are shown in Table V, as well as the data of transport aviation common incidents in which severities are less serious. A difference can be found that the percentages of human-factor serious incidents are near or more ten times than the percentages of human-factor common incidents. This means that human mistakes and errors more likely result in safety occurrences with serious severities than the other factors such as bad weather conditions and malfunctions of system and equipment. Therefore this paper pays attentions in human-factors.

Noticeably, the most human-factor transport aviation serious incidents happened in 2010, in which the only fatal transport aviation accident in this decade happened, the percentage of the human-factor serious incident ranked the first and the number of serious incident ranked the second. The transport aviation serious incidents, human-factor serious incidents and their percentages gradually declined to a low level in 2015, synchronously. Although one aviation accident happened in 2015, the last transport aviation accident, no one was fatally or seriously injured. Synchronously again, the transport aviation serious incidents, human-factor serious incidents and their percentages rapidly increased in 2016-2018, shown in Fig. 2.

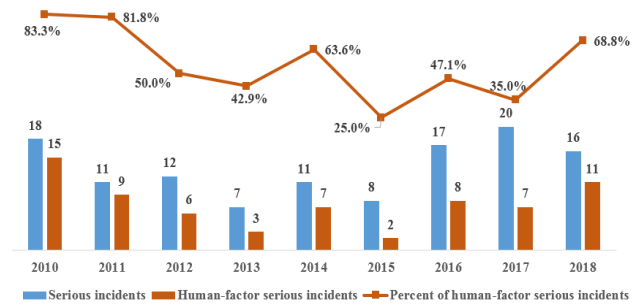


Fig. 2. 2010-2018 Transport aviation serious incidents, human-factor serious incidents and their percentages

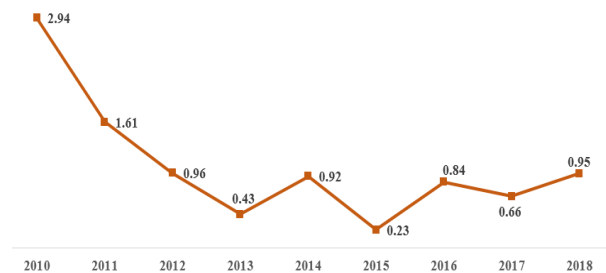


Fig. 3. 2010-2018 Human-factor transport aviation serious incident rates

Counteracting the contribution of aviation activities' prosperity, rates of human-factor transport aviation serious incident, i.e. the numbers of the incidents per million flight hours, are shown in Fig. 3. The rate declined in 2010-2015 and increased in 2016-2018. This fluctuation is similar and synchronous with ones of transport aviation serious incidents, human-factor serious incidents and their percentages.

It was noticed that the period of 2016-2018 is contemporary with the period of 2015-2017, in which transport aviation fleet and activities experienced the rapid development in this decade, details provided in II. INDUSTRY DEVELOPMENT DATA ANALYSIS. Strong relationships can be observed among transport aviation accidents, serious incidents, human-factor serious incidents and their

percentages and industry developments.

It can be found that at the end of 2018 the safety situation approached the situation in 2010 based on the comparison of data including transport aviation accidents, serious incidents, human-factor serious incidents, etc. shown in Table VI.

TABLE VI. SAFETY DATA COMPARISON BETWEEN 2010 AND 2018

Transport aviation	2010		2018	
	Number	Rank	Number	Rank
Accident	1	-	0	-
Serious incident	18	2	16	4
Human-factor serious incident	15	1	11	2
Percentage of human-factor serious incident	83.3%	1	68.8%	3
Rate of human-factor serious incident	2.94	1	0.95	4

C. Transport Aviation Risk Assessment

From the analysis of transport aviation development data and safety data, it can be found that:

- The probability and severity of transport aviation accident were well controlled in China.
- Transport aviation serious incidents, human-factor transport aviation serious incidents and their percentages increased in 2016-2018.
- The period of 2016-2018 is contemporary with the rapidest developing period (2015-2017).

Transport aviation risks are quantified by a model based on the Heinrich's Law combined with human factors and development factors and the result is shown in Fig. 4.

$$V_R = (N_H P_H + N_S P_S + N_I P_I + N_N P_N) \times D_F \times D_H \times D_A \quad (1)$$

Where V_R is the value of transport aviation risk, N_H is the number of human-factor transport aviation serious incident, N_S is the number of the other transport aviation serious incident, N_I is the number of human-factor transport aviation common incident, N_N is the number of the other transport aviation common incident, P_H , P_S , P_I and P_N are their powers respectively, D_F is the development factor of fleet, D_H is the development factor of flight hour, and D_A is the development factor of airline.

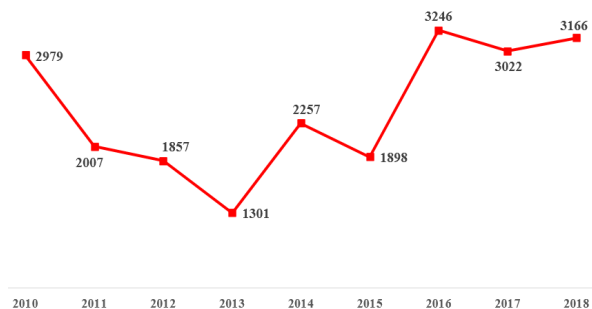


Fig. 4. 2010-2018 Transport aviation risk values

The transport aviation risk values in 2016-2018 are higher than the value in 2010. It can be concluded that a potential of one transport aviation accident is born and growing.

