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Chapter 13

Maintenance Resource Management for Technical Operations

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INTRODUCTION

On April 28, 1988, a Boeing 737-200 operated by Aloha Airlines experienced explosive decompression and structural failure at 24,000 ft. It resulted in a dramatic separation of the fuselage upper lobe and made startling headlines like, “And Then, Whoosh! She was Gone” (Wright & Tanji, 1988). The accompanying photos showed evidence of what might have been considered impossible in the past. The National Transportation Safety Board (NTSB) noted that the probable cause of the accident was “the failure of the Aloha Airlines maintenance program to detect the presence of significant disbonding and fatigue damage which ultimately led to...the separation of the fuselage upper lobe” (NTSB, 1989, p. v). Almost a year later, on March 10, 1989, Air Ontario accident in Dryden, Canada, also revealed a number of systemic factors, including maintenance failures (Commission of Inquiry, 1992a). On June 10, 1990, a British Airways BAC 1-11 experienced explosive decompression when the captain’s window blew out (King, 1992). These three accidents resulted in both an intense focus on maintenance-related accidents as well as a unique, multiparty collaboration between the United States Federal Aviation Administration (FAA), the United States National Aeronautics and Space Administration (NASA), Transport Canada (TC), and the United Kingdom’s Civil Aviation Authority (UK CAA), as well as partnerships across airlines, maintenance repair and overhaul facilities, and universities.

Early efforts to assess safety-related issues in maintenance and develop appropriate intervention programs relied heavily on the success of the cockpit resource management (CRM) program among the flight crew during

the decade of the 1980s, which was focused on crew communication and teamwork. Thus, the early maintenance resource management (MRM) programs, which were essentially CRM principles applied to the maintenance environment, also focused on communication and teamwork among the maintenance personnel (Fotos, 1991; Taggart, 1990). Pre/post training evaluation tools developed by Gregorich, Helmreich, and Wilhelm (1990) were modified from CRM to MRM to suit the audience while maintaining their psychometric integrity and applied to the assessment of MRM programs (Taylor, Robertson, Peck, & Stelly, 1993). Similarly, much of the style and content of the MRM training intervention was borrowed from the successful CRM programs as studied by Helmreich, Foushee, Benson, and Russini (1986).

Concurrent with the emerging research in MRM, three other major accidents drew attention to safety in maintenance operations: June 1995 Valujet accident in Atlanta, Georgia; August 1995 Atlantic Southeast Airlines accident in Carrollton, Georgia; and 1996 Valujet accident in Miami, Florida. Reviews of these three accident cases, along with the knowledge from previous accidents and effects of early MRM training interventions resulted in improved understanding of the maintenance environment, resulted in the beginning of a shift from individual-level blame to system-level responsibility, and led to both conceptual as well as psychometric separation of MRM from CRM. For example, in 1994, Gordon Dupont from TC identified twelve overarching issues in aviation maintenance, which were later known as the “dirty dozen”: lack of communication, complacency, lack of knowledge, distraction, lack of teamwork, fatigue, lack of resources, pressure, lack of assertiveness, stress, lack of awareness, and norms (CAA, 2002, p. 20). Concurrently, Dr. James Taylor from Santa Clara University built a robust survey instrument to study the pre/post effects of MRM training programs (Taylor, 1998, 2000a). Through such efforts of various scientists and practitioners, MRM matured beyond a CRM application to the maintenance environment and a clear definition of MRM emerged: MRM is “. . . an *interactive* [emphasis added] process focused upon improving the opportunity for the maintenance technician to perform work more safely and effectively” (ATA, 2002, p. 5).

Typical MRM programs were dominated by awareness-level training with the following components (Patankar & Taylor, 2004a, 2004b):

1. *Dirty Dozen elements*: Lack of communication, complacency, lack of knowledge, distraction, lack of teamwork, fatigue, lack of resources, pressure, lack of assertiveness, stress, lack of awareness, and norms. Safety nets associated with each of these elements were also discussed.
2. *Accident case analysis*: One or more exercises were designed to illustrate how a chain of events (at times each event is a minor deviance) can lead to disastrous consequences.

3. *Organization-specific problem*: Focus was placed on a particular problem that the organization wants to rectify immediately. Examples of such problems include shift turnovers, logbook errors, ground damage, or lost-time injuries.
4. *Interactive exercises*: Typically, the training also included at least one interactive exercise to illustrate concepts such as the value of teamwork or hazards of verbal turnovers.

In the subsequent decade, collaborations across government agencies (FAA, NASA Ames Research Center, UK CAA, and TC), airlines (e.g., Continental, United, US Airways, and Southwest), repair stations (e.g., AAR, TIMCO, and BF Goodrich), major manufacturers (Boeing and Airbus), and universities (e.g., Santa Clara University, San Jose State University, Purdue University, University of Buffalo, and Clemson University) resulted in a number of research projects, design of practical training interventions, and assessment of those interventions. Concurrently, the aviation industry also suffered a number of serious public health, security, and economic challenges like the Asian economic crisis of 1997, terrorist attacks of September 11, 2001, the Severe Acute Respiratory Syndrome (SARS) epidemic in 2003, the US financial crisis of 2007–08, and the H1N1 Swine Flu pandemic of 2009. These challenges had substantial impact on MRM programs: the initial efforts to build and sustain MRM programs had to be redesigned, updated, and regrouped into different other programs in order to cope with the decline in available resources, as well as retirements or transfers of many committed champions of the MRM programs. Awareness of these external factors provides valuable insight into the need to stay true to the core value of safety in the aviation industry and to remain resilient to external challenges.

This chapter starts with a brief historical overview of the MRM program; next, it presents some of the most commonly used incident review tools and the associated taxonomies. Finally, it reviews the influence of MRM programs on the safety culture in technical operations and identifies emerging opportunities for continued research and development.

13.1 HISTORICAL OVERVIEW

Taylor and Patankar (2001) presented the evolution of MRM programs across four generations:

1. CRM-based training in communication skills and awareness;
2. Behavior-focused MRM training in interpersonal communication and error causation;
3. Individual awareness and readiness for behavioral change; and
4. A systemic approach to behavioral change in maintenance.

As mentioned in the Introduction section of this chapter, three maintenance-related aviation accidents led to an intense focus on the maintenance environment and the human factors associated with errors in maintenance. For example, the NTSB investigation report (NTSB, 1989) regarding the Aloha Airlines accident cited the failure of Aloha's maintenance program—specifically, inspection and quality control, as well as the FAA's surveillance of those programs, and the human factors associated with maintenance and inspection of transport category aircraft. For the first time, the actual environment in which maintenance personnel carry out their assigned tasks, as well as the human factors associated with repetitive inspection tasks and circadian rhythms, were considered. Of particular note is Dr. Colin Drury's (a professor at the State University of New York at Buffalo at that time) testimony noted in the investigation report:

He (Dr. Drury) indicated that in the inspection process, it is not easy for the human being to perform a consistent visual search because (1) the area the searchers can concentrate on at any one time is limited by the conspicuity or size of the defect to be looked for and (2) the search process may not be systematic enough; therefore, the searcher is prone to miss areas that were thought to have been covered. Further, there is the vigilance decrement during long inspection periods that have low event rates and to some extent involve social isolation. . . such vigilance decrements occur during very long and isolated inspection duty times in which there is a low probability of finding a defect. In such cases, the human being tends to proceed through the task by saying no when a decision is to be made.

NTSB (1989, p. 55)

This testimony and the NTSB's recommendations were particularly influential in (1) raising the awareness about the conditions under which maintenance personnel perform critical tasks and are thereby susceptible to errors due to human factors issues; (2) acknowledging that the aviation maintenance sector is complex—it has several interacting parties with sometimes conflicting goals or priorities—and errors made at a given time may not result in serious consequences in the immediate future, but lay dormant for a long time before manifesting themselves; and (3) shaping the investigation and reporting of subsequent NTSB investigations—for example, in the case of the Aloha investigation, Dr. John K. Lauber, a renowned scientist and developer of CRM programs, served as one of the Board Members and later John Goglia, an aircraft mechanic, served as a Board Member.

13.1.1 First Generation

Taylor and Patankar (2001) reported three cases that illustrate the purpose, content, and outcomes of the first generation MRM programs. These programs were in effect from 1989 through 1995. Early on, the purpose of the

MRM programs was similar to that of the company's CRM program—to improve safety through improved awareness, interpersonal communication, and teamwork. For example, [Taggart \(1990\)](#) reported the following topics in one of the training programs:

1. Interpersonal communication;
2. Assertion and conflict management;
3. Stress awareness and management;
4. Value of shift-turnover briefings;
5. Situational awareness;
6. Leadership behavior; and
7. Case studies.

These training programs were very practical—they had specific case studies woven across the instruction program as well as individual and team exercises to raise awareness about human fallibility in communication, conflict management, and shift-turnover briefings. The programs were conducted in small group sessions over several weeks and the early sessions included mostly management personnel. Posttraining feedback indicated that over 80% of the participants would expect at least a moderate change in their on-the-job behavior. However, the program was suspended shortly after completion of the first round of training because the company was liquidated.

Another program, started in 1991 and emphasized open and assertive communication ([Fotos, 1991](#)). In this program, the training topics included the following:

1. Organizational “norms” and their effect on safety;
2. Assertiveness;
3. Individual leadership styles;
4. Stress awareness and management;
5. Problem solving and decision-making skills; and
6. Interpersonal communication skills.

The delivery of the training program included interactive exercises, role play, and team exercises ([Stelly & Taylor, 1992](#); [Taylor & Robertson, 1995](#), p. 49). Over 2000 management and professional engineering staff were trained through this program. Enthusiasm for this program was higher than for the previous case—nearly 90% of the participants said there would be at least a moderate change in their on-the-job behavior ([Taylor & Robertson, 1995](#), p. 15). Over a 26-month period, the program participants reported a gradual improvement in attitude toward change and moved from passive practices (like being a better listener) to active practices (like will not hesitate to speak up) ([Taylor & Christensen, 1998](#); [Taylor & Robertson, 1995](#); [Robertson, Taylor, Stelly, & Wagner, 1995](#)). During the same time frame, lost-time injuries and ground damage incidents decreased ([Taylor & Robertson, 1995](#)). Thus, there were three levels of improvements: enthusiasm

about the training content, individual attitude toward safety, and safety outcomes. Unfortunately, even this program did not continue past the initial 26-month run and it had to be put on hold as the management's attention shifted toward economic priorities such as station closures and cost-cutting; soon the excellent results of their MRM program began to reverse (Taylor & Christensen, 1998, pp. 128–129).

