Chapter 6
Assessing Safety of Dual-Purpose Systems

The review materials are presented that contain a summary of the main positions of the RRS doctrine and the SST tools in connection with the assessment of the prospects for the development of SMSs (AA SMS) and corresponding GOST-R standards in civil aviation of the Russian Federation, taking into account ICAO recommendations on the basis of Annex 19 for dual-purpose ATSs.

One of the areas of application of such SMSs is the helicopter industry, where safety issues are considered very deeply, but mainly from the standpoint of the requirement of operational documents (AFMs, instructions for piloting helicopters and rules for performing aerial works) [1–5].

In the helicopter industry, there are a large number of documents regulating the design and development of helicopters as general aviation, but there are also special industry requirements in the form of "OSTs". At the same time, international standards for safety management are also used.

6.1 Recommendations of ICAO Amendment No. 101 Regarding the Requirements for the Development of SMSs (AA SMSs) for Industrial Production

The content of ICAO Amendment No. 101 should be considered as an international standard for AA SMSs in the field of ensuring the safety of industrial production, products, and articles in the transport sector.

The importance of this amendment for the RF civil aviation is that SMSs should be created and implemented in civil aviation and in a number of industries that produce dual-purpose equipment. The main recommendation of the amendment for the issue is the need to provide acceptable levels of safety for the ATS use throughout the life cycle of ensuring the functional worthiness and airworthiness of products and processes for aviation equipment operation, taking into account the design and

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production stages. SMSs should be created taking into account this recommendation for both operators and service providers (according to Annex 19).

In this regard, the scientific provisions of the new doctrine “Reliability, risk, safety” are proposed to be used as a basis for a consistent (non-contradictory) combining of the RT requirements to the quality of industrial complexes and to the safety of the manufactured equipment on the basis of the risk indicators set out in the SST (Chaps. 1 and 2).

The problematic issues that need to be addressed are:

1. Definition of a list of standards required to ensure compliance of technical and economic characteristics (TECs) of products with Amendment No. 101.
2. Development of procedures for *recalculating the residual production risk* into ATS operational risks during their life cycle.
3. Standardization of modules and procedures for risk analysis and ATS state management taking into account hazards in the MCFs (“minimal cut set of failures”) and in J. Reason chains.
4. Creation of the classifier of industrial safety by types of articles production.
5. Development of procedures for analysis of risk trends, depending on ATS key hazard factors from possible threats (IOSA type standard).

6.1.1 Classifier of Industrial Safety Types in the System Safety Theory

The need to create a classifier of this type, industrial safety (IS), is associated with a large difference in safety requirements for products and samples of equipment in different industries. This applies in particular to the specifics of the methodology for calculating the risks of adverse consequences during the life cycle (LC) of products and articles. The functional SST module is proposed as a basis of the IS classifier (from Chap. 2 of the book), as well as the principle of assessing the significance of the risks of rare events such as “catastrophes” with the “near-zero” probability. Thus, from the classical RT follows the need to take into account, according to I. Aronov (Chap. 1), the factors of “passive safety” ($F1$—in the form of design requirements usually controlled by industry acceptance procedures) and operational factors ($F2$) included in the rules for the operation of industrial products. This approach makes it *possible to monitor the safety state on the basis of the acceptable risk concept* [6–11].

The types of industrial safety (IS) are as follows.

(a) Types of industrial safety by factor F1, which are determined by standards for production of “cars”, “air and sea vessels”, “buildings and structures”. Within the classical theory of product reliability, the following principle is usually used: “to ensure the capability of equipment ($F1$) to withstand external force loads that vary over time”. This distinguishes “structural safety” in the group of functional failures by "design factors"—$F1$, according to I. Aronov ("passive safety") [12].

(b) The safety of the system operation is determined by the second factor $F2$ for functional failures (FOs) from the "operational" class in the form of consequences and harm arising from equipment failures and multiple events from MCFs during operation taking into account the impacts and the manifestation of human factors (HF).