IV. GENERAL AVIATION SAFETY SKETCH

It is internationally accepted that general aviation has much more accidents and victims than transport aviation. Analysis in fluctuations and trends of general aviation safety indicators is more useful than the indicator comparison between general aviation and transport aviation.

A. General Aviation Accidents and Victims

The numbers of general aviation accident in every five years from 1955 to 1989 are almost above 20, with an average value of 22.28. The number decreases from 24 in 1985-1989 to 11 in 2000-2004. General aviation safety was promoted to a higher level in 1995-2004, the safest decade. But since 2004, the number increases continuously and rapidly at an average annually increasing rate of 51% and reaches a peak of 38, 31% higher than the historical record, at the end of 2018 shown in Fig. 5.

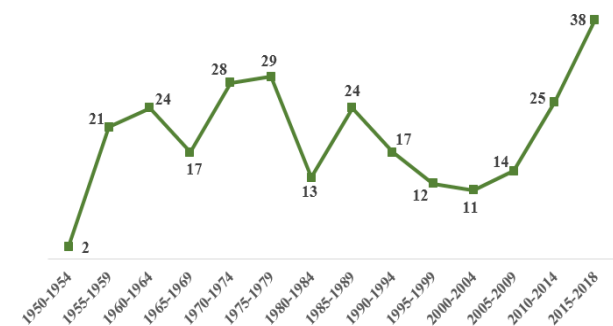


Fig. 5. 1950-2018 General aviation accidents

More details can be found at the annual statistic shown in Fig. 6. In last nine years, the numbers of general aviation accident and fatal accident raised up. The number of general aviation accident experienced a rapid increase in 2013, then declined a little, but reached the ceiling again in 2018. The number of fatal general aviation accident also increased without a continuous break and peaked to 8, 33% higher than the historical record, in 2018. The number of victim in general aviation accidents experienced a similar fluctuation.

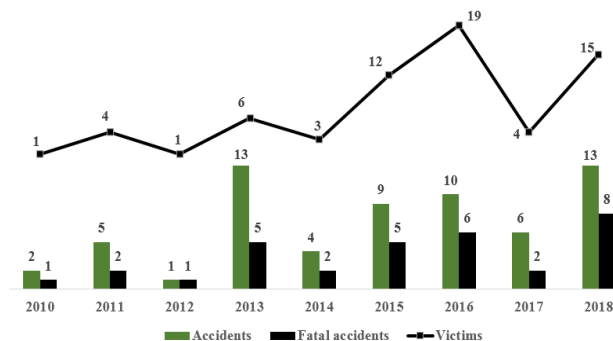


Fig. 6. 2010-2018 General aviation accidents, fatal accidents and victims

Counteracting the contribution of aviation activities' prosperity, rates of general aviation accidents, the numbers of accidents and fatal accidents per million flight hours, shown in Fig. 7, show the similar fluctuation shown in Fig. 6.

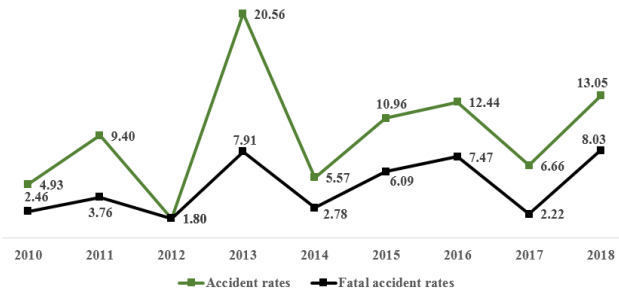


Fig. 7. 2010-2018 General aviation accident rates and fatal accident rates

Obviously, 2013 is a watershed, since which the numbers and rates of general aviation accident, fatal accident and victim moved to a higher level. 57.1%, 56.3% and 61.5% of general aviation accidents, fatal accidents and victims respectively happened in period of 2013-2016. This period is contemporary with the period of 2012-2015, in which general aviation airlines, fleet and activities experienced the rapidest development in this decade, details provided in II. INDUSTRY DEVELOPMENT DATA ANALYSIS.

It is also noticed that no improvement signal appeared at the end of 2018. Most of safety indicators broke, reached or approached the historical records in 2018 shown in Table VII.

TABLE VII. SAFETY DATA IN 2018

General aviation	2018	
	Number	Rank
Accident	13	1
Fatal accident	8	1
Victim	15	2
Rate of accident	13.05	2
Rate of fatal accident	8.03	1

B. General Aviation Incidents

General aviation incidents are classified to one type instead of two types of serious incidents and common incidents. The numbers of general aviation incident, the numbers of human-factor general aviation incident and the percentages of human-factor incident are shown in Fig. 8. The number of general aviation incident raised up to a higher level in 2013 and so did the number of human-factor incident and their percentages in 2015. Only fluctuation of general aviation incident number is synchronous with fluctuations of general aviation accident, fatal accident and their rate.