The third case reported by Taylor and Patankar (2001), under the first generation of MRM programs, illustrates the beginning of training for the actual aviation maintenance technicians (rather than just managers and engineers). Although only 450 personnel (about 300 technicians) were reported to have completed this training, 80% of them reported that they expected moderate to large changes in their behavior as a result of the MRM training (Taylor, Robertson, & Choi, 1997). With respect to behavioral changes, 40% committed to active behavioral changes as a result of the MRM training and about 45% committed to passive behavioral changes. Furthermore, there was even stronger (compared to the previous case) improvement in lost-time injuries and ground damage incidents. Thus, this case also proved that MRM programs can be effective in improving attitudes, behaviors, and performance outcomes. More importantly, the frontline personnel are more responsive to the training as evidenced in the higher level of improvement in performance outcomes. Again, this program did not continue past the initial phase due to resource constraints.

13.1.2 Second Generation

During 1992–94, while the first generation MRM programs were being implemented, an example of a second generation program emerged. The content of this program was differentiated from the first generation programs in two ways: (1) it emphasized behavioral change rather than just an attitudinal change that was emphasized in the first generation programs and (2) it included company-specific cases from maintenance and was directed at maintenance technicians rather than managers and/or engineers. Additionally, there was a strategic differentiation: this program was built on an informal agreement between the company, the FAA, and the maintenance technicians' union. The agreement was that the union would encourage their members to participate in the training program and be forthcoming in their errors so that the company could focus on systemic issues and implement changes that would minimize the opportunity for similar errors in the future. In exchange for such cooperation from the union, the company promised to address the broad systemic issues rather than just individual-level corporate disciplinary action (assuming the error was inadvertent) and the FAA Flight Standards District Office also adopted a broader, collaborative stand recognizing that individual-level disciplinary actions were not effective in long-term improvements in safety. Moreover, all the parties recognized the

importance of engaging the erring technician in the safety conversation in order to minimize recurrence of similar errors. The agreement between the FAA, company, and the union was built on the trust among the three individuals (John Goglia, Joe Kania, and Jim Ballough) representing the three parties and their respective credibility among their affiliate groups. This critical risk taken by the three individuals and the subsequent success of the second generation MRM programs was foundational to the modern-day Aviation Safety Action Program (ASAP) and the Safety Management System (SMS) Program.

The purpose of this second generation program was much more focused: reduce the number of maintenance documentation errors. The overall program lasted two years and was spread over three phases: focus group discussion and data collection, implementation of the first-order changes, and implementation of the second-order changes. The initial focus group discussions and data collection efforts led to specific recommendations to management that could reduce the documentation errors. Examples of such recommendations included formal training in documentation for all maintenance technicians. The result of this training was immediate and the errors decreased, but it did not last long (Taylor & Christensen, 1998; Taylor, 1995). The second-order changes included more structured efforts, but in the form of a control group and an experimental group. As part of the MRM training, the experimental group/station received specific content (awareness, role-playing, group exercises, and tutorials) on how to reduce documentation errors. All other stations formed the control group. The experimental group's errors declined and stayed lower than the control group (Taylor, 1994, 1995).

By 1995, the experimental group of second generation programs concluded as the managers and supervisors who supported the training left the station/company. Their successors were encouraged to continue support the MRM program and the company-FAA-union relationship continued until the airline economic crisis following the terrorist attacks of September 11, 2001.

13.1.3 Third Generation

About the same time as the second generation program was being launched in the United States, the report of the Canadian Commission of Inquiry into the Air Ontario accident of March 1989 was released. In this report, the Honorable Commissioner Moshansky took a very broad, systemic stand on the investigation and noted several limitations of the aviation system that allowed the accident to occur. This philosophical shift—from individual blame to systemic responsibility—and review of the specific role of air carrier management, practical recommendations for the airline, the regulator, and the global aviation industry laid the foundation for broader systemic changes across the global aviation industry. Similar to the value of

Dr. Drury's testimony in the case of the Aloha Airlines accident, in the case of the Air Ontario accident, Dr. Robert Helmreich was invited to review the investigative data and make his recommendation. Dr. Helmreich, a professor at the University of Texas at Austin, was funded by the NASA Ames Research Center to conduct this study. Based on his study, Dr. Helmreich claimed the following:

The results of this analysis suggest that the concatenation of multiple factors from each category allowed the crew to decide to take off with contaminated wings. According to this view, no single factor taken in isolation would have triggered the crew's behaviour prior to and during take-off, but in combination they provided an environment in which a serious procedural error could occur. This array of contributory influences without a single, proximal cause warrants classification of the accident as a system failure.

Commission of Inquiry (1992b, Appendix 7, p. 322)

In 1994, TC developed a different kind of MRM program called, Human Performance in Maintenance (HPIM), which was based on a 2-day program developed specifically for maintenance technicians. One of the striking and most impactful features of this program was the introduction of the "Dirty Dozen." Gordon Dupont was at TC at that time and he analyzed a number of accidents and created the list of 12 most common maintenance-related causes: (1) lack of communication, (2) complacency, (3) lack of knowledge, (4) distraction, (5) lack of teamwork, (6) fatigue, (7) lack of resources, (8) time pressure, (9) lack of assertiveness, (10) stress, (11) lack of awareness, and (12) norms. He had these illustrated in the form of memorable posters and they became an integral part of most MRM programs throughout North America (Taylor & Christensen, 1998, pp. 145–146).

The HPIM program was different from the previous generation MRM programs in two important ways: first, it focused on awareness and coping mechanisms or safeguards and second, it focused on the individual technician rather than the broader system. Although the HPIM program was developed for the Canadian audience, and the first two generation of MRM programs were a mix of awareness and behavior programs, thereafter, the majority of the North American MRM programs developed during 1994–98 focused on awareness and individual coping. For example, in 1996 a major US airline developed its MRM program to create an awareness of the impact of human performance on maintenance-related errors and personal safety. The Dirty Dozen were thoroughly integrated in this program. This program was developed by a team of technicians, supervisors, and the company's training department. Thus, it had broad support and had good instructional design. As a result of this training, over 60% of the participants said there would be a moderate or large change in their on-the-job behavior (Taylor & Christensen, 1998), which is substantially lower than that claimed by the first generation MRM programs. In terms of behavioral intentions, about 46% of

the participants committed to passive changes and 27% committed to active changes. This outcome is also substantially different from that reported in the third case of first generation MRM programs. Given that the training focused on awareness rather than behavior, such intentions were not surprising. On the other hand, statistically significant improvements were found in attitudes about sharing responsibility, communication, and stress management immediately following the training sessions, and they remained stable for several months after the training (Taylor & Christensen, 1998, pp. 154–155).

Furthermore, a strong correlation was noted between improvement in attitude about stress management and improvements in both loss time injuries and ground damage (Taylor, 1998a). Thus, the training was causing the intended improvement in attitude, and the change in attitude must have translated into a change in behavior which resulted in reduced rate of injuries and ground damage.

In spite of the success of this third generation MRM program, the focus on individual-level awareness and coping resulted in “bridge to nowhere” scenarios. The original enthusiasm of the participants started to decay as they felt alone or unsupported in their quest for safety improvements, and eventually, they became frustrated and angry at their managers and co-workers for failing to fulfill the promise of the MRM program (Taylor, 1998), concluding in lost hope for the usefulness of the MRM program in the future (Taylor & Christensen, 1998, pp. 152–160).

In another example of a third generation MRM program, the training was divided into two days, but the two days were separated by several months. This airline worked with its union and the local FAA to develop the MRM training program based on the Canadian HPIM model, but decided to split it into two days that were separated by several months. The separation of the training days enabled the trainers to introduce the various topics on the first day, allow the participants to return to work and reflect on the training content, and return to the training topics for a more applied approach on the second day, when the emphasis was on how to manage errors through practiced assertiveness and awareness of risk factors. Thus, this approach seemed to be a bridge between the behavioral focus of the first two generations and the purely awareness-level focus of the third generation MRM programs. Most of this training was accomplished in one city during 1998 and in another city in 1999. In 1998, the likelihood for voluntary change increased from 60% to about 65% from phase 1 to phase 2 of the training program, while in 1999, the likelihood for such a change increased from 69% to 85%. Similarly, attitude and opinion changes after the two training days/phases showed significant improvement. However, in 1998, field interviews several months after phase 2 of the training revealed that the safety standards and MRM program implementation were deteriorating due to lack of management follow-through. The intentions to change at both cities were largely passive

(between 44% and 61%), while the active change responses ranged between 8% and 14%. With respect to performance changes, both cities showed a significant decline in ground damage incidents following the start of the MRM program and the decline continued for about 16 months after the second phase of the training. (Taylor & Robertson, 1995; Taylor et al., 1997). Again, the third generation MRM programs showed an improvement in participant attitudes, commitment to change their behaviors (mostly passive behaviors, but some active behaviors as well), and a sustained improvement in performance outcomes. Thus, by all measures these training programs were successful. Nonetheless, they lacked continued support and follow-through from management (Taylor, 1998) and they remained focused on improving awareness and passive influence over behaviors (Taylor & Patankar, 2001). They also did not have clear safety performance goals, rapid feedback of results, and appropriate reinforcement for those who demonstrated the desired safety behaviors.