The general classifier of IS types will be as follows:

(a) ***PB-1—for energy systems and production*** as a function of factors $F1$ *and* $F2$ characterizing nuclear power plants, hydropower plants, chemical plants, transport hubs such as large airports (Domodedovo, Khitrovo, etc.) and seaports (St. Petersburg, Nakhodka, and others).

b) ***PB-2—for production complexes and corporations*** producing technology-intensive small-scale products significant in terms of IS indicators: production of aircraft in the Russian Federation within the UAC system, Boeing Corporation, Airbus, and also in the production of railroad and motor transport, the production of nuclear vehicles, including nuclear-powered submarines (NPSs).

(c) ***PB-3—production of various products safe for use by the human population*** (household appliances, medicines and food products, etc.).

The book proposes to use convenient indicators of the level of safety in each of the IS types through the level of risk per the SST—not only "probabilistic" ones. Thus, it is proposed to adopt the RRS doctrine.

6.2 Methodological Basis for Implementing the Recommendations of Amendment No. 101 on the Basis of ILS Principles

6.2.1 IS Monitoring Subsystems

The classifier of industrial safety types developed taking into account the RRS principles makes it possible to designate and apply practically two most important *indicators of production quality* in the IS sphere, such as "safety" and "reliability", in the simplest way [13].

It can be assumed that it is this approach in the ILS system with the use of the MEL and MSG strategy that provides a high level of industrial safety for Boeing and Airbus aircraft operated in civil aviation of the Russian Federation.

Three main subsystems of the ILS system are shown in Figs. 6.1 and 6.2.

It is shown that the ILS-based "*safety monitoring*" *allows maintaining the "residual risk"* at an acceptable level and even reducing operational risks if the MSG and MEL strategies are adopted (as in "Airbus" company) [14].

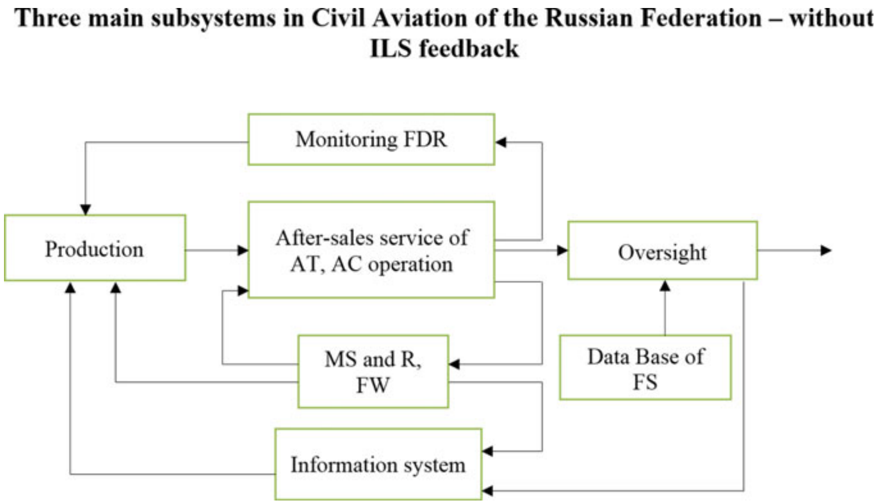

Fig. 6.1 QMS & SMS Interaction (upon A. Ynoussy)

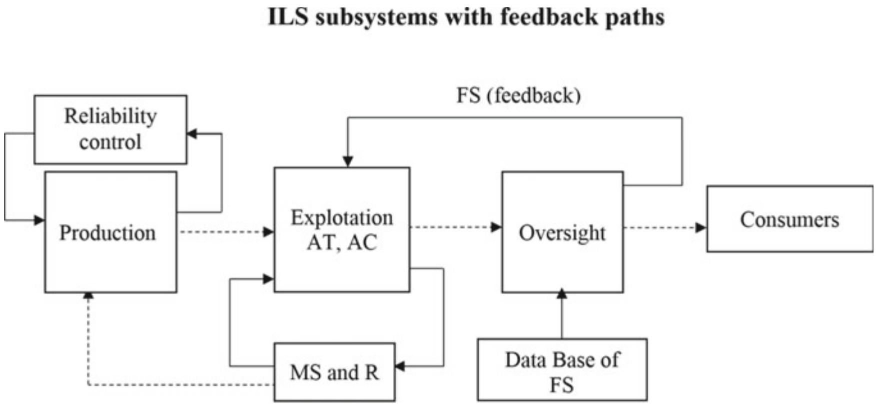

Fig. 6.2 Feedbacks in blocks for RS & FS

Figure 6.1 shows subsystems for maintaining aircraft airworthiness without feedback paths typical in the past for traditional production of aircraft and ATSs in the Russian Federation. This was done on the basis of the classical RT methods, i.e., without adjusting for flight safety indicators. Currently, the adjustment for flight safety is mandatory.