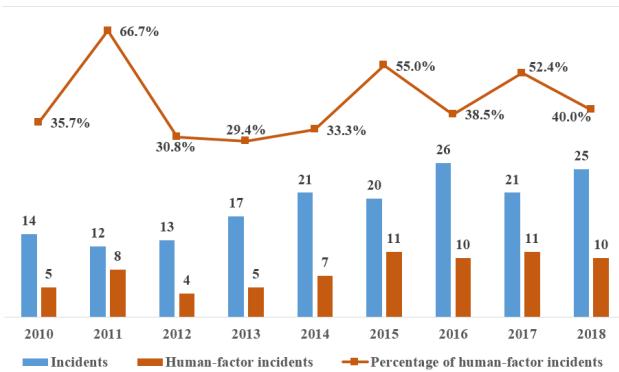


Fig. 8. 2010-2018 General aviation incidents, human-factor incidents and

their percentages

Counteracting the contribution of aviation activities' prosperity, rates of human-factor general aviation incident, the numbers of the incident per million flight hours, are shown in Fig. 9. The rate increased in 2012-2015 and decreased in 2015-2018. This fluctuation is not synchronous with fluctuations of general aviation safety indicators discussed above.

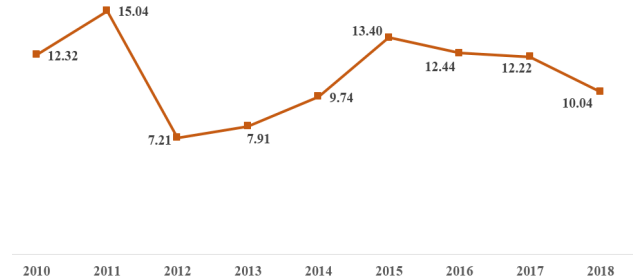


Fig. 9. 2010-2018 Human-factor general aviation incident rates

Only one general aviation incident indicator's fluctuation was found synchronous with fluctuations of general aviation accident indicators. Strong relationships were not observed among general aviation incident indicators and general aviation accident indicators. In certain degree, this difference between general aviation and transport aviation results from general incident classification mixing incidents with serious severities and incidents with slight severities together.

C. General Aviation Risk Assessment

From the analysis of general aviation development data and safety data, it can be found that:

- The probability and severity of general aviation accident were not well controlled in China.
- General accidents, fatal accidents and victims increased in 2013-2016.
- The period of 2013-2016 is contemporary with the rapidest developing period (2012-2015).
- General aviation safety situation in 2018 is the worst in this decade.

Because it is meaningless to predict whether a general accident will happen or not based on risk values, risk rates are introduced to measure general aviation safety level in unit time. Transport aviation risk rates are quantified by a model based on the Heinrich's Law combined with human factors and development factors and the comparison with general aviation risk rates is shown in Fig. 10.

$$R_R = (N_A P_A + N_B P_B + N_C P_C + N_D P_D) / H_F \quad (2)$$

Where, for general aviation, R_R is the value of risk rate, N_A is the number of fatal accident, N_B is the number of the other accident, N_C is the number of human-factor incident, N_D is the number of the other incident, P_A , P_B , P_C and P_D are their powers respectively, and H_F is the flight hours; and for transport aviation, R_R is the value of risk rate, N_A is the number of human-factor serious incident, N_B is the number

of the other serious incident, N_C is the number of human-factor common incident, N_D is the number of the other common incident, P_A , P_B , P_C and P_D are their powers respectively, and H_F is the flight hours.

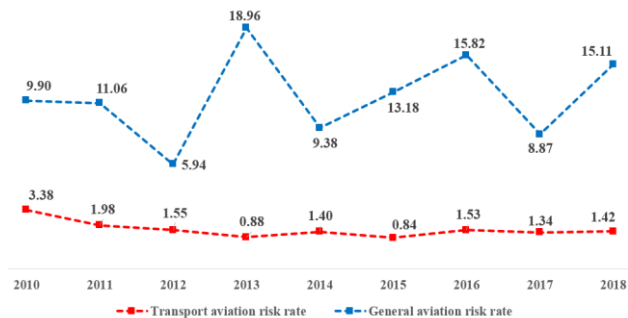


Fig. 10. 2010-2018 Transport aviation and general aviation risk rates

Comparing with the decline of transport aviation risk rate, general aviation risk rate increased to a high level in 2013-2018. It can be inferred that the capacity to control and reduce general aviation risks is weakened.

V. CONCLUSION

In summary, this paper analyzes China transport aviation and general aviation development data and safety data from 2010 to 2018. Risk assessments are conducted by a quantitative model based on the Heinrich's Law combined with human factors and development factors. According to the outputs of the quantitative model, it is concluded that China civil aviation is in a stage of high risks with a growing potential of one transport aviation accident and a weakened capacity to control and reduce general aviation risks.

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