Chapter 8

Crew Resource Management, Risk, and Safety Management Systems

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8.1 SAFETY MANAGEMENT SYSTEMS

The Federal Aviation Administration (FAA, 2015) defines safety management systems (SMS) as a "comprehensive and preventative approach to managing safety" (p. 1). The International Civil Aviation Organization (ICAO, 2013) uses a similar definition and articulates equivalent processes in a detailed safety management manual. In fact, the ICAO has recommended its member-states to implement SMS (Hollinger, 2013). SMS builds upon the organization's safety culture rooted in safety policy, and emphasizes three fundamental ongoing processes of safety risk management, safety assurance, and safety promotion. This requires some definitions. Antonsen (2009) defined *Safety Culture* as the product of formal measures taken to minimize risk to an acceptable level and to ensure that stakeholders feel secure and in control, and the informal understood priorities of the organization and key subgroups within it. From this perspective, SMS is one of the formal measures, accompanied by procedures, training, and reporting and monitoring systems. But informal measures, the perceptions of frontline workers and supervisors of how work is to be accomplished, are also critical. Culture is an emergent product of both—leaders may influence culture by what they say and write into procedure; employees act upon both what is stated and what they understand. So the SMS Advisory Circular emphasizes that culture cannot be "created or implemented, but [emerges] over time and as a result of experience" (p. 7). *Safety Policy* is often the highest level public statement of that safety culture, wherein senior management clearly articulates its expected standards of performance and how the organization approaches

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risk. An SMS becomes the formal mechanism by which an airline makes decisions about risk. The Advisory Circular states the following requirements for Safety Policy:

§ 5.21 Safety policy.

1. The certificate holder must have a safety policy that includes at least the following:
   a. The safety objectives of the certificate holder.
   b. A commitment of the certificate holder to fulfill the organization's safety objectives.
   c. A clear statement about the provision of the necessary resources for the implementation of the SMS.
   d. A safety reporting policy that defines requirements for employee reporting of safety hazards or issues.
   e. A policy that defines unacceptable behavior and conditions for disciplinary action.
   f. An emergency response plan that provides for the safe transition from normal to emergency operations in accordance with the requirements of § 5.27.
2. The safety policy must be signed by the accountable executive described in § 5.25.
3. The safety policy must be documented and communicated throughout the certificate holder organization.
4. The safety policy must be regularly reviewed by the accountable executive to ensure it remains relevant and appropriate to the certificate holder.

FAA (2015, p. 16).

Safety Risk Management is a formal process of identifying risks faced in an airline's operations, deciding which risks are acceptable and which require mitigation, documenting those decisions, and implementing them in the policies, procedures, training, and infrastructure of the airline. Were an airline built from scratch using this approach, decisions about which aircraft to purchase, what airports to serve, where to perform maintenance, and how to document policy and procedures and accomplish training of various workforces would be included. But, most airlines predate SMS. It may be straightforward to make post-SMS implementation decisions in this manner, but it is challenging to develop an inventory of past decisions and a profile of airline risk. Ideally, SMS would result in a present-state inventory of hazards, the risks they present to the airline, and the mitigations in place. Continued application results in disciplined decisions about revision to operations to conform with the airline's approach to safety management.

Safety Assurance involves the monitoring and measuring of the airline's daily activities to ensure that the level of safety achieved matches expectation and that policy and risk mitigation are functioning as intended. Airlines use flight operations quality assurance (FOQA; FAA, 2004a; monitoring flight performance data downloaded from aircraft), Aviation Safety Action Programs (ASAP; FAA, 2002; reviewing safety concerns and events reported by pilots, dispatchers, mechanics, and other employees), line oriented safety audits (LOSA; FAA, 2006a; collecting standardized observations of samples of flights), training data from Advanced Qualification Programs (AQP; FAA, 2006b; collecting performance data from simulator and line flight evaluations), and other programs to observe and quantify risk. This both feeds back to formal decisions and policy and makes the airline aware of emerging hazards.

Safety Promotion communicates to each employee group its safety functions and how the airline expects them to respond to hazards and approach risks encountered on the job. This includes both training necessary to qualify and maintain qualification and policy, procedure, and *ad hoc* publications. "Because a key component of SMSs is the effective control of risk, every member in your organization must understand and take responsibility for the role they play in controlling risk by their actions and behavior" (FAA, 2015, p. 46).