In this scheme, the after-sales service of AE is practically absent from the manufacturer's list of spare parts supplies. Proactive flight safety management on the part of the manufacturer by factors $F1$ *and* $F2$ is provided insufficiently.

Monitoring and control of *"residual risks"* for ATSs by $F1$ are not fully predicted.

In these schemes, the *after production "residual risk" can be significant*. However, with the transition to the *continued airworthiness technology by the "technical condition"*, taking into account the flight safety index, the MEL program, and the new standards, it is possible to keep the "operational risk" $\hat{R}_0$ at an acceptable level: Equation Chapter (Next) Sect. 6.6

$$\hat{R}_{0x} \sim \left(\hat{R}_0 < \hat{R}_{0x}\right). \tag{6.1}$$

A similar scheme was introduced into the K-32 helicopter operation system [15].

In particular, it is allowed to maintain the residual risk $\hat{R}_0$ in the industrial safety with the level of the risk event R by probability at the following level:

$$\mathrm{P}(R|\ \Sigma_0) \sim \mu_{1\,P} \cong 10^{-6}. \tag{6.2}$$

Other levels cannot be assigned, as it will be not provable and unacceptable. But worse values of up to ~10^{-3}, 10^{-4} are allowable, although undesirable. These are allowable, since due to new maintenance and repair technologies it is possible to keep the overall level at an acceptable level of risk.

6.2.2 Functions in the ILS System for Airbus Aircraft

An overview of the continued airworthiness functions of these aircraft is provided here in order to demonstrate the benefits of flight safety management methods based on risk calculation (e.g., per the RRS).

The features of the ILS system under consideration per in Fig. 6.2 are as follows.

1. The after-sales service of aircraft with the supply of spare parts from the manufacturer for maintenance and repair is provided throughout the life cycle of ATSs.
2. Mandatory monitoring of risks in civil aviation using FDR and ACARS for checking residual risks and reliability indicators provided by the ATS manufacturer.
3. The reliability of the aircraft functional systems is monitored by the acceptable level of risk $\tilde{R}_{0*}$, i.e., $\mu_1 \sim P_0$ based on redistribution of risk by the PSA method (by I. Aronov).
4. Proactive management of calculated risks in airlines (or by providers) is provided taking into account the results of the PSA, the safety assessment for aviation activities in accordance with the level of acceptable risk based on integral criteria with an assessment of financial costs for flight safety and compensation for non-pecuniary damage. Such technology of flight safety provision even with high *"residual risks"* allows reducing the cost of aircraft production, as *high reliability of product complexes due to multiple redundancy is not required*. A model of the ILS system application in Russian aircraft is the system of maintenance and repair planning, and maintaining continued airworthiness of AN-148 aircraft.

> The Antonov Experimental Design Bureau (Ukraine) developed guidelines for the MEL and MMEL programs by analogy with Boeing aircraft.

In addition, the MMEL guidelines for AN-148 aircraft contain the rules for checking and *replacing units* on the basis of "risk indicators". The *risk assessment methodology is not presented*, but there are references to the ATS manufacturer [16].

The noted problem is solved quite simply within the RRS doctrine. At the same time, it is possible to explain the essence of the ATS manufacturer's procedures. But for this, it is necessary to create a set of corresponding new standards in civil aviation of the Russian Federation. The minimum number of various standards required to implement the above methodology for calculating risks is about 500 documents.