13.1.4 Fourth Generation

Around 1999, a fourth generation of MRM programs began to differentiate itself in two important ways: (1) these programs took a systems perspective and expected the entire aviation maintenance system to change and not just the individual technician and (2) these programs had very clear objectives—to raise awareness, change behavior, and impact specific performance outcomes. While these programs continued to build upon the best practices from previous generations, like including the Dirty Dozen topics and incorporating role-playing and interactive exercises, they started incorporating cases involving internal maintenance error investigations. The management and the technicians knew from previous experience and research findings that employee–management trust was low and improved transparency with data-sharing and open communication would help strengthen the employee–management trust. Also, one critical investigative lesson learned through the Aloha Airlines accident, the Air Ontario Accident, and the BAC 1-11 accident was that the underlying systemic causes of human errors must be investigated thoroughly in order to develop meaningful, comprehensive preventive solutions for the future. Thus, the fourth generation programs included specific tools for human factors investigations of maintenance errors, thereby translating the awareness of elements like the Dirty Dozen into practical, actionable tools (Allen & Marx, 1994; FAA, 1997). However, the fundamental challenge of interpersonal trust between technicians and managers, as well as between technicians and the local FAA inspectors continued to challenge the continuation of MRM programs. As a result, the efforts to advance MRM program development and implementation kept returning to the notion that technicians, management, and the FAA must uphold their commitment to certain fundamental tenets: focus on systemic

issues rather than individual blame; implement nonpunitive error-reporting system; and follow-through on their commitments. It was known from previous studies that the technicians did not tend to trust others very easily because they tend to be more individualistic (Taylor & Patankar, 1999; Taylor, 1999) and self-reliant (Taylor & Christensen, 1998). Thus, the fourth generation programs not only addressed individual awareness and behavioral issues, but also gradually shifted toward seeking a deeper, cultural change (Taylor & Patankar, 2001).

Taylor and Patankar (2001) presented two cases that illustrate the transition of the fourth generation MRM programs toward cultural change. In the first case, the emphasis was on individual behavior, regardless of the attitudinal readiness. This approach was quite the opposite of previous attempts to seek attitudinal change first and hope for a behavioral change to follow. In this case, certain behaviors were expected from the maintenance, flight, management, and dispatch personnel. Their emphasis was on a structured communication protocol, called the Concept Alignment Process (Lynch, 1996; Patankar & Taylor, 1999), which was specifically designed to expect procedural compliance, integration of risk analysis in tactical decision-making, vigilance and safeguard against individual complacency, and question another team member's decision in a safe and respectful environment (Lynch, 1996). The key to the success of this program was a reinforcement cycle: prescribed behavior led to procedural changes for flight, maintenance, as well as management; these procedural changes were supported and implemented; the participants' acceptance of the new communication protocol increased and their attitude toward the protocol improved; and improved attitude led to improved adoption and more consistent adherence to the prescribed behavioral protocol, which led to further organizational changes (Patankar & Taylor, 1999). One of the key performance outcomes of this program was that it not only resulted in changes to internal organizational procedures, but it also impacted the FAA's approved procedures and manufacturer's service bulletins. While the internal impact was not surprising, the external impact brought to light the potential for a broader influence of MRM programs.

In the second case of a fourth generation MRM program, Taylor and Patankar (2001) presented an airline's MRM program that involved both awareness training, which was based on the Dirty Dozen, as well as behavioral training related to improved decision-making and human error incident investigation. This program was representative of the state-of-the-art at that time. It utilized the available training materials and past practice in terms of the Dirty Dozen topics and the associated case examples, but it also incorporated behavioral aspects such as the Concept Alignment Process and known tools and techniques associated with the investigation of human error in maintenance. Additional information available through the FAA, NASA, and other public domain web sites was also made available. Thus, the

expectation was that the participants would continue to build their awareness after the training and practice their behavioral skills taught in the course. Furthermore, the company was also better prepared to act on the systemic improvement ideas that might arise from the training participants. The company management was open to making the necessary changes and keeping everyone informed of the changes as well as rationale for adopting or not adopting the suggested changes.

13.1.5 Fifth Generation

After the terrorist attack of the World Trade Center in New York, on September 11, 2001, the aviation industry went into a tailspin: financial losses followed by cost-cutting measures, retirements, employment changes, and redirection of resources. As a result, most companies in the United States suspended their MRM programs. In 2003, the FAA funded a different type of project. Instead of continuing to fund research related to traditional MRM programs, they funded a project related the Aviation Safety Action Program (ASAP) in maintenance. This change in research focus was consistent with the internal shift the airline industry had made—it had shifted from the traditional CRM/MRM programs to ASAP programs, which were consistent with the core concept over which MRM programs were built. As presented in the discussion about the second generation MRM programs, the core concept was that three parties—company, labor, and regulator—need to come together and focus on systemic improvement rather than individual blame. Also, by that time, there was sufficient awareness regarding the human factors principles and so the MRM training could focus on event investigation and classification of human error. Thus, the fifth generation MRM programs were in fact, Maintenance ASAP programs, which continued to use the basic MRM concepts (like the Dirty Dozen and case studies), but focused more on the integration of human factors in event investigation methods. However, since the adoption of ASAP programs was much slower in the maintenance community (in 2003, there were only six programs in maintenance; whereas, there were 28 programs in flight), the FAA was interested in learning about the barriers to adoption, particularly if the barriers were related to the FAA's ASAP policy (FAA, 1997, 2002).

The purpose of a Maintenance ASAP agreement between the FAA, air carrier, and the labor union is to provide a nonpunitive forum for technicians to come forward and disclose their errors to the FAA and the air carrier so that systemic solutions could be implemented and similar errors, due to similar causes, could be minimized. Since the advisory circular pertaining to Maintenance ASAPs used language similar to the flight domain, it was hypothesized that it would be difficult to apply the same circular in the maintenance domain. Patankar and Driscoll (2005) conducted an extensive

field study and reported eight best practices across successful Maintenance ASAP programs; of those, five are presented here:

1. Use the template MOU provided by the FAA, but create an addendum to provide maintenance-specific details about the specific program: The original template MOU was based on the needs of the flight crew. It was incredibly difficult to create an entirely new MOU for maintenance; thus, it was recommended that the maintenance community try to accept the flight MOU and add a separate document to provide details about the maintenance ASAP program.
2. Try to keep an open mind and accept as many ASAP reports as possible: In the beginning, the Maintenance ASAP program suffered from the same interpersonal trust issues as those discovered during the early generation MRM programs. Since the intent of the Maintenance ASAP program was to provide a nonpunitive pathway to report errors and implement systemic solutions, it was recommended that the ASAP program's Event Review Committee (ERC) accept as many reports as possible.
3. Consider a report as "sole source" if it is from anyone within the company: In the early stages of the Maintenance ASAP program, there was much debate about what would be considered a "sole source" report because if it was not a sole source report, it could be subject to company and/or FAA action. To simplify matters, the recommendation from the industry was to consider all reports from within the company to be sole source reports.
4. Try to link ASAP reports from different professional communities to leverage the overall benefits: In some companies, there were separate ASAP programs and ERCs for each professional community—flight, maintenance, and dispatch. While there were several reasons to keep these reports and programs separate, the industry also noted potential to link the reports so that comprehensive solutions could be developed.
5. Follow through on labor, management, and FAA commitments: Since an ASAP program is a tripartite agreement, all three members must honor their commitments, regardless of the political pressures or cost of the corrective actions. Thus, the industry strongly advocated for consistent commitment from all parties.

Concurrent with the challenges associated with policy guidance, procedures, and consistent implementation, the Maintenance ASAP program also faced the challenge of developing, enforcing, and updating its own "community standard" for unacceptable behavior. Taylor (2004) focused on this issue and reported on his findings regarding acceptance criteria for maintenance ASAP events. Taylor noted that for the maintenance community, the notion of "intentional disregard for safety" was a difficult concept to define, but could be approached with a risk-based philosophy of error management, and decisions could be made on a case-by-case basis. Taylor concluded that the

regulators, union representatives, and air carrier representatives responded similarly to the accept/reject decision with respect to the ASAP cases provided to them. Thus, the community standard approach could be used in Maintenance ASAP programs to detect intentional disregard for safety, without having to explicitly define it.

In a parallel development, the flight community had been working with the FAA and hosting Information Sharing meetings (called the FAA InfoShare). Until about 2004, the maintenance community did not have a strong presence at these meetings, but some of the attendees thought that it was time for the community to come together and start presenting their experiences with MRM and M-ASAP programs to the broader audience, much like the flight community was doing. So, members from American Airlines, Southwest Airlines, AAR Corporation, United Airlines, Continental Airlines, Delta Airlines, International Association of Machinists (IAM), Aircraft Mechanics Fraternal Association (AMFA), FAA, NASA Ames Research Center, and Saint Louis University started organizing and holding separate Maintenance InfoShare meetings. Until about 2008, these meetings were held separately, but thereafter, there was sufficient momentum and interest that they could be integrated in the national InfoShare meetings, along with flight and dispatch communities. Today, these meetings are robust and are attended by over 1000 participants from a variety of professional communities (flight, maintenance, dispatch, cabin, regional airlines, universities, etc.) and there is a broader exchange of lessons learned and informal consultation with the FAA representatives.

As a result of all of the above concurrent developments and substantial efforts on the part of hundreds of safety champions in the aviation maintenance industry, the number of Maintenance ASAP agreements has grown exponentially from just six in 2003 to 168 as of August 31, 2017; in the same period, the Flight ASAP agreements have grown from 28 to 188 (FAA, 2017a). This growth and overall success of the program is a true testimonial to the cultural change in aviation maintenance—now, it would be fair to say that the maintenance industry has moved from a blame culture to a just culture (Marx, 1998, 2001; Reason, 1997); however, there continue to be some exceptional cases where a person experiences a punitive treatment either from the company or from the FAA. Also, although the fifth generation of MRM programs provided a stronger integration of attitudinal and behavioral approaches to training and strengthened employee—management—regulator trust, they remained largely reactive safety programs.