So, how might this approach be applied? Consider the case of a hypothetical airline that has identified a potentially lucrative market operating from a US hub to a Central American resort destination. While its airport is near sea level and the majority of its days are sunny and clear, the airport is surrounded by mountainous terrain and experiences tropical rainfall and low visibility on occasion. The SMS accountable executive conducting the safety assessment notices that the airport has an instrument landing system (ILS) to approach the single runway from one direction, but a nonprecision approach (no vertical guidance) using only the VOR on the field from the other. However, both a circle-to-land maneuver from the ILS approach and a GPS-based nonprecision area navigation (RNAV) approach overlaid upon the VOR approach have been published. The executive calls together a team of technical, training, and management personnel to assess the hazards. They identify terrain as a hazard to operations during night or low visibility approaches to the non-ILS runway, and determine that the circle-to-land maneuver, backed up by the Ground Proximity Warning System (GPWS), does not provide sufficient mitigation under the airline's safety policy. What mitigations might the airline apply? They might require use of the ILS and prohibit operation to the non-ILS runway during low visibility or night, but this would on some occasions prohibit dispatch to the airport and in others could require diversion to another airport due to a tailwind exceeding limitations at time of the approach. With a nonprecision approach to the other runway, these could be overcome, but nonprecision approaches are empirically more risky than precision approaches (Flight Safety Foundation; FSF, 2000). Our hypothetical airline prefers GPS/RNAV approaches with constant-angle descent guidance where available. Consistent with that, the airline could require that only aircraft also capable of using the GPS overlay of the nonprecision approach be dispatched to the airport. This disqualifies aircraft not equipped with GPS receivers and crews not qualified or current on this type of approach. Ultimately, the team chooses this solution, adds a note to its flight manual prohibiting circle-to-land maneuvers and requiring use of the ILS or the GPS overlay to their respective runways during night and instrument meteorological (IMC) conditions. They publish a special note on flight plans to the destination to highlight the requirement, and incorporate the airport into the airline's qualification and continuing qualification simulator training for the coming year.

Notice the assessments conducted, hazards identified, and mitigations selected; these are the essence of the Safety Risk Management process. Notice also that it would be legal to operate into the airport with none of these mitigations in place. Compliance with published circle-to-land maneuvers meets FAA and ICAO requirements for terrain separation. But our hypothetical airline has formalized its safety policy, a process of risk management, and implemented a set of mitigations which set a higher standard of safety. The team's decisions do not preclude the ability to dispatch or operate into the airport. Safety assurance could be applied here by timely review of FOQA data, reminding pilots to report any anomalous conditions encountered at this airport, increasing the frequency of line evaluations on this route, or making it a target of LOSA observations. Safety Promotion was incorporated into the flight plan alerts and manual notes, incorporation of the airport into simulator training, and could be enhanced by *ad hoc* publications discussing the airport or the airline's implementation of SMS. A direct link to crew resource management (CRM) training is possible as well—the airline might choose to emphasize strategies for terrain awareness and avoidance at both the policy and crew level as part of its qualification or continuing qualification CRM training.

How might SMS actions or deficiencies be observed following an accident? On August 14, 2013, UPS Flight 1354, an Airbus A-300-600 crashed short of the runway at Birmingham, Alabama (National Transportation Safety Board; NTSB, 2014). Runway 06/24, the longest available at the airport was noticed to be closed for maintenance at the time of the approach. Weather was overcast with low and variable ceilings in predawn darkness. The open runway 18 had a nonprecision approach using a localizer, and a GPS-based nonprecision area navigation (RNAV) approach. The Captain briefed the RNAV approach to runway 18, to be flown in profile mode—the aircraft autopilot and flight guidance would be coupled to the localizer and would provide a calculated constant descent angle from the final approach fix to the decision altitude of 1200 ft above mean sea level (ft msl), where the crew must decide to continue to land or execute a missed approach. But when cleared for the approach, "the Captain did not request and the First

Officer did not verify that the flight plan [in the Flight Management Computer (FMC)] included only the approach fixes; therefore, the direct-to-KBHM leg that had been set up during the flight from Louisville remained in the FMC. This caused a flight plan discontinuity message to remain in the FMC, which rendered the glideslope generated for the profile approach meaningless" (p. xi). As a result, when the Captain reached the final approach fix, no vertical guidance was provided. Starting the descent late, he attempted to complete (without announcing) the nonprecision approach by switching the autopilot to vertical speed mode and monitoring the published step-down fixes and altitudes. The First Officer, noticing the mode change, made the 1000 ft above field elevation callout, but not the decision altitude callout. Descending at a high rate, the aircraft flew through the decision altitude. A "sink rate" warning was annunciated by the Ground Proximity Warning System (GPWS) and the Captain reduced the descent rate as he reported the runway in sight. However, the descent rate remained at about 1000 ft/min, and the aircraft impacted trees about one mile short of the runway and then the ground, killing both crewmembers.

What were the hazards faced by the crew? Early morning darkness and IMC. A closed runway requiring an approach to a shorter runway with only a nonprecision approach available. Terrain up-sloping to a forested ridgeline north of the airport. An approach time at the window of circadian low for crew alertness, meaning a high potential for fatigue. What would an SMS do with any of these hazards in advance of this accident? The NTSB investigation identified a number of actions by the airline evidencing SMS application to this airport and similar circumstances and mitigating a number of hazards for this flight. For example, nighttime instrument approaches using a nonprecision approach are empirically challenging, but the airline had equipped its aircraft with GPS receivers enabling the crew to fly the RNAV approach to 18 and had trained crews to proficiency on the procedures. (The A-300/600 had been manufactured prior to implementation of these technologies for airline operations but with the ability to add them when certified for use.) Only the Captain's switch, mid-approach, to a more manual operation (vertical speed attempting to honor altitude restrictions) removed that layer of protection. The airline had in place training on the consequences of fatigue, a fitness for duty policy and fatigue risk management plan published in the Flight Manual, and a fatigue event reporting and review process. (The NTSB was critical of how the First Officer used her off-duty time during the trip, failing to take advantage of rest opportunities, as evidenced by her smartphone usage.) The airline had implemented a stabilized approach policy requiring abandonment of an approach if the aircraft were descending at a rate greater than 1000 fpm below 1000 ft above the field. The accident approach exceeded the criterion, but was not abandoned by the crew. The NTSB did note that the aircraft was capable of an automated "minimums" callout that UPS had not implemented and that a software update for the