6.3 Evaluation of the Prospects for Transition of Civil Aviation of the Russian Federation to the New IS Standards and Provision of After-Sales Services for Industrial Production (F1 Factor) and Operation of Equipment (F2 Factor)

6.3.1 Status of Development

It was noted above that the systems of the type considered are developed and implemented at various scales of performance and significance in the Western aviation community in relation to the production and operation of Airbus and Boeing aircraft, types A-320, B-737, A-380, B-747, B-767, etc. The regulatory requirements for the system are set forth in the IOSA (IATA) documents [17–19]. The main characteristics of the ILS systems for the production and operation of aircraft are as follows: maintenance of standard safety indicators, organization of the maintenance and repair system in accordance with the principle of continued airworthiness of aircraft according to their technical condition, flight safety management through SMSs, analyzing aircraft flight parameters using onboard recorders FDRs, and real-time monitoring of aircraft flight parameters based on ACAR (ACARS) systems for modern aircraft similar to A-380 [14].

Possible areas of IS system modernization are identified here as first approximation on the basis of analysis of the results and consequences of known *"accidents", "catastrophes",* and abnormal *"natural phenomena"* (such as *"floods", "tornadoes", "snowfalls", "temperature drops", "massive fires"*).The main areas are the following: *abandoning the principle "if it is reliable, then it is safe"* and the transition to the principles of "risk calculation" according to Annex 19, including RRS and SST principles.

6.3.2 *Structure of the Set of Standards*

The Ministry of Transport of the Russian Federation acknowledged that it is necessary to create an SMS of international type in the civil aviation of Russia in the form of AA SMS based on ICAO SARPs and Annex 19 [8].

The main requirements and the list of SMS modules are presented in the paper of Amir Yunossi's group from the FAA (in the "Blue folder" [20] as described in Chap. 4 of this book).

The method of probabilistic safety analysis is described in the NASA document (2002–2007) "Probabilistic Risk Assessment Procedures for NASA Managers and Practitioners" (Version 2.2.—Washington, DC 20546, Aug. 2002)—its content is presented in the appendix to the book.

The structure of the set of standards required to regulate aviation safety regarding helicopters is given in Fig. 6.5. The issue of creating standards for helicopters (as GPA) is considered to be a priority, as noted above, since the number of such documents in this domain is small. On the scale of civil aviation of the Russian Federation, the number of standards in the field of flight safety is also small, but at least international trends in Annex 19 are taken into account.

6.4 MSG Strategy for the Development of a Maintenance and Repair Program (Reliability) for Western-Made Aircraft

Some features of these programs are considered in order to assess the possibility of increasing flight safety based on the recommendations of Annex 19 and the RRS doctrine.

6.4.1 *Maintenance Program Structure*

The baseline of the programs is the requirements for ensuring flight safety, reliability (fail-safety), and maintainability (serviceability).

1. If a failure or combination of failures of elements affects flight safety, then with increasing failure rates, the following options are possible: The element is serviced according to the operating time or considering its state with some parameter control. However, the documents [21] do not address the following issues: How to assess the change in safety levels for various maintenance and repair strategies?

6.4.2 Aircraft Maintenance and Reliability Assurance Programs in MSG-1, MSG-3

Such programs are mainly studied and developed in FSUE State Research Institute of Civil Aviation (GosNII GA).

Three phases are established for the production and application of ATSs with monitoring of parameters in scenarios with functional failures.

Stage* 1 *(Phase* 1*)—achievement of standard RT indicators on the basis of the PF without taking into account the requirements for industrial safety.

Stage* 2 *(Phase* 2*)—providing indicators of high reliability of systems, taking into account the requirements of industrial safety and norms of the "residual risk" during their life cycle, based on the industrial ILS strategies for Ka-32 helicopters (research of "Aviatekhpriemka", research director is Evdokimov V.G.).

Stage* 3 *(Phase* 3*)—assessing and maintaining the level of system safety (IS) by managing risk parameters based on proactively identified risk factors and types of risks for selected systems by functional failures.

The action strategy in civil aviation of the Russian Federation within the RRS doctrine in the transition to the IATA ILS system

The main requirements are as follows: The *system produced must be highly reliable*; the manufacturer of the equipment must provide quality (RT property) such that the "residual risk" ***by the probability of a risk event*** is ***not worse than*** $\mathbf{10^{-4}–10^{-6}}$. (This indicator is established by the ATS developer in agreement with the operator).