13.1.6 Sixth Generation

Regular participation in the InfoShare meetings led the maintenance community to consider some of the other programs that were successful in flight operations and air traffic control communities, particularly the ones that

would be proactive, continue to foster a just culture, and provide sufficient protection of data. Thus, toward the end of 2008, the maintenance community's attention turned toward the line oriented safety audit (LOSA) program that had been operational in the flight community since the 1990s (Klinect, Wilhelm, & Helmreich, 1999; Klinect, Murray, Merritt, & Helmreich, 2003). The LOSA name was changed to Line Operations Safety *Assessment* (rather than Audit) to make it more consistent with the nonpunitive intent of the program (Ma & Rankin, 2012). It was based on a strong theoretical model of Threat and Error Management (Klinect et al. 1999), and it had proven to be successful in improving safety in the United States as well as abroad (ICAO, 2002). Ma et al. (2011) reported the early rationale for the exploration of LOSA programs in maintenance as follows:

1. Implementation of a LOSA program in Maintenance and Ramp operations would enable proactive identification of threats and errors before they lead to an incident or accident, thereby reducing ground damage and personal injuries.
2. Early success with Maintenance and Ramp LOSA programs demonstrates their ability to not only reduce ground damage (decline in ground damage attributable to human error ranged from 43% to 73%), but also their ability to improve efficiencies and reduce potential for human error by simplifying procedures like the lock-out and tag-out procedure for B767 leading edge devices at one of the partner air carriers.
3. Improved communication and coordination of safety expectations with airport officials and external contractors working on air carrier aircraft.

There are two fundamental principles behind successful LOSA programs:

1. The root causes of fatal accidents are similar to those of events involving substantive damage and injuries as well as unreported errors that did not result in any harm. This principle is based on the Heinrich ratio (Heinrich, 1941), which states that for every fatal outcome, there are about 30 major harm outcomes and about 300 unreported or no harm outcome scenarios. Thus, the assumption is that if one increases the vigilance regarding routine threats and errors, the operator(s) will be able to stop the error trajectory from manifesting itself in harm (this is the proactive aspect of this approach), and if the operator(s) is mindful of the systemic causes for such errors, he/she could enhance the safety even further by implementing systemic solutions (this is the predictive aspect of this approach).
2. The data from LOSA observations are collected anonymously and are maintained entirely within the organization; therefore, there is no need for an approval from the FAA/regulator. While the anonymity and lack of formal agreement with the FAA may create a certain degree of separation from punitive action, the company is still expected to honor its non-punitive policy for data collected under the LOSA program.

The move toward a Maintenance LOSA program is also an attempt to centralize all safety programs under the programmatic umbrella of an SMS Program (FAA, 2013). This integrated approach allows for education and voluntary reporting programs from all employee groups to be managed under a cohesive programmatic umbrella, which not only improves administrative efficiency, but also improves the potential for cross-program leveraging of data and predictive analytics. Furthermore, if all the employee groups receive similar treatment regarding anonymity, confidentiality, nonpunitive report handling, there is a greater likelihood of improved interpersonal trust among the employees, management, and the regulator.

CAUTION: Most organizations with fifth or sixth generation MRM programs have built a robust awareness of the fundamentals of maintenance human factors (MHF) and they tend to assume that maintenance and ramp personnel are familiar with topics like the Dirty Dozen. Therefore, fundamentals of MHF are not included in the 11 major steps to LOSA implementation, as suggested by Ma and Rankin (2012). The organizations that have not incorporated such fundamental human factors training in their maintenance programs, would find it useful to incorporate at least the following presentation provided by the FAA: https://www.faa.gov/about/initiatives/maintenance_hf/training_tools/.

13.2 MRM RESEARCH PROGRAM

13.2.1 FAA–TC–UK CAA

As presented earlier in this chapter, the 1988 Aloha Airlines accident was the first airliner accident publicly acknowledged as one caused by maintenance errors. Recognizing that much of the transport aircraft fleet across the nation was aging, and similar challenges could be lying dormant at other companies, in June 1989, Dr. William Shepherd, from the Biomedical and Behavioral Sciences Division of the FAA, called the first meeting on human factors issues in aircraft maintenance and inspection (Shepherd & Parker, 1989). The objective of this meeting was to identify key human factors issues that impact maintenance and inspection actions, and Dr. Shepherd sought to both raise the awareness of the conditions under which an aircraft maintenance technician performs his/her job, as well as to identify research efforts necessary to improve safety in aviation maintenance and, if necessary, make appropriate recommendations for regulatory changes. The recommendations arising out of this initial meeting could be categorized as follows:

1. **Modernize technical training:** It was widely recognized that the extant technical training and performance requirements in the FAA Part 147 curriculum are inadequate for the modern aircraft technology that is in

use. The participants recommended a thorough review and rewrite of the regulatory requirements so that both technical requirements as well as instructional technologies could be enhanced. It was also noted that the supply of trained aircraft maintenance technicians was inadequate to meet the future demand; therefore, enhanced marketing efforts were recommended.

2. Add soft skills training: The need for supplementing technical training with soft skills focused on the need for training in interpersonal communication and management of stress and time pressures in the work environment.
3. Create means for ongoing research on aviation MHF: There was a need for ongoing research in aviation MHF ranging from task analysis of actual technician and inspector jobs to improvement in maintenance instruction and data as reported in various technical publications and manuals. Also, the participants expressed the need for a centralized database of industry information concerning maintenance technologies, procedures, and problems.

Overall, the participants encouraged Dr. Shepherd to continue with such meetings on a regular basis and engage the industry, academic researchers, consultants, and FAA representatives in a collaborative dialog. Thus, in response to the above recommendations and overwhelming support from the aviation maintenance industry, the Human Factors in Maintenance Research Program was born, and it was housed under the Office of Aviation Medicine. Ms. Jean Watson was appointed the Program Manager. From then on, the FAA followed a structured process of engaging the aviation maintenance industry in identifying research requirements, identifying and selecting appropriate researchers (both academic and nonacademic), leveraging resources from other federal agencies, and disseminating results through annual conferences, published reports and proceedings, as well as journal articles, books, book chapters, software, website archives, and videos. Today, most of the training materials and research reports are available at the following site: https://www.faa.gov/about/initiatives/maintenance_hf/.

Just months before Dr. Shepherd organized the first Human Factors in Aviation Maintenance and Inspection meeting, in March 1989, Air Ontario's Fokker F28 crashed in Dryden, Ontario, Canada. The subsequent investigation resulted in almost 200 recommendations, including those related to aviation MHF. Thus, Transport Canada (TC) was also highly motivated to develop stronger awareness regarding human factors in aviation maintenance. The year 1990 onward, representatives from TC started to participate in the FAA's Human Factors in Aviation Maintenance and Inspection meetings. In 1993, TC hired Gordon Dupont to develop their HPIM training

program and released the program in 1994 (as previously discussed in Section 13.1.3 under Third Generation MRM Programs). Almost concurrent with this development in Canada, and triggered by the 1990 BAC 1-11 accident in the United Kingdom, the UK CAA's interest in MHF also began to grow. The participation of representatives from both TC and the UK CAA, as well as airlines and maintenance organizations from Canada and Europe continued throughout the 1990s. Ultimately, the FAA, TC, and the UK CAA decided to take turns hosting the meetings. The first international meeting was in fact the Twelfth Human Factors in Aviation Maintenance and Inspection Symposium, which was hosted by the UK CAA in 1998 and held at Gatwick Airport. In 1999, the 13th symposium was in Daytona Beach, FL; in 2000, the 14th symposium was in Vancouver, BC; in 2001, the 15th symposium was in London, UK; in 2002, the 16th symposium was in San Francisco, CA; and in 2003, the 17th (and final) symposium was in Toronto, ON.

There are numerous outcomes that could be linked with this series of seventeen symposia that lasted for 14 years. Some of the key outcomes are as follows:

1. Built the legitimacy of Maintenance Human Factors (MHF): Through numerous funded research projects, many serious academics from a variety of universities, as well as the NASA Ames Research Center, were drawn to research opportunities. They developed a substantive scholarly body of knowledge and built the foundation upon which text books and training materials could be developed. The applied nature of research in this field enabled the industry partners to fully participate in the research studies and not only appreciate the value of academic research, but also strengthen it by providing practical guidance and validation. Thus, the research outcomes had both practical significance as well as substantive contributions to the advancement of the state of knowledge in the field of MHF. Additionally, two of the most critical appointments that could be directly attributed to the success of the MHF program were as follows:
 - a. In 1995, Mr. John Goglia was appointed to the Board of the NTSB and he served till 2004. He was the first aircraft mechanic to ever serve on the NTSB Board and throughout his term, he was the most effective champion of human factors in maintenance.
 - b. In 2002, Mr. James "Jim" Ballough, an early believer in human factors created the position of the Chief Scientist and Technical Advisor for Human Factors in Aviation Maintenance with the FAA. He selected Dr. William "Bill" Johnson for that position and brought MHF on equal footing with flight deck human factors and other technical disciplines.
2. Created foundational materials and ready-to-use products for training: The FAA, TC, and the UK CAA used results of research projects and

industry best practices derived from various generations of implementation to develop foundational materials such as the PEAR Model, the SHELL(L) Model, Reason's Swiss Cheese Model, the Dirty Dozen, and various role-playing exercises, case studies, and videos that are commonly used in MHF courses across the western world. Such widespread shared use led to the development of a common body of knowledge, including shared understanding of terminology such as fatigue, sleep deprivation, closed-loop communication, and safety nets. The impact and dissemination of research results is demonstrated by the depth and breadth of outcomes posted on the following websites:

- a. Most of the FAA-funded research products, including reports, tools, and training materials are available at https://www.faa.gov/about/initiatives/maintenance_hf/
 - b. Ashgate Publishing, Ltd., which was recently acquired by Taylor & Francis, has built up a niche in aviation human factors and published a number of seminal works. Their catalog of current publications is available at <https://www.routledge.com>
 - c. TC's publications and videos are available at <http://www.tc.gc.ca/eng/civilaviation/publications/menu.htm>
 - d. The UK CAA has published guidance material to help approved maintenance organizations comply with the EASA Part-145 requirements. This document is available at <http://publicapps.caa.co.uk/docs/33/CAP716.PDF>
3. Contributed toward regulatory guidance materials and requirements: The various MRM programs implemented at the participating airlines and repair stations achieved numerous changes to maintenance tasks, organizational procedures (like maintenance manuals updates), and industry-wide best practices (like nonpunitive error-reporting policies). At the national and international levels, the reports and recommendations from various research projects and conversations at the symposia contributed toward the development of the following legislative changes:
- a. Canadian Aviation Regulations, Subpart 7: SMSs. In 1999, TC began its journey toward system-wide implementation of SMS programs by first developing an overall framework for the entire Canadian aviation industry. It was published as, *Flight 2005: A Civil Aviation Safety Framework for Canada* (Transport Canada, 1999). Canada became the first country in the world to regulate the implementation of SMS in the aviation industry, but took a phased approach to building awareness through guidance materials and progressive phase-in requirements across all the industry sectors (flight operations, maintenance, design, airports, etc.). Subsequently, in *Flight 2010*, TC increased the emphasis on risk-based decision-making (Transport Canada, 2006). Today, Subpart 7 of the Canadian Aviation

Regulations delineates the general requirements of SMS programs at all approved, certificate-holding organizations. Advisory Circular 107-001 provides guidance regarding development and maintenance of a Safety Management Program at large or complex organizations ([Transport Canada, 2015](#)).