EGPWS system was available that would have provided an additional, slightly earlier warning of terrain conflict. So, from accident analysis, only three potential SMS additions were identified—a prohibition on changing autopilot modes to continue an approach, consideration of automating available and critical callouts, and consistent updating of TAWS software. Perhaps the latter two could have been identified in Safety Risk Management. The former would likely be identified only through Safety Assurance, if a crew reported a similar error or if FOQA monitoring identified similar autopilot mode usage and accompanying exceedances. Perhaps the mode change issue could be added to the stabilized approach policy, as well.

At least one other airline, years before, identified the up-sloping terrain north of runway 18 as a potential issue though its Safety Assurance processes. A crew was cleared for the approach to runway 18 in early morning visual conditions and noticed the proximity of the trees during their approach. They reported it to their ASAP program. Approaches to this runway are rare for airline crews and the Captain was concerned others needed to be made aware of the terrain. Ultimately, that airline asked their chart vendor to provide an airport familiarization page with color photographs for Birmingham for addition to their flight manual. The vendor continues to offer qualification and familiarization charts for the airport. But, these charts are not required. The NTSB did not discuss this as relevant to the accident. It appears only as a reference in the public docket (NTSB, 2013). Another airline prohibits use of this runway during its operations. So, we are aware that multiple airlines made safety management decisions about operations into the airport. Some consider it relatively benign. Others purchase vendor-published photographic familiarization charts. At least one airline chose not to use the accident runway. In our opening section, we said that an SMS becomes the formal mechanism by which an airline makes decisions about risk. These differing approaches to flight operations at Birmingham reflect differences in risk assessment and experience.

More broadly, what are the implications of an accident for an SMS? Reason (1997) argues for defenses in depth or layers of protection. Despite our best efforts, defenses will fail on occasion. SMS can serve as a method for identifying defenses in infrastructure, policy, procedure, and training and monitoring to assure their effectiveness. The UPS accident illustrates that even when much is in place from an SMS perspective, an accident can still occur. But the accident provides further feedback to prevent future events. Human behavior is probabilistic, rather than deterministic. Unlike physics, we cannot determine with certainty that an action will affect every person in the same way. But, we *can* make desired and undesired actions and consequences more and less likely. As a result, we never know whether mitigations are necessary or sufficient to always prevent incident or accident, but can only judge whether risk is sufficient to offer defenses in depth. And we can commit to continuously improve. The NTSB probable cause statement emphasized CRM-related behaviors:

> *The National Transportation Safety Board determines that the probable cause of this accident was the flight crew's continuation of an unstabilized approach and their failure to monitor the aircraft's altitude during the approach, which led to an inadvertent descent below the minimum approach altitude and subsequently into terrain. Contributing to the accident were (1) the flight crew's failure to properly configure and verify the flight management computer for the profile approach; (2) the captain's failure to communicate his intentions to the first officer once it became apparent the vertical profile was not captured; (3) the flight crew's expectation that they would break out of the clouds at 1000 ft above ground level due to incomplete weather information; (4) the first officer's failure to make the required minimums callouts; (5) the captain's performance deficiencies likely due to factors including, but not limited to, fatigue, distraction, or confusion, consistent with performance deficiencies exhibited during training; and (6) the first officer's fatigue due to acute sleep loss resulting from her ineffective off-duty time management and circadian factors (p. 90).*

In the sections that follow, we explore CRM interfaces with SMS, methods for incorporating risk identification and mitigation into CRM training, and future expectations for collaborative advances in CRM and SMS.

8.2 CRM INTERFACES WITH SMS

CRM has evolved alongside improving information streams about airline operations (Farrow, 2010) and concepts of safety management. Naturally, each of these has become entwined, with a number of benefits. Whilst having its roots in aviation, CRM has coexisted within an SMS especially in the realm of using effective teamwork to produce better quality products, for instance in the automotive industry. In this section, we consider how CRM, construed as a skillset, an approach to flying, and a body of knowledge, can serve an SMS process, and how SMS can improve training and implementation of CRM.

Considering CRM as a skillset reveals how it may both serve safety promotion functions and provide more specific mitigations to some issues. Helmreich and Foushee (1993) discussed behavioral markers of three dimensions which were subsequently codified as skills in the FAA CRM advisory circular (AC120-51e; FAA, 2004b). These dimensions were communication and decision skills, team building and maintenance skills, and workload management and situation awareness skills. As airlines implemented Advanced Qualification Programs (AQP; FAA, 2006b), they were required to integrate these skills into the performance objectives required to operate their aircraft. Most described a high level skillset composed of these dimensions and within phase of flight and abnormal or emergency performance objectives describing how these skills were to be implemented. American Airlines (1996) provides a good summary of phase-independent CRM skills:

41. Maintain Principles of GLOBAL CRM.
  41.01. Captain's Authority/Responsibility (CRM)
    41.01.01. Exercise Pilot in Command Responsibility IAW FAR 1.1, FM Part 1. [CA]
    41.01.02. Maintain the safety of passengers and aircraft [CA]
    41.01.03. Coordinate crew duties within the framework provided by AA [CA]
    41.01.04. Communicate plans and decisions to the crew [CA]
    41.01.05. Enforce standardization, policies, and procedure [CA]
    41.01.06. Respond to any safety-related concern raised by any crewmember [CA]
    41.01.07. Counsel and develop the aviation skill and knowledge of junior crewmembers [CA]
  41.02. FO/FE Responsibility (CRM)
    41.02.01. Comply with Second in Command responsibility IAW FM Part 1. [FO, FE]
    41.02.02. Maintain the safety of passengers and aircraft [FO, FE]
    41.02.03. Support decisions articulated by the Captain within the limits of safety, legality, and procedure. [FO, FE]
    41.02.04. Request a plan or decision if none is articulated by the Captain [FO, FE]
    41.02.05. Follow procedure and techniques requested by the Captain [FO, FE]
    41.02.06. Crosscheck and back the Captain up. This requires maintaining vigilance and proficiency in the aircraft and with procedures. [FO, FE]
    41.02.07. Report to the Captain any safety-related concern and advocate a safe course of action. [FO, FE]
    41.02.08. Develop your proficiency and learn from the Captain [FO, FE]
  41.03. Establish an effective communications process (CRM)
    41.03.01. Conduct effective briefings. [CA]
    41.03.02. Contribute to effective briefings. [FO]
    41.03.03. Establish and maintain a communications "loop." [CA & FO]
    41.03.04. Communicate decisions. [CA]
    41.03.05. Resolve disagreements or conflicts. [CA & FO]
    41.03.06. Debrief critical flight events. [CA]
  41.04. Maintain situation awareness (CRM)
    41.04.01. Prepare, plan and maintain vigilance. [CA] [FO]
    41.04.02. Distribute workload and avoid distractions. [CA]
    41.04.03. Prioritize actions and decisions. [CA]

41.05. Develop and maintain teamwork (CRM)

41.05.01. Establish appropriate duties and responsibilities by crew position. [CA]

41.05.02. Demonstrate motivation appropriate to the situation. [CA]

41.05.03. Maintain an effective group climate. [CA]

41.05.04. Protect crewmembers from the consequences of work overload. [CA]

41.05.05. Coordinate with other groups: F/A's, gate agents, dispatch, ground crew. [CA]

41.06. Use judgement in use of automated systems and mode (CRM)

41.06.01. Operate the airplane using different levels of automation as appropriate. [CA] [FO]

41.06.02. Verify that automation is doing what you expect. [CA] [FO]

41.06.03. When using automation, back each other up. [CA] [FO]

41.07. Crew coordination unique to abnormals and emergencies (CRM)

41.07.01. Upon detecting an existing or impending emergency condition, immediately notify the Captain. [FO]

41.07.02. Acknowledge the emergency and call for the accomplishment of any memory items. [CA]

41.07.03. In any emergency, designate which pilot is responsible for flying the airplane. [CA]

41.07.04. Direct attention primarily to the control of the airplane. However, monitor the accomplishment of the procedural items. [PF]

41.07.05. Read the MFDU (for an alerted procedure) or the Emergency checklist for a nonalerted procedure. Both challenge and response should be read aloud. [PNF]

41.07.06. The pilot accomplishing each item will repeat the response after assuring the item is accomplished. [PF] [PNF]

41.07.07. Upon completion of the checklist, announce: "____ checklist complete." [PNF]

41.07.08. Refer to the expanded information in the OM for additional, supplementary, clean-up action or information, time and conditions permitting. The section and page where the expanded checklist can be found is noted on the checklist. [PNF]

41.07.09. After completing a procedure in the OM, ensure that all other procedures and checklists are completed as appropriate for the phase of flight. [CA]

To these core dimensions, airlines have added phase specific skills and actions. Most list skills required by phase of flight (preflight, engine start, taxi-out, takeoff, climb, cruise, descent, precision approach, nonprecision approach, go-around, landing, taxi-in, and aircraft parking). For example at American Airlines (1996), for each phase, a subelement called, "establish and maintain crew coordination during [phase name]" was developed and carried over though proficiency objectives. Here is their nonprecision approach objective:

09. Perform NONPRECISION APPROACH.
    09.01. Establish and maintain crew coordination during Approach. (CRM)
        09.01.01. Brief the selected approach. [CA]
        09.01.02. Designate who will fly the approach and who will land the aircraft. [CA]
        09.01.03. Coordinate duties and responsibilities of crewmembers in case of a "Go Around." [CA]
        09.01.04. Monitor the approach and use standard callouts as the primary mechanism of crew coordination. [PF] [PNF]
        09.01.05. Monitor autopilot and instruments throughout approach. [PF] [PNF]

Revisiting the UPS accident, consider how each of these points might mitigate specific elements of the NTSB probable cause statement. A sufficient briefing might prevent the route discontinuity error that caused the lack of vertical guidance. A focus on criticality of standard callouts might prevent a descent below minimums without required visual reference by alerting the pilot flying of reaching the decision point.

By incorporating CRM elements into its AQP task analysis and carrying them through its proficiency objectives, an airline engages in Safety Promotion. It trains skills and techniques deemed necessary to safe flight, based upon breakdowns observed in previous accidents and incidents and behaviors observed among effective crews confronting similar challenges. By carrying skills to the individual phase of flight, an airline pursues mitigations to characteristics or behaviors observed in previous accidents. For example, the nonprecision approach subtask is at least partially responsive to concerns expressed by FSF (2000). FSF developed an approach and landing accident reduction toolkit in response to the study of an average of 17 accidents during this flight phase each year between 1980 and 1998. Among their recommendations were application of CRM skills, approach briefings, identification of unique approach hazards, and being prepared to go-around. Airlines' carrying of CRM to specific actions by phase of flight evidences use of CRM as mitigation of safety management issues.

Most current CRM programs are based in Threat and Error Management (TEM; Helmreich, Klinect, & Wilhelm, 1999). TEM operationalizes CRM as an approach to daily flying that may be construed as a localized implementation of SMS. TEM suggests that most adverse events can be described in terms of risks or challenges present in an operational environment (threats) and the actions of specific personnel that potentiate or exacerbate those threats (errors). While most accident sequences begin with some provocation in the operating environment, every flight is presented with some number of hazards. Only the risks that the crew recognizes and mitigates separate an accident chain from a routine outcome. Pilots, flight attendants, mechanics, dispatchers, etc., should be alert for developing threats and should position themselves to catch and correct any mistakes. The latter is a secondary function of procedures and checklists—we do and then we review. Importantly, some risks are constant, but many are contingent upon the situation and vary by phases of activity. This regularity may be used to predict and prevent error (Helmreich et al., 1999). Applied to the UPS accident, TEM would urge crewmembers to discuss the threat of the coming phase of flight—a nonprecision approach to an unfamiliar runway in early morning darkness and marginal weather—expecting them to develop and discuss their plan for each. What will be critical to a successful approach? What might we reasonably expect to go wrong? How will we deal with that?

From a TEM perspective, CRM training should be both a vehicle for addressing risks identified through an airline's Safety Management and Feedback systems and make use of its airline's risks and incidents as a vehicle for communicating its core concepts. As TEM argues for individual pilots and crews to identify and mitigate threats in flight, SMS programs identify and mitigate threats to aggregate operations. Because CRM training provides individual pilots skills to mitigate risk to individual flights, its content should be driven by the macro threats faced by the airline. SMS becomes the intel for the substance of CRM. CRM becomes one vehicle for fortifying the workforce against the identified risks.

An example of this grew out of implementation of Enhanced Ground Proximity Warning Systems (EGPWS; or generically Terrain Awareness and Warning Systems, TAWS). These systems took advantage of digitized global satellite-mapped terrain databases enabling much earlier warnings of potential terrain conflict. Previous versions (GPWS) had been based upon the radar altimeter and gave a few seconds of warning of terrain conflict. In those few seconds, an alerted crew had to maneuver their aircraft into a rapid climb, optimizing angle of attack and engine thrust to gain as much clearance from terrain as possible. This is an escape maneuver (similar to what is trained for windshear recovery) and crews were trained in initial/qualification and recurrent/continuing qualification courses to perform these maneuvers since the 1970s. TAWS can give a continuous picture of terrain or can generate cautions 30 seconds or more prior to conflict and alerts as that margin closes. Soon after TAWS implementation, crews reported encountering terrain "cautions" to which they responded with an escape maneuver. Notice that the new system had made available two levels of alert, caution and warning; escape maneuvers were necessary only for the latter. Airlines discovered this through their Safety Assurance processes. A number of CRM programs used such incidents to discuss the philosophy of warnings (TAWS and Traffic Collision Avoidance Systems, TCAS, use caution and alert levels), situations leading to encounters, and crew coordination techniques to avoid and respond to warning level alerts.

Given over 30 years of experience, CRM can be viewed as a body of knowledge of applications to flight operation experience. These are observable in the InfoShare meetings developed by the FAA Flight Standards organization (Huerta, 2014). Most airlines have attempted to adjust at least their recurrent/continuing qualification curricula to respond to the context in which their airlines operate. During the postderegulation growth cycle of the late 1980s, courses focused on defending operations from the risk of rapid transition of crewmembers with resulting low levels of experience in aircraft type. During the recession that followed, courses focused on complacency and maintenance of proficiency as crews stayed in career position for extended periods. With the advent of ASAP programs, many challenges became visible, and CRM classes became an opportunity to introduce issues to be reinforced in simulator training. Terrain awareness became an issue at some airlines, as cases of unexpected terrain conflict gained attention, particularly among pilots operating to newer markets with significant terrain threats.

Two examples of building this kind of knowledge are Key Dismukes' work on pilot monitoring and Immanuel Barshi's work on procedure optimization for crew performance. Both were influenced by precursor research in accident investigation or airline information sharing. Sumwalt (1999) had cited multiple studies finding poor monitoring to have contributed to accidents and incidents, and argued that while most CRM courses enabled and motivated pilots to challenge deviations from intended flight path, few emphasized the skills necessary to reliably *identify* those deviations. Dismukes and Berman (2010) conducted cockpit observational studies and observed that monitoring of data and actions is required constantly, is overwhelmingly successful, but fails with sufficient frequency as to be observable on most flights. Though most monitoring failures were inconsequential, even a 1% failure rate can be devastating at the wrong time. They argued for countermeasures in policy, procedure, training, checking, mentoring, and system design. FSF (2014) pulled together a working group to package this body of knowledge into practical actions recommended for airlines to increase the effectiveness of flight path monitoring by pilots.

Degani and Wiener (1990) observed that while proceduralization has been the bedrock of cockpit safety, few procedures could be described as being optimal for enabling crew performance. They argued for rooting procedures in philosophy of operations and more concrete policy. Loukopoulos, Dismukes, and Barshi (2003) observed that checklist design often requires pilots to perform tasks concurrently and that each flow is frequently interrupted or suspended, making prospective memory errors likely (remembering to take or resume an action at some future point). Barshi engaged airlines in tackling procedures, such as taxi for takeoff, that demand multitasking, to create more intact action sequences and make error less likely. This enabled Barshi, Mauro, Degani, and Loukopoulous (2016) to craft a comprehensive guide to flight deck procedure design. FAA (2017) incorporates these recommendations. Farrow discusses methods to generalize the proceduralization of CRM behaviors in Chapter 17, A Regulatory Perspective II.

To be fair, these examples are not CRM per se, but part of the broader field of human factors. However, airlines have made use of this work in their classroom CRM and simulator LOFT/LOS training and in revision of their procedures to improve safety through improved crew performance. To the extent that CRM programs and SMSs engage the broader literature, they tap into and apply the body of knowledge. This literature is a resource for guidance to safety risk management and responses to findings from safety assurance.

8.3 INCORPORATING RISK AND RESPONSE INTO CRM TRAINING

Because of the SMS commitment to Safety Assurance, new risks are discovered. They were not identified in the Safety Risk Management process and have yet to result in accident, but monitoring data streams allowed identification of unmitigated risk. CRM training is an excellent opportunity to address many of these findings. Considering that most airlines have adopted a career-long approach to emphasize skills necessary to each role (First Officer, Captain) assigned through career progression, CRM can emphasize identified risks at each level. For example, while Captains and First Officers alternate pilot flying and pilot monitoring roles, the captain retains leadership and command responsibility throughout. How do we best train Captains to organize against threats and errors? How do we optimize flying skill, monitoring, and communication among First Officers? We can infuse training materials with their airline's approach to safety risk management and import what we learn during safety assurance. This allows continuous improvement of CRM training. We can also make strategic decisions about what to emphasize in each recurrent/continuing qualification training cycle and link classroom and simulator training curricula. The UPS accident is a good vehicle for introducing these concepts in a CRM classroom, designing simulator scenarios that challenge these skills, and debriefing crews on the effectiveness of their mitigating actions. Pilots hear concepts and see examples in the classroom, then practice and receive feedback in the simulator. In turn, teaching core skills in the context of successful and unsuccessful threat and error management is the best way to make training real. Careful selection of safety reports or FOQA observations, reenacted in the simulator and presented in the classroom, allows the instructor to lead a class through the same conditions that resulted in a report. Pilots in the classroom can be coaxed into similar judgments of a threat, challenged to detect and correct a developing chain of errors, and draw broader lessons from the individual occurrence. Presenting similarly constructed simulator scenarios reinforces those lessons. Using this approach, issues and examples from Safety Assurance programs become the staple for teaching CRM.

Airline industry response to increasing flight path automation represents one good example of this process. Wiener (1993) summarized research identifying concerns and inconsistent performance among initial cadres of pilots operating FMC aircraft and argued this would become a CRM problem. "Not only were the world's airlines facing an industrial revolution in the cockpit, but they were simultaneously witnessing the beginning of the end of the era of the flight engineer and the three-pilot flight deck" (p. 200). "Flightdeck equipment and configuration materially affect the quality and perhaps quantity of communication and crew coordination in the cockpit" (p. 208). Wiener et al. (1991) documented a number of these issues experimentally. Comparing DC-9-30 and MD-88 crews flying an identical scenario, they found higher workload reported on the MD-88 during abnormal flight conditions, longer time to landing following an abnormal event on the MD-88, a doubling of communication acts following an abnormal event on the MD-88, and a change in the dominant form of communication from command/instruction-response on the DC-9-30 to question-response on the MD-88. Research findings were accompanied by airline operating experience—pilots reported examples to their airlines and the Aviation Safety Reporting System (ASRS); airlines observed them in line incidents and flight checks or LOSA. By 1994, Delta Air Lines, American Airlines, and Federal Express had implemented courses on aircraft automation based upon this research. Sarter and Woods (2005) documented a variety of events in which pilots were surprised by actions taken or not taken by autoflight systems and traced them to underlying problems in mode communication by flightdeck systems and mode awareness among pilots. FAA (1996) documented vulnerabilities among FMC-generation aircraft, including understanding the capabilities, limitations, modes, and operating principles of automated flightdeck systems and choosing levels of automation appropriate to flight situations.

In response, the Air Transport Association (now Airlines for America; A4A) tasked its Human Factors committee to review research and member airline experience to make recommendations for policy, procedure, and training. This led to four reports (ATA, 1997, 1998, 1999, 2000) emphasizing review and revision of operating philosophy and training for FMC aircraft, offering more detailed policy than previously published in order to correct specific issues or system misunderstandings, proposing a framework for communicating aircraft differences in performance of standard navigation tasks, and communicating specific issues during introduction of Required Navigation Performance (RNP) aircraft. For example, ATA (1998) offered this draft revision to Automation Policy:

1. Operating Policy

   Pilots will be proficient in operating their aircraft in all levels of automation. However, the level of automation used at any time should be the most appropriate to enhance safety, passenger comfort, schedule, and economy. Pilots are authorized to choose what they believe to be an appropriate level of automation.
2. Choosing among levels

   In general, choices among levels can be guided by their functionality and the demands of the situation.
   a. Where immediate, decisive, and correct control of aircraft path is required, the lowest level of automation—hand-flying without flight director guidance—may be necessary. Such instances would include escape or avoidance maneuvers (excepting aircraft with flight-director windshear guidance) and recovery from upset or unusual attitudes. With the exception of visual approaches and deliberate decisions to maintain flying proficiency, this is essentially a nonnormal operation for flight guidance or FMS-generation aircraft. It should be considered a transitory mode used when the pilot perceives the aircraft is not responding to urgent aircraft demands. The pilot can establish a higher level of automation as soon as conditions permit.
   b. When used with flight director guidance, hand flying is the primary takeoff and departure mode. It is also the primary mode for landings, except for autolands.
   c. Where short-range tactical planning is needed (i.e., radar vectors for separation or course intercept, short-range speed or climb rate control, etc.), Mode Control or Flight Guidance inputs may be most effective. This level should be used predominantly in the terminal environment when responding to clearance changes and restrictions, including in-close approach/runway changes.
   d. Autoflight coupled to the FMS/GPS is the primary mode for nonterminal operations and should be established as soon as "resume own navigation" or similar clearance is received. This level exploits programming accomplished preflight. Where the longer-range strategic plan is changed (i.e., initial approach and runway assignment, direct clearances, etc.), Flight Management inputs remain appropriate. However, when significant modifications to route are issued by ATC, the pilot should revert, at least temporarily, to lower levels of automation.
3. Confirming inputs to autoflight systems

   Pilots must confirm the results of autoflight selections to prevent mode or course surprises and confusion. A selection on the Mode Control or Flight Guidance panel must be checked against its result on the Flight Mode

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Annunciator. An input into the FMS/GFMS-CDU must be checked against its resulting course displayed on the Nav Display, and *the pilot making the input must confirm the resulting course with the other pilot prior to executing the change when feasible*. And in all cases, both pilots must continue their scan to ensure the autopilot performs as directed and anticipated.

4. Cross-checking FMS data against charted procedures

For a variety of reasons, displayed FMS legs making up a departure, arrival, or approach procedure may not correspond with charted fix names, bearings, or radials even though the database is designed to follow the same ground track. However, from time to time, pilots have encountered situations where the FMS did not fly a procedure as defined by radio navigation or in compliance with ATC expectations. Therefore, pilots must brief and cross-check charted procedures against FMS data to ensure they have selected the correct procedure and will comply with their clearance.

Before departure, thoroughly review your assigned departure and cross-check the waypoints obtained with your desired course. If you select or build a transition, verify between pilots that it matches your clearance and produces the desired track. Ask ATC for clarification if any conflict exists.

Before arriving in the terminal area, thoroughly brief the arrival and approach you expect to fly and cross-check fixes presented by the FMS against fixes depicted on the approach chart. Should the runway or approach change and you wish to use the FMS for the new approach, that same level of cross-check is essential. If time constraints or circumstances prevent your cross-check, decline the clearance or tune and identify radio aids to navigation and fly the approach in a lower level of automation.

5. Raw data monitoring and cross-check requirements

Except for those aircraft designed to meet Required Navigation Performance (RNP) for the Approach Phase (B-737 or B-777 with Advanced FMS, for example), Flight Management Systems are certified for en route and terminal navigation, but not for approaches. Except where prohibited by bulletin or company-specific pages in the Airway Manual, pilots may accomplish a SID and its transitions, navigate en route, and accomplish a STAR and its transitions to the initial approach fix solely by FMS navigation, *but not approaches*.

Except for published FMS, GPS, and RNAV instrument approach procedures, approaches are flown relative to ground-based NAVAIDs. For all other approaches, prior to the initial approach fix, one pilot must tune, identify, and monitor (on a CDI display, where available) the NAVAIDs that define the approach. These actions are necessary to ensure the path flown by the aircraft complies with the ground track required by the approach procedure. The function of the FMS and Nav display during an approach is to assist your situation awareness—not to fly the approach. Any discrepancy between the Nav Display or Flight Director based on FMS/GFMS guidance and raw data from NAVAIDs defining the approach must be challenged and resolved immediately. Should the ground-based signal be lost, the crew must abandon

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that approach if in instrument conditions. On all instrument approaches inside the final approach fix in IMC weather conditions, a go-around is required whenever unreliability or full-scale deflection of the ground-based approach NAVAIDs is encountered. *[Note: this paragraph describes what is necessary for the pilot to comply with FMS certification.]*

Specific autoflight and display modes required for precision and nonprecision approaches are specified in each aircraft flight manual. Requirements to accomplish published FMS, GPS, and RNAV instrument approaches are published in the operating manual of fleets so equipped. In addition, ground-based NAVAIDs defining a course must be tuned, identified, and monitored where specified by bulletin or company-specific pages in the Airway Manual, and when operating in Latin America below FL250. *[Note: this paragraph describes additional, company-specific requirements.]*

6. Dealing with ATC clearance changes

Proper use of automation will reduce your workload, freeing you to complete other tasks. Improper use will do just the opposite. Whenever possible, avoid FMS/GFMS programming during critical phases of flight. Complete as much programming as possible during low workload phases. ATC clearance changes in the terminal area directly challenge this requirement.

A departure change during taxi for takeoff requires review of the assigned departure. If the FMS is to be used for navigation during the departure, pilots must cross-check the waypoints obtained with the desired course. However, pilots may choose to navigate the departure by ground-based NAVAIDs if update and cross-check of FMS moving map displays would distract from primary ground and flight duties.

While pilots must tune, identify, and monitor all applicable approach NAVAIDs for every approach and landing, it is not necessary to update FMS moving map displays close-in to the landing airport where "heads down" data entry would distract from primary flight duties.

Member airlines customized and implemented most of the ATA recommendations over the next few years. CRM courses were often the forum for introducing or reviewing changes documented in Aircraft Operating Manuals and made use of events tied to each issue reported or observed through Safety Assessment processes. Member airlines also challenged pilots to use these new policies or skills in Line Oriented Simulation events.

How successful was this approach? FAA (2013) reported the results of a working group study of worldwide incidents and manufacturer and operator structured interviews. Its findings suggest the threat has evolved, requiring further intervention. Evolution involved "increased aircraft onboard capabilities for flight path management, increased use of FMS functions, transition away from conventional procedures constructed upon ground-based navigation aids to increased use of RNAV-based navigation (RNAV and RNP), reliance on the quality and availability of digital data, increased focus on managing costs, and changes in new hire pilot demographics" (p. 2). They reported new vulnerabilities in knowledge and skill for manual flight operations, including prevention, recognition, and recovery from unusual attitudes, transition from automated control, and energy state management. They were concerned about crew coordination relating to aircraft control and the retention of manual flying skills. And they emphasized:

- Pilots sometimes rely too much on automated systems and may be reluctant to intervene;
- Autoflight mode confusion errors continue to occur;
- The use of information automation is increasing, including implementations that may result in errors and confusion; and
- FMS programming and usage errors continue to occur (p. 3).

These findings indicate that some of the original concerns continue to be present, and that other vulnerabilities have accompanied increasing aircraft capabilities. From an SMS perspective, airlines should treat this report as new feedback from a more global safety assurance process. They should engage in another round of Safety Risk Management, allocating mitigations to various policy, procedure, and training functions, followed by ensuring safety assurance processes can assess effectiveness of their interventions. Expect CRM classroom and Line Oriented Simulation to be called upon again to communicate risk and mitigation strategy, and to practice and receive feedback on the associated skills.

8.4 EXPECTATIONS ABOUT SMS AND CRM IN THE FUTURE

Both SMS and CRM are still evolving (Velasquez & Bier, 2015) with SMS at a faster rate than CRM, largely because of its acceptance by company governance. While SMS progresses through a system safety approach, CRM has had its own evolution from localization in the cockpit; through to "corporate resource management"; and contemporarily, threat and error management. Kern (2001) for instance argues that the next "generation" of CRM will establish its clear operational interfaces with human factors issues such as fatigue, complacency, and automation.

On the other hand, SMS will evolve as risk management, control, and assurance tools become more mature to the extent that such tools are easier to implement. However, some of the inarguable intersections of both SMS and CRM which attract continuous improvement and promise are:

- SMS and CRM are the logical platform for safety culture to be examined and developed;
- As more safety data is collected by an organization, there is greater demand to blend such data (i.e., ASAP, FOQA, CRM training feedback,

LOSA, etc.) in order to gain a better and meaningful understanding of an organization's safety health;
- Like CRM, SMS will have to be endorsed by top management in order to be successfully implemented (Broyhill & Freiwald, 2012); and
- SMS and CRM are in the best position to inform organizations about improving the level of predictive value of the confluence of human and system risk data.

8.5 CONCLUSION

SMS require a disciplined approach to identifying and mitigating hazards and risk within an airline's operations and assessing the adequacy of mitigation. These are enabled by an organization's safety culture and implement processes of safety risk management, safety promotion, and safety assurance. CRM interfaces with these systems in several ways. As a skillset, CRM may both serve safety promotion functions and provide more specific mitigations to some issues. SMS and CRM are complementary in that SMS targets the improvement of the safety system while CRM is intended primarily for the user (Velasquez & Bier, 2015). When organized as threat and error management, CRM serves as an approach to daily flying that may be construed as a localized implementation of SMS. Given over 30 years of experience, CRM can be viewed as a body of knowledge of applications to flight operations experience, setting the stage for effective responses to issues identified through safety assurance functions. CRM training also benefits directly from what an airline learns through its safety monitoring and assurance processes. SMS becomes the intel for the substance of CRM. CRM becomes one vehicle for fortifying the workforce against the identified risks.

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