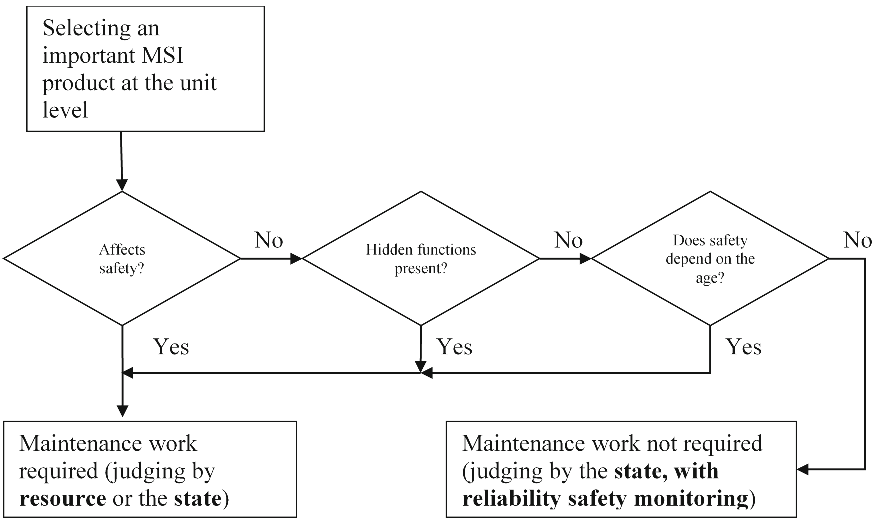

Fig. 6.3 Simplified block diagram of the MSG-3 analysis

MSG-1/2	HT	OC	CM	–		–
	MSG-3	DS/RS	IN/OP/FC	–	SV	LU
Affects safety	With the MSG analysis	X	X			
Hidden functions present		X	X			
Affects efficiency		X	X		X	X
Affects operation		X	X		X	X
Authority requirements		X	X			
Limitation of service life		X				

Fig. 6.4 Selection of maintenance methods

CONTROL DIAGRAM
FOR HELICOPTER FLIGT-SAFETY
SERVICE PROCEDURES

A. Modules of "Flight worthiness"

A1 *– Logistic and lysis of the Maintenance*

A2 *– Development of Maintenance and Repair System*

A3 *– Development of Suporting System for Flight Worthness*

B. Contents if A – procedures

A1 *– Reliability.*

A2 *– Concept of MRS/ Development*

A3 *– Codifications. Initial Parameters of MRS. Control system of Details Supply and Scores for Bying of Helicopters.*

Notes: **MRS** – Maintenance & Repair System

Fig. 6.5 Scheme of FS-service procedures

In developing a system as a whole and AA SMS modules for JSC "Russian Helicopters", provisions from the AA safety management methodology and principles of risk calculation and management are applied taking into account the recommendations of the ICAO Annex 19 (version of 2012).

When operating systems, the second factor $F2$ is considered—an "operational" one characterizing effects and harm to consumers due to "failures" of products or ATS system as a whole when using the AE influenced by the external environment and existence of internal adverse factors in the system (with loss of AE functional properties) (Fig. 6.3).

The scheme for analyzing ATS properties according to MSG-2 [16] is shown in Figs. 6.4 and 6.5.

6.5 Design Requirements for Ensuring Flight Safety of Helicopters with an External Cargo Sling Load System

6.5.1 Methodical Approach to the Formation of the Logistic Support System for the After-Sales Service of Ka-32 Helicopters

A helicopter of this type is a sample of dual-purpose aircraft. In this regard, this section provides a scheme for implementing the methodology of logistic support for ensuring the airworthiness of dual-purpose aircraft using the example of the Ka-32 helicopter [1].

The task of creating an SMS within a set of requirements for ensuring industrial safety is solved, taking into account the recommendations of ICAO amendment No. 101 on how to compensate for the residual risk due to systematic errors in the design and manufacture of Ka-32 helicopters. For helicopters such as MI-27, K-32, design features of the surveillance system in the cargo cabin of the external sling load system should be known, especially when cargo is transported by two helicopters with some beam suspension system.