- b. International Civil Aviation Organization (ICAO). In 1986, the ICAO Assembly adopted Resolution A26-9 regarding flight safety and human factors, and the Air Navigation Commission formulated the subsequent objectives. Among those objectives was the development of training materials to raise awareness regarding how human factors issues impact safety in every aspect of the aviation industry—design, operation, navigation, air traffic control, and maintenance. ICAO began with the publication of a series of *Human Factors Digests* (earliest guidance material on Human Factors in Aircraft Maintenance and Inspection dates back to 1995, Circular 253), but subsequently integrated their content into a two-part training manual: *Human Factors Training Manual*, Doc 9683-AN/950 ([ICAO, 1998](#)). With respect to the handling of MRM in this Manual, the following topics were included: contemporary maintenance problems; human errors in maintenance; organizational perspective on human errors in the maintenance and inspection environment; illustration of various cases of maintenance errors; human factors issues such as interpersonal communication and shift turnovers; variations in technical training methodologies and tools; teamwork and organizational factors; and job design. In 2003, ICAO published the *Human Factors Guidelines for Aircraft Maintenance Manual* ([ICAO, 2003](#)). Many of the outcomes from the Human Factors in Aviation Maintenance and Inspection Research Program were incorporated in this document: general background on human factors in aviation maintenance; key issues in maintenance error; countermeasures to maintenance errors; skills training in shift turnover/handover, task turnover/handover, and planning and recording of nonscheduled maintenance; environmental factors impacting maintenance actions and errors; ergonomic audit programs; document design for aircraft maintenance; and fatigue management. In 2008, ICAO published amendments to Annex 6, which included the requirement for all operators of international general aviation operations with certificated maximum take-off weight exceeding 5700 kg or those equipped with turbojet engines, to establish and maintain a SMS ([ICAO, 2008](#), section 3.3.2). In February 2013, ICAO developed the new Annex 19, dedicated to safety management, and adopted it in November 2013—this annex provides comprehensive guidance on SMS implementation requirements and timelines for both operators and regulators ([ICAO, 2013](#)).

- c. European Aviation Safety Agency (EASA) and UK CAA. EASA incorporated the human factors training requirements under Joint Airworthiness Requirements (JAR) Part-145. The deadline to comply with this requirement was July 1, 2005 and for alternate means of compliance, the deadline was September 28, 2006 (CAA, 2003, Chapter 11, p. 1). All approved maintenance organizations were expected to have in place a process for initial and recurrent human factors training. The guidance material, with respect to interpretation and compliance with the JAR-145 requirements, from UK CAA (CAA, 2003) began with the discussion of safety culture and organizational factors leading to maintenance errors; thereafter, it continued with focus on error management, individual-level human factors issues such as fatigue, environmental factors, maintenance procedures and documentation, communication, planning, professionalism, event reporting systems, and concluded with human factors training for maintenance professionals.
- d. FAA. While ICAO, TC, EASA, and UK CAA took the compliance-based approach to implementation of MRM and SMS programs, the FAA took a voluntary approach to MRM and SMS adoption and produced numerous materials that could be used for awareness training. The FAA also updated its Aviation Maintenance Technician Handbook (General) by adding Chapter 14 on Human Factors (FAA, 2008), and further revised it in 2011. In recent years, the FAA has committed to comply with the ICAO requirements and is making efforts to make the appropriate regulatory changes (FAA, 2016). For example, in 2015, the FAA issued the final rule requiring all air carriers operating under Part 121 to develop and implement an SMS program; it also indicated that a similar requirement might be extended to Part-145 operators (approved repair stations) through the corresponding Part 121 air carriers. The requirements for human factors training are not specifically listed in the final rule, but under Subpart E (Safety Promotion), it is expected that the workforce will “attain and maintain the competencies necessary to perform their duties relevant to the operation and performance of the SMS” (FAA, 2015, §5.91, p. 1328). Also, according to the latest Notice of Proposed Rulemaking regarding the implementation of SMS programs at certificated airports, the requirement for an SMS program will only apply to small, medium, or large hub airports—the comments in response to this NPRM are under review (FAA, 2016). Thus, the US aviation industry is on a good path to sustainable implementation and continuous improvement of MRM and SMS programs.

13.2.2 Government—Academia—Industry

The majority of the research related to MHF was carried out in the United States. It was funded by the FAA and/or the NASA; conducted by academic researchers (faculty and students) or consultants; and supported by industry partners. Some of the key advantages of this government—academia—industry partnership were as follows:

1. Government funding allowed for the research products to be available to the broader aviation industry rather than specific consulting clients, advance the body of knowledge and produce numerous academic publications, and provide content and recommendations for the production of numerous policy documents.
2. The academic partners served as trusted agents between the government agencies and the industry partners. The participating faculty and students brought a high degree of rigor, neutral assessment and objective guidance, and consistency in reporting results from several years of sustained efforts.
3. The industry partners not only provided access to their personnel and facilities, but actively engaged in the research projects—they developed the initial research requirements, appointed internal liaison personnel to help the research teams with project logistics, provided matching support in terms of personnel time, and complimentary air tickets. They also tested, critiqued, and used the products arising from the research projects. Some partners also hired the students who participated in the research projects.

Overall, the impact of the MRM research program was global in scope. For example, the ICAO, FAA, TC, and UK CAA guidance materials were developed from the results of the MRM research efforts. Similarly, a broad range of training materials and handbooks were also developed from the MRM research efforts:

1. Human Factors Guide for Aviation Maintenance and Inspection. Available at https://www.faa.gov/about/initiatives/maintenance_hf/training_tools/media/HF_Guide.pdf
2. MHF Presentation System (consisting of Powerpoint slides). Available at https://www.faa.gov/about/initiatives/maintenance_hf/training_tools/
3. Aviation MHF (CAP 716): Guidance material on the UK CAA interpretation of Part-145 Human Factors and Error Management Requirements. Available at https://www.faa.gov/about/initiatives/maintenance_hf/training_tools/
4. TC videos, posters, and guidance material. Available at <http://www.tc.gc.ca/eng/civilaviation/publications/menu.htm>

13.3 MRM TRAINING CONTENT AND DELIVERY

13.3.1 MRM Training Content

The target population for MRM training has varied over the years, but it is now generally believed that such training should be aimed at field personnel as well as the full line of supervisory and management personnel (Aircraft Maintenance Technicians/Engineers, quality assurance/control personnel, ramp personnel, incident/accident investigators, maintenance supervisors and managers, planning and maintenance program engineers, as well as technical training instructors). Generally, a broad overview of the fundamental human factors topics is recommended for all, but focused behavioral training and skills exercises are recommended based on the job categories and level of oversight responsibilities. For example, all personnel may receive a 4-hour general introductory course, and the different professional groups may receive a follow-on series of 8-hour workshops to build their proficiency in applying the general concepts to their routine job duties.

The *ICAO Human Factors Training Manual* (ICAO, 1998) recommended several training syllabus objectives (see Table 13.1). Available at <https://www.globalairtraining.com/resources/DOC-9683.pdf>.

The following training syllabus objectives were recommended. Each objective is further designated as either skill (S), knowledge (K), or attitude (A). Also, each objective could be taught at one of three levels of proficiency:

1. Level 1: Familiarization (be able to describe in simple terms, give examples, and use typical Human Factors terms).
2. Level 2: Basic Theory and Application (be familiar with the fundamental theoretical constructs underlying the Human Factors issues, familiar with the current literature, and apply the Human Factors knowledge to practical situations).
3. Level 3: Advanced Understanding of Theory and Applications (understand the underlying theoretical concepts and their interrelationships, give detailed examples, combine knowledge of multiple concepts in a logical, comprehensive and practical manner, and interpret results from various sources to apply corrective actions as appropriate).

By the time the ICAO manual was published, MRM programs in North America were in their third generation of evolution; however, they were largely focused on raising awareness. This emphasis on awareness was consistent with the fact that the large majority of training objectives listed in Table 13.1 were intended to raise either the knowledge level (awareness) or improve attitude (as a result of improved awareness). The introduction of the

TABLE 13.1 ICAO Recommended Training Syllabus Objectives

Training Objectives	Knowledge (K); Skill (S); or Attitude (A)
1. General Introduction to Human Factors	
a. Understand the basic concepts of human factors, recognize human factors contributions to aircraft accidents, and understand the goal of human factors training.	K
b. Appreciate the need to address human factors in aviation maintenance	A
2. Safety Culture and Organizational Factors	
a. Understand the concepts of a good safety culture and organizational aspects of human factors	K
b. Appreciate the importance of a good safety culture	A
3. Human Error	
a. Understand key error models and theories, recognize different types of errors and know the techniques used to avoid or recover from them, understand the difference between errors and violations, apply risk assessment methods to proactively manage error-inducing conditions, Appreciate that human error cannot be totally eliminated; it must be controlled.	K
b. Demonstrate a proactive attitude toward procedural compliance, avoidance of rule violations, and vigilance toward errors and error-inducing conditions.	A
4. Human Performance and Work Environment	
a. Recognize the effect of physical limitations and work environment on human performance, and be aware of various safety practices to guard against human physical, psychological, and physiological limitations.	K
b. Appreciate that humans are susceptible to environmental, physical, psychological, and physiological conditions, as well as effects of alcohol, drugs, and medications, and there is a tendency to take shortcuts.	A
c. Develop ways to improve situational awareness, cope with stress and fatigue, manage workload, stay motivated, and avoid complacency.	S

(Continued)

TABLE 13.1 (Continued)

Training Objectives	Knowledge (K); Skill (S); or Attitude (A)
5. The Maintenance Organization's own Human Factors Program	K
a. Achieve an in-depth understanding of the structure and aims of the company's own Human Factors program, including error-reporting programs, error/event investigation process, and disciplinary policies.	
b. Appreciate the importance of reporting incidents, errors, and problems.	A

Dirty Dozen by TC led to accelerated adoption of a number of knowledge- and attitude- level ICAO training objectives in a simplistic, but memorable manner across the world. As the MRM programs continued to mature, particularly in the fifth and sixth generation programs, the emphasis shifted toward application and synthesis of basic Human Factors knowledge, incorporating increased Level 3 proficiency. [Table 13.1](#) summarizes the training objectives and their knowledge/skill/attitude designations as recommended by (ICAO, 1998, pp. 2-1-19-22).

The UK CAA recommends the following topics in order to comply with the above ICAO requirements:

1. Safety Culture and Organizational Factors;
2. Errors, Violations, and Noncompliance with Procedures;
3. Factors Associated with the Individual (fatigue, shiftwork, stress, etc.);
4. Environmental Factors (includes tooling and ergonomic audit programs);
5. Procedures, Documentation, and Maintenance Data;
6. Communication, Handover, and Sign-offs;
7. Planning, Preparation, and Teamwork;
8. Professionalism and Integrity; and
9. Organization's Error Management Program (including error-reporting polices, investigation process, and solutions tracking process).

The FAA's recommendations for current generation MRM programs also include Fatigue Risk Management and Return on Investment Analysis. Both these topics have been particularly salient in the United States because the continuous duty-time for maintenance technicians can be extended beyond reasonable limits, and since the MRM programs are voluntary, they need to demonstrate a positive return-on-investment.

13.3.2 Delivery Options

Most airlines and repair stations (Maintenance, Repair, and Overhaul facilities) offer their own MRM training. A typical distribution of emphasis, and awareness (knowledge and attitudinal change) versus behavioral (skills change) training is presented in [Table 13.2](#). Generally, the Phase 1 awareness training is a 16-hour program; whereas, the rest of the training programs tend to be offered as 8-hour recurrent training programs. As illustrated in [Table 13.2](#), each phase builds upon the awareness developed in the preceding phase and adds a behavioral or skill development component to it. While the broad categories of emphasis remain fairly stable, the specific topics, exercises, case studies, etc. vary. However, they all strive to achieve the learning objectives stated by ICAO (see [Table 13.1](#)).

Three delivery styles have been used:

1. Half-Day Introductory Seminar: a 4-hour introductory seminar is typically aimed at senior management to get their support for the full training program.
2. Seminar/Workshops: 1-day or 2-day events.
3. Seminars Spaced 3–6 months apart: A series of 1-day progressive training events separated by 3–6 months.

13.4 RESULTS OF MRM TRAINING

13.4.1 Key Findings Across all Generations of this Research Program

MRM Training Programs, in General, Are Effective in Raising Awareness About Human Performance Limitations and Have Been Correlated With Improvements in Safety Performance Outcomes

In the United States, MRM training programs were received very well by the frontline maintenance personnel. The general pattern of scores on attitudinal survey items indicated an improvement soon after training, stable scores even one year after the training, but a decline thereafter and a shift toward negative scores thereafter. Subsequent interviews with the participating personnel indicated that while they were enthused during the training and remained optimistic that their colleagues and supervisors would implement appropriate changes to their work environment (consistent with the human factors elements discussed in the MRM training), they were disappointed because they did not see significant follow-through from their management. After sustained periods of nonimprovement in management follow-through, their initial enthusiasm turned from disappointment to frustration and finally to anger. Thus, the attitudinal scores declined and turned negative ([Taylor, 1998](#)).

TABLE 13.2 Phased Approach to MRM Training Implementation

Emphasis Area	Type of Training (Awareness/Behavioral)				
	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
Dirty Dozen	Awareness				
Individual and Team Skill Development	Awareness	Behavioral			
Individual and Organizational Error Mitigation Strategies	Awareness	Awareness	Behavioral		
Error Investigation and Analysis	Awareness		Awareness	Behavioral	
Proactive and Predictive Analysis and Systemic Improvements				Awareness	Behavioral

Although the emphasis of the MRM training was on raising the overall foundational knowledge about human factors issues and improving the participants' attitude toward human factors, the enthusiastic response to MRM training was correlated with improvements in work performance. For example, stress management was a key topic in these MRM programs—the participants must have taken most positively to this aspect of the training because they showed the greatest improvement in attitude toward stress management and this improvement was most positively correlated with decline in lost-time injuries as well as ground damage (Taylor, 1998). Based on a number of longitudinal studies, Taylor & Christensen (1998) reported that the MRM training programs resulted in an improved attitude toward safety, and this attitudinal improvement correlated with parallel and subsequent performance improvements such as reduction in lost-time injuries, ground damage, and logbook errors.

In search of a theoretical explanation for these observed effects of training, it seems Alvarez, Salas, and Garfano (2004) might offer valuable insight. They attribute transfer performance (the degree to which what is learned results in a measurable change in performance) to individual characteristics (mostly motivation to learn and transfer), training characteristics (content and delivery mechanisms most likely to support transfer), and organizational characteristics (generally termed as organizational climate conducive to transfer of training). With respect to the MRM programs, the participants seemed to be very motivated to learn and transfer (as indicated by the posttraining attitudinal scores), but the organizational climate for transfer of training was not always conducive to realize the full potential of the MRM training (as evidenced by the interview data that claimed lack of management follow-through). Thus, future implementation of MRM programs might benefit from Sitzman and Weinhardt's (2015) training engagement theory, which advocates for continuous assessment of engagement and commitment from multiple levels of the organization so that there is an ongoing attention to the training and multilevel vested interest in the training program's success.

Individual Professionalism and Interpersonal Trust Are Two Key Indicators of Safety Climate/Culture in Aviation Maintenance

MRM training programs, throughout all six generations, tend to emphasize the role of the individual maintenance technician in reducing errors, as evidenced by individual-level procedural compliance, stress management, situational awareness, fatigue management, workload management, and complacency, as well as interpersonal communication. It is not surprising that this increased emphasis on individual-level accountability, as a part of professionalism, has given rise to the importance of interpersonal trust as a matter of mutual accountability. Thus, individual professionalism and

interpersonal trust have emerged as the most consistent indicators of safety attitudes and behaviors, as well as the resultant safety climate/culture in aviation maintenance (Taylor & Patankar, 2001).

Individual professionalism is found to be comprised of two key factors: stress management and assertiveness (Patankar & Taylor, 1999, 2001; Taylor & Christensen, 1998). Stress management is not only about self-awareness of environmental, operational, and personal factors that lead to increased stress, but also about being able to manage that stress and being able to prevent such stress from manifesting itself into human error. Assertiveness, on the other hand, refers to one's commitment to respectfully speak up in support of safety, regardless of labor-management challenges, social pressure, or personal risk, as well as to be able to receive input from others.

Interpersonal trust, in the context of aviation maintenance, is defined as willingness of maintenance personnel to trust their co-workers on matters of professionalism and safety—they should be able to rely on one another to carry out their commitments and to protect each other from hazards. Thus, interpersonal trust and open communication tend to be mutually-supportive properties. Patankar, Taylor, and Goglia (2002) studied interpersonal trust across five maintenance organizations and discovered that one-third of the mechanics did not trust that their supervisor would act in the interest of safety. The significance of interpersonal trust began to emerge in fourth generation MRM programs and grew stronger in the fifth and sixth generation programs. In the early stages (fourth generation), the realization of the significance of interpersonal trust was limited to co-workers and employee–management relationship. As the MRM programs continued to mature through the fifth generation, the notion of interpersonal trust became foundational to the sustainability of MRM programs, and in the sixth generation programs, the level of trust expected from co-workers, managers, regulators, and industry-wide colleagues has set a new high standard without which incorporation of programs like ASAP and LOSA, and predictive analytics available due to sharing of safety data, would be impossible.

Aircraft Maintenance Engineers/Technicians Are Among the Most Individualistic People in Aviation

Hofstede (1984), through his landmark study of IBM workers around world, classified work values of different people. Those who were more inclined to value group harmony or community goals over individual autonomy were classified as “collectivistic,” and those that valued individual autonomy over group or community harmony were classified as “individualistic.” Hofstede noted that the individualistic versus collectivistic differentiation mapped very well across national boundaries—people from western countries were more individualistic than those from eastern or South American countries. This study laid the foundation for classification of cultures based on national

boundaries. Helmreich and Merritt (1998) called such differentiation “national culture” and built on the underlying concepts across professional and organizational boundaries to define “professional culture” and “organizational culture.” Helmreich and Merritt applied Hofstede’s individualistic versus collectivistic measure to airline pilots and surgeons and discovered that the surgeons were more individualistic than Hofstede’s original sample of IBM workers and that the pilots were more individualistic than the surgeons. When Taylor (1999) conducted a similar study of aircraft maintenance technicians, he discovered that the technicians were more individualistic than pilots. Thus, on the continuum of individualism-through-collectivism, aircraft maintenance technicians tend to be the most individualistic, which is quite the opposite of the goals of MRM programs. Therefore, in order for MRM programs to be effective in improving interpersonal communication and teamwork, they must place greater emphasis on behavior modeling and skills training. In terms of cross-national implications, subsequent studies (Patankar & Taylor, 2001; Patankar, 1999; Taylor & Patankar, 1999) have noted that while the North American MRM training transitions well to Asian audiences, the assertiveness scores increased more significantly in Taiwan and India. Therefore, a typical North American MRM training could be used in more collectivistic national cultures, but certain populations may respond differently to the modules related to assertiveness.