It is important to establish requirements for ensuring flight safety in the performance of aerial works with cargo on external suspension.

The basic theoretical provisions adopted in this book are that when developing an SMS, the ICAO definition is taken into account: "*Risk is an amount of hazard in the system by the factors of random occurrence of a risk event and damage*", which is constructive. Types, consequences, and criticality of failures of the main units, components, and assemblies of the system safety are analyzed according to Technological Diagram [8]:

It is proposed to consider some features of the development of the classification of industrial safety types in an AA SMS for helicopters.

6.5.2 Recommendations for Helicopter SMS Development Strategy

The AA SMS for helicopters should be developed with the requirements of ICAO Amendment No. 101 in mind. Therefore, it is necessary to take into account the features of the industrial safety concept and not only the type of flight safety that is studied in operation of various types of aircraft. The key point in this case is the identification of factors of "structural safety", which significantly affects the choice and maintenance of an ***acceptable level of residual risk***.

In the case of helicopters, these are factors ***F*-1** (in *IS*-2), for example, onboard display facilities, navigation instruments, communication with ***GLONASS or GPS*** satellite systems, and the location of the cargo suspension assemblies (at the center of mass or at the bottom of the hull, presence of sensors detecting the resonance of helicopter blades, vibrations of engine shafts and bearings, etc.). To this end, the following known principles, as formulated above (by ICAO), are adopted for the SMS.

***Principle No.* 1**. Ensuring high reliability of the system, in particular, by creating and applying multiple protection lines. According to the PSA recommendations (from Chap. 1 of this book), it is shown that the guaranteed residual risk $\Delta\hat{R}$ for the system in terms of the probability of a risk event should be typical at the level of 10^{-4}–10^{-6}—not worse—per year or for a given period T of system operation (i.e., up to 10^{-4}–10^{-6} for the frequency of one catastrophe per year, e.g., for NPPs, according to IAEA). Then the integral risk $\Delta\tilde{R}$ must correspond to the PSA norms for the risk event R :

$$\Delta\hat{R} \sim (R/\Sigma_0)\ 10^{-4} - 10^{-6}(\text{for the NPP life cycle})$$

Classification of ATSs and types of AA as hazardous and safe when using helicopters for aerial works is performed on the basis of the ICAO risk concept by proactively establishing the possibility of occurrence of hazardous (risk) events with two properties in ATSs.

***Principle No.* 2**. Assessing risks of catastrophes based on the provisions of the new doctrine (RRS from the SST) by searching for catastrophes using chains of events such as J. Reason chains without using probabilistic indicators, but with risk indicators and comparing them with acceptable levels of risk.

***Principle No.* 3**. Synthesis of preventive corrective influences on the system for ensuring safety taking into account the risk factors on the set of identified possible paths to a catastrophe (without the PSA methods and *without probabilistic indicators*) by the ICAO tuple (4.8) from Chap. 4. The structure of the safety assurance system and the characteristics and the application of a given number of protections are changed considering the system safety indicators if these protections provide a method for reducing risks of catastrophes.

6.6 Importance of the New RSS Ideology (Adopted in the SST for Flight Safety Evaluation) for Science and Practice in Comparison with Russian and Foreign Approaches to the Construction of Safety Management Systems Based on the Calculation of Risks

6.6.1 Assessment of the Significance of RRS Methods for Evaluation of ATS Operation Safety

In light of the new RRS doctrine, one has to consider the PSA approach intensively developed in the classical RT in the last two decades, as conditioned by the rigid need to solve the problem of evaluating ATS safety level for rare events, but *within the principles of the hypercube of truth (Boolean lattice)* [15] that proved to be difficult.

The strongest positions in the PSA method that were put forth within the classical RT by Malinetskiy [22] ("heavy tails") and M. Fujita *"On confidence domains for determining the values of the probabilities of processes in the regions of pdf "tails"* [23] cannot solve the problem.

Malinetskiy [22] *proposed, in fact, a constructive, very important way of searching for the lower limits of pdf "tails"*, but also, as *M. Fujita, could not find a way to determine the reliable formula for pdf.*

The actual tasks are: *confirmation of the priority importance of the RT to ensure high reliability of systems* up to the boundaries of the still distinct significance of the probability of a risk event—up to 10^{-6} (not better, according to the GOST-R standard). The second aspect of this statement boils down to the fact that it is necessary to *ensure, with the help of the PSA, the solution of only correct tasks to assess the operability of systems* using the PF of LAFs type and others and at the same time ***transfer the solution of all "safety" issues to the domain of fuzzy subsets***;

In connection with this, it is proposed to substantiate in the *SST a completely different apparatus of a "fuzzy subset method" type to find solutions for assessing system safety based on the logic of calculating risks in fuzzy measures*.

6.6.2 List of Projects of Scientific and Technical Research on the Implementation of the SST Provisions in Flight Safety Management Systems

Themes of possible projects

The development of standards for the calculation of risks and the substantiation of SMS requirements based on the SST provisions should be recognized as the most important research domain. At the same time, it is necessary to take into account aspects of the "rare events problem", methods for constructing J. Reason chains, hazard models (by ICAO, per the SST), to consider physical and Boolean bases of the universal (clear) set of facilities of real technical systems, to apply the "minimal cut sets of failures", etc.

Domain No. 1. *Standardization of SMS terms, definitions and structures, taking into account the provisions of the RRS doctrine together with the SST.*

At the Assembly No. 37 (October 2010), ICAO adopted a resolution to establish a working group with representatives from the IAC, the RF, and the Air Navigation Commission (ICAO) to develop issues in this domain in connection with the preparation of the ICAO standard for SMSs (in the form of Annex 19).

Domain No. 2. *Organization of cooperation with "Airbus" and "Boeing" corporations (within reasonable limits).*

This is necessary, since the practical achievements of the aviation community in the application of the methodology for calculating risks for assessing the flight safety level are quite significant.

This is especially noticeable in the development of technologies to maintain the airworthiness level of operated aircraft, taking into account the *maintenance and repair* systems based on the *MSG and MEL* strategies.

The content of procedures and algorithms to ensure industrial safety includes the development of methods to maintain functional worthiness (or functional reliability) in the field of production and operation of dual-purpose equipment with the provision of standard reliability indicators in the life cycle of products.

The *scientific "breakthrough"* is the development of theoretical foundations for solving the rare events problem based on the application of the methodology for assessing the quality of functioning of a complex system with *fuzzy subsets* of hazardous (risk) event classes predetermined in the classical RT.

The *technical result* should be considered as the practical application of the developed approach on the examples of SMSs in civil aviation in the form of algorithms, procedures, and computer programs providing creation of databases on risk factors, identifying conditions for the occurrence of catastrophes and the development of safety management methods in civil aviation by changing current and predicted states of systems taking into account manifestation of risk factors in systems. The effectiveness of applying new approaches such as "J. Reason chains", as well as the method of creating barriers and proactive management of the system state based on "*common sense*", as in Arzamas-16, is established.

The list of indicators of the AA safety level regulated by ICAO through Annex 19 is defined within the methodology for calculating risks using special tools for measuring and identifying risks and threats based on approaches to solving the rare events problem (per ICAO—events with the "near-zero" probability) without the use of probabilistic indicators and PSA calculations.

The methods of the classical reliability theory are used as tools for creating highly reliable systems at the stages of design and manufacturing helicopters and maintaining airworthiness at various stages of the products life cycle.

6.7 Conclusions

1. The main result of this chapter is that when assessing risks in the field of fuzzy subsets, it becomes correct and simple to calculate the risks only for "damages" and only for one value of the event randomness measure with the "near-zero" probability. This is justified by the fact that the level of high reliability of the system and the "rarity" of hazardous events is guaranteed through the introduction of quality management systems and "reliability" standards, especially for dual-purpose equipment.
2. *The task is to move to the new ICAO flight safety (and industrial safety) programs with the new doctrine "Reliability, Risk, Safety" within the system safety theory developed with due regard to Annex* 19.

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