Return-On-Investment (ROI) for MRM Training Can Be Demonstrated

In the United States, the implementation of MRM training has been voluntary. Thus, most companies needed to demonstrate a positive return-on-investment in order to offer such programs and make them part of the broader safety strategy. The FAA has provided a basic return-on-investment calculator tool (FAA, 2017b). This tool provides a good way to generate an initial estimate of the ROI to be expected from an MRM program. However, while it accommodates for a less than 100% probability of success with the MRM program (training may not achieve 100% of its goals), it does not accommodate for other concurrent or recently completed safety initiatives that might influence the overall safety performance outcome. In order to objectively measure the financial impact of MRM training, while giving credit to non-MRM safety initiatives that might have been concurrently or previously supported, Taylor (2000b) presented a formula that distills the effects of MRM instruction for a realistic assessment of return-on-investment from MRM training alone. In this formula, a “causal operator” is used as a multiplier (between 0 and 1) to appropriately right-size the estimated ROI. The actual value of this causal operator is based on the pre/post comparison of change in participant attitudes resulting from an MRM training program. Thus, if there was a 30% improvement in participant attitudes after the

MRM training, the training program could take credit for only 30% of the total ROI. Patankar and Taylor (2004a) presented two examples to illustrate that substantial positive ROI is possible from expensive MRM programs that affect “high value” outcomes (such as the lost-time injuries example). Also, at times, MRM programs may be successful at improving safety outcomes, but not result in a positive ROI. Therefore, it is important to plan and design one’s MRM program to impact the specific targets and their associated ROI.

Lercel, Steckel, Mondello, Carr, and Patankar (2011) classify ROI analysis in terms of three levels: micro, mid, and macro. According to this classification, the type of analysis suggested by the FAA and Taylor (as discussed in the preceding paragraph), would be regarded as micro-level analysis. At the next higher level, the analysis shifts to company-wide safety programs. Thus, the analysis of a company-wide SMS program, which may include programs like MRM, CRM, and LOSA, as well as implementation across number of locations, would be considered a mid-level tier of ROI analysis. Although Lercel et al. did not report any mid-level examples from the aviation industry, they presented compelling examples from construction and pharmaceutical industries to illustrate both company-wide benefits of safety programs as well as risks of a safety-related failure. At the macro level of analysis, Lercel et al. illustrated the devastating effects of safety incidents (even those with a relatively benign or positively heroic outcome) on company stock prices—essentially, companies could lose substantial market value as a result of a safety incident, regardless of the actual outcome (in terms of loss of life/property).

Since safety programs are rarely implemented in isolation, Taylor (2000b) introduced the concept of causal operator to right-size the impact of a particular safety program such as the MRM training. Lercel et al. (2011) acknowledged the same fact, but presented the “Safety Investment Combination Matrix” as a way to compound the financial impact of multiple safety programs. This approach presents all the safety programs combined into one, comprehensive investment, much like a mutual fund with respect to financial investments. Such a portfolio-based approach fundamentally shifts the notion of safety programs from “costs” to “investments”; brings top management interest by connecting safety program success with corporate financial success; enables longer-term outlook by considering the overall impact of all safety programs rather than financial benefits of discrete programs; leverages the benefits of multiple, concurrent programs; and accommodates short-term negative returns from one or two individual programs.

MRM Programs Have Had a Profound Impact on the Safety Culture Across the Global Aviation Maintenance Community

According to Schein’s (1988) model of organizational culture, shared values are the essence of any group’s collective culture, and such values

are formed based on shared experiences of the individuals in that group. One could argue that in the early years of MRM programs, the shared experience of aircraft maintenance engineers/technicians revolved around blame. Accident/incident investigations focused on “who” made the mistake and the corrective actions were largely punitive to the individual responsible for the mistake. Thus, theoretically, if one had to change this blame-oriented culture in aviation maintenance, it was essential to create a different shared experience. While they may not have realized it at the time, the founders of the second generation MRM programs—John Goglia, Jim Ballough, and Joe Kania—knew from personal experience that the technician who made the mistake was most knowledgeable about the circumstances leading up to the mistake and therefore needed some degree of protection from disciplinary action so that he/she could help prevent similar errors in the future. As the second generation programs went through implementation and the three parties—company, FAA, and the union—demonstrated that they could uphold their mutual agreement, all three parties created a new shared experience. Over time, repeated and consistent emphasis on nonpunitive error management helped move the aviation maintenance community away from blame-oriented culture. However, it took almost a decade for this cultural shift to be institutionalized as a formal, replicable process: it came in the form of ASAP programs as part of the fifth generation MRM programs. Thus, today, the artifact that illustrates the shift from a blame culture to a reporting or just culture within a particular organization is the ASAP agreement between labor, management, and the regulator. The claim that such cultural shift is a national phenomenon is supported by the rise in Maintenance ASAP programs from 6 to 168 from 2003 to 2017.

On a global scale, the collaboration between the FAA, TC, and UK CAA resulted in specific requirements and guidance materials from ICAO, and many of the member States have ratified these requirements and customized the ICAO guidance materials to meet their needs. The recommended training syllabi as well as supporting materials such as posters, books, and videos have helped institutionalize a common body of knowledge expected from all aviation maintenance technicians. Also, the Aviation Accreditation Board International (AABI; the accrediting body of collegiate aviation programs) has included the requirement for a robust safety management program in all AABI-accredited aviation colleges/universities. Thus, the MRM research efforts that were initiated in the United States have contributed toward a policy- and practice-level impact across the globe, and they have penetrated many of the premier collegiate programs so that the future maintenance technicians will enter the industry with sufficient knowledge, appropriate attitude, and essential skills to practice behaviors consistent with the expectations of a just safety culture.

13.4.2 Implications for the Future

The story of MRM programs makes for an interesting case study in large-scale culture change. Trigger events like the three seminal accident cases—Aloha Airlines, Air Ontario, and British Airways BAC 1-11—challenged the prevailing unquestioned assumptions about the maintenance environment, practices, and personal vulnerabilities. The resultant accident investigations also played a critical role in shifting the mindset from individual-level blame to system-level responsibility. Thus, when MRM programs were created and implemented, they offered an alternate shared experience to the maintenance personnel, management, and regulators. As each party learned from the new experience and held steadfast on their mutual commitment, the old assumptions melted away, interpersonal trust improved, shared values changed, and workplace performance outcomes improved. Both internal and external leaders (people who held formal positions) and influencers (people who did not hold direct operational responsibilities) played their part in shaping the interventions, providing objective feedback from the success and challenges in implementing the interventions, and developing reports and training materials. Holistically, an intricate web of social systems, comprising of individuals, corporations, labor unions, universities, and government agencies, achieved a fundamental shift in shared values across the global aviation industry. This is not to say that the process was flawless or the experience was without challenges and setbacks; nonetheless, people persevered, adapted to the changing fiscal, geopolitical, and regulatory constraints, and in some cases passed on the responsibilities to their successors to continue the core pursuit.

Looking forward, future opportunities for large-scale cultural change should bear in mind the following observations: (1) large-scale, industry-wide, and global cultural change could take decades, but it is possible; (2) development of both awareness and behavioral change programs is essential, and such programs should be implemented across the entire workforce vertical (from preemployment academic programs to executive level seminars); (3) leaders and influencers must stay committed to the core cause, but be willing to adapt to the changing external and internal conditions; (4) positive financial returns can be achieved, but they need not be preconditions for starting modest efforts; (5) government, industry, and academia can partner very effectively in leveraging each other's strengths; and (6) once there is sufficient political support, legislative changes at the national and international levels are most effective in institutionalizing the cultural change.

To build on the Information Sharing meetings hosted by the FAA, and the ongoing efforts to share safety data across air carriers, the next level of improvement in safety culture calls for research projects that leverage the power of integrating data regarding normal operations, lessons learned, best

practices, and impact achieved across the flight, maintenance, cabin, and dispatch siloes. Such studies need to be funded by government agencies like the FAA, TC and the UK CAA so that the reports are publicly available and usable across the industry. Aviation is a global industry and multinational collaborations are essential to foster continued improvements in the industry's safety culture.

13.5 INCIDENT REVIEW TOOLS AND TAXONOMIES

13.5.1 Maintenance Error Decision Aid

The maintenance error decision aid (MEDA) was developed by the Boeing Company (Rankin, 2007). This tool was developed during 1992–95 and coincided with the parallel development of second and third generation MRM programs. With the growing adoption of MRM programs across major air carriers in the early 1990s, and the concurrent push toward identification of broader systemic and human factors related root causes of airliner accidents, the aviation industry wanted a practical tool that they could use to investigate maintenance-related errors. Once the MEDA tool was developed, field-tested, and ready for broad distribution, the Boeing Company started providing the tool and the accompanying training on how to use it to all its customer airlines. Thus, the tool as well as the basic concepts of human factors in maintenance, nonpunitive reporting systems, and emphasis on systemic solutions were promulgated across the international air carrier community.

The MEDA process involves five steps: event, decision, investigation, prevention strategies, and feedback. By setting the trigger on an “event” rather than an accident or incident, the MEDA process encouraged review of all undesirable outcomes. Also, it allowed the operators to track events that were important to them. Examples of such events included flight cancellation, gate return, and inflight engine shut-down. All the events were associated with actual cost incurred by the air carrier (although the cost varied by company), and therefore the process encouraged the users to consider financial implications of both the errors as well as the solutions. In the decision phase, the operator is expected to determine whether or not the event was maintenance-related; only if it was maintenance-related, the operator would use the MEDA process further to conduct the investigation. The predeveloped MEDA form guided the investigators in determining the underlying causes of the event and enabled them to determine whether the event occurred due to an error or a violation. According to MEDA, an error is an unintentional human error and a violation is an intentional human action; maintenance-related events can be caused by either errors, violations, or a combination of the two. MEDA also allowed the investigators to consider appropriate prevention strategies. Finally, the

feedback phase was intended to communicate back to the workforce the nature of the event, results of the investigation, and strategies to be employed to prevent similar events in the future. As of 2007, Boeing claimed that over 500 of its customer organizations have used MEDA training, and the outcomes ranged from a 16% reduction in delays due to maintenance to 48% reduction in operationally significant events. Thus, MEDA has proven to be an effective tool to mitigate lower-level events and thereby reduce the risk of higher-consequence events (assuming that the contributing factors for both levels of consequences are similar or the same).

According to the MEDA taxonomy, maintenance errors are classified into the following categories (Boeing, 2001):

1. installation error;
2. servicing error;
3. repair error;
4. fault isolation, test, or inspection error;
5. foreign object damage error;
6. airplane/equipment damage error;
7. personal injury error; and
8. other.

Next, the MEDA process calls for the identification of various contributing factors:

1. information;
2. equipment, tools, and safety equipment;
3. aircraft design, configuration, and parts;
4. the job or task;
5. technical knowledge and skills;
6. individual factors;
7. environment and facility;
8. organizational factors;
9. leadership and supervision; and
10. communication.

The MEDA Guide (Boeing, 2001) provides additional guidance on what the investigator should consider in responding to the various contributing factors. Using the MEDA Guide could help improve consistency in the interpretation of contributing factors and the information collected by the organization is more likely to be reliable.

With respect to the error prevention strategies, the MEDA process first calls to review the existing strategies that may not have been effective in the given instant. If so, rather than creating a new strategy, it might be wise to review the factors that make the existing strategy ineffective, and then consider a new strategy, if one is needed.

13.5.2 HFACS for Maintenance

The Human Factors Analysis and Classification System (HFACS) was developed by the Naval Safety Center and subsequently extended to include maintenance-related events (called the HFACS–Maintenance Extension or HFACS-ME) (Schmidt, Lawson, & Figlock, 2001). One of the core principles of the HFACS-ME model is that accidents are a combination of latent conditions and active failures; thus, in order to develop long-term preventive measures, one should address the latent conditions. Latent conditions and active failures are classified into four broad categories: unsafe management conditions, unsafe maintainer conditions, unsafe working conditions, and unsafe acts of the maintainer. As a result of this approach, it is likely that any given investigation will reveal latent conditions that could contribute to other undesirable events in the future. Schmidt et al. (2001) analyzed 15 NTSB accident reports and discovered that 100% of them reported unsafe management conditions, 73% reported unsafe maintainer conditions, 67% reported unsafe working conditions, and with respect to unsafe maintainer acts, 87% reported errors (unintentional human error) and 47% reported violations (intentional risky or illegal actions).

13.5.3 LOSA in Maintenance and Ramp Operations

While both MEDA and HFACS-ME are both excellent tools, they are designed to be used to investigate events that have already occurred; hence, they are reactive. On the other hand, the line oriented safety assessment (LOSA) observations are intended to actively intercept errors as they happen and identify potential problems; hence, data from such observations can be used proactively (Crayton, Hackworth, Roberts, & King, 2017). The foundational taxonomy for Maintenance LOSA is quite similar to MEDA; just the trigger point is not an actual event, but a routine observation of normal operations. For example, the first contributing factor listed in MEDA is “Information.” While filling out a MEDA report, the investigator must consider various questions related to information and then fill out a narrative response. On the other hand, in the case of a LOSA observation, the observer can select from a drop-down list of options and report whether the information is not understandable, unavailable, incorrect, etc. (FAA, 2017c).

It is important to note that LOSA observations are a combination of understanding the safety risk and threats, as well as how the threats are being managed. Thus, when there is an eminent safety risk and a threat, but the threat is not managed effectively to contain the risk, it will result in an undesirable event. If the threat is managed within acceptable limits, the underlying data will provide some opportunities for analysis regarding whether or not broader risk management strategies need to be developed.

13.6 INFLUENCE ON SAFETY CULTURE IN TECHNICAL OPERATIONS

Ployhart, Hale, and Campion (2014) reviewed a number of definitions of culture and concluded that they converge on three dimensions: (1) artifacts, (2) values and beliefs, and (3) underlying assumptions, which are consistent with Schein's theory of organizational culture (1988, 2010, 2015). Hofstede's (1984) work focuses on shared values and has been used most commonly for studies involving cultural comparisons. Helmreich and Merritt (1998) extended the use of values-based differentiation to categorize groups of people in accordance with national boundaries (national culture), organizational boundaries (organizational culture), and professional boundaries (professional culture). Thus, Hofstede's comparative scales such as individualism versus collectivism or power distance could be used in the context of different national groups, organizational groups, or professional groups. With respect to safety culture, the key shared value is safety. Thus, safety culture is a focused study of organizational culture. Therefore, in order to examine the influence of MRM programs on the safety culture in technical operations, one needs to focus on how the shared values and beliefs were influenced, how the underlying assumptions might have changed as a result of the MRM programs, and what specific artifacts were created to memorialize the changes in shared values and beliefs.

13.6.1 Shared Values, Beliefs, and Assumptions

Schein (2015) claims that over a period of time, assuming that the group membership remains fairly stable, most groups go through certain experiences and learn not only how to avoid mistakes, but also what behaviors are rewarded, thereby forming their shared values and beliefs. In the case of technical operations, maintenance personnel had experienced a blame-oriented culture wherein it was common for error investigations to focus on the person who might have committed the error rather than addressing latent issues in the system. Thus, the maintenance community had learned to not speak up or maintain their personal notes on how to prevent errors. However, certain key leaders knew that in order to address the challenge of maintenance errors, they needed to earn the trust of their maintenance personnel and engage them in solving the system problems. Therefore, when John Goglia, Joe Kania, and Jim Ballough decided to work together to address this issue, they took the foundational step toward changing the shared experiences of maintenance personnel and thereby setting in motion the long journey toward a sustainable cultural change in aviation maintenance. At that time, a deeper, underlying assumption in the maintenance community was that if the technician was forthright in admitting his/her mistake, he/she would be subject to not only corporate disciplinary action,

but also to a certificate action by the FAA. Thus, it was essential for both the company and the FAA to provide the technician with consistent protection while not making the protection serve like a “get out of jail free” card (full amnesty). This approach was also foundational to today’s notion of a just culture, wherein there is a clear separation between inadvertent errors and intentional disregard for safety; the latter is punishable. Reflecting on how the culture in technical operations matured over the six generations of MRM programs, it is clear that the shared experience of the technicians, managers, and the regulators must have changed, which eventually led to the development of formal tripartite agreements among company, union and the FAA. Once these agreements started to be formalized and supported, the subsequent shared experiences served to reinforce the shared organizational values regarding safety, nonpunitive reporting, and just culture.

13.6.2 Role of Leaders and Influencers

For the purpose of this section, leaders are defined as persons holding formal positions of leadership in labor unions, companies, or regulatory agencies. On the other hand, influencers are defined as persons who do not hold any formal positions like the leaders, but they are generally well-regarded by their professional communities and can influence attitudinal and behavioral changes. In the case of MRM programs, there has been a robust coalition of leaders and influencers, and some have trades places as well. For example, pioneers like John Goglia, Joe Kania, and Jim Ballough started off as influencers (although they had formal roles, their authority was limited), and subsequently secured high-profile formal leadership roles and continued to “transform their individual drive into collective purpose and commitment” (Pettigrew, 1979).

At this point, it is important to acknowledge the role of all the major labor unions:

- IAM and Aerospace Workers;
- AMFA;
- International Brotherhood of Teamsters;

Representatives from these organizations played a critical role in protecting the rights of the individual maintenance technician and advancing the overall safety agenda, as well as serving as role models for higher standards of professional behavior. For example, they worked with their membership to develop key behaviors that would form the baseline expectations of professionalism from their members. Violation of any one of these behaviors constituted negligent behavior and hence the individual did not receive amnesty, bringing about a balance between accountability and benevolence (Patankar and Baines, 2003). Numerous individuals across all the labor

unions served as role models and champions of just culture, thereby routinely reinforcing the shared safety values.

Similarly, US air carriers like American, Continental, Delta, Northwest, Southwest, United Airlines, and US Airways offered their staff and facilities to help collect data, participate in research studies, and test prototype training materials. The in-kind contribution of their employees' time and access to physical resources could easily be measured in millions of dollars. Also, many of the large repair stations like AAR, B.F. Goodrich Aerospace, Lufthansa Technik, and TIMCO contributed their resources to support MRM research. More importantly, each of these partners used research results to improve their internal MRM training programs, safety policies, and consistent practice of desired behaviors by the frontline personnel as well as senior management. They also supported participation in regular information sharing meetings across the industry so that the best practices and lessons learned could be available for customization and adoption by other companies.

Academic and federal researchers were key influencers of safety culture in technical operations. Some of the most notable contributions, in the area of MRM/MHF research, came from Clemson University, FAA Civil Aero Medical Institute, NASA Ames Research Center, Purdue University, Saint Louis University, San Jose State University, Santa Clara University, and the University of Buffalo. Faculty researchers and their students worked with practically all the US air carriers and most of the repair stations, as well as some foreign air carriers, to develop robust research tools, analytical techniques, datasets, and results. Outcomes from these research projects as well as testimonials from key faculty members served as external influencers of training materials, guidance documents, policies, and regulations.

Several leaders in the FAA, TC, UK CAA, and the ICAO have also made an incredible impact on the safety culture in technical operations. While they helped build awareness, hosted training programs and conferences, funded research, and hosted information sharing events, their most critical contribution has been in the area of legislative influence—they were influential in developing and approving regulations that require MHF training and specify the topics that must be covered in such training programs. This level of direction and specificity created regulations, policies, and guidance materials as significant artifacts of cultural change in technical operations and enabled consistent adoption of safety values across the global aviation industry.

13.6.3 MRM as a Planned Intervention

There is a long history in training research that delineates the role of training as a planned intervention (Alvarez et al., 2004). As noted in the preceding sections, the various generations of MRM programs have aimed at both improving awareness and changing individual behavior. While some programs had specific behavioral change goals directed at addressing problems

like documentation errors, others simply assumed that a change in awareness would translate into change in behaviors and ultimately into change in performance outcomes such as reduction in ground damage or lost-time injuries. For the most part, however, the *planned* aspect of the program was limited to individual-level awareness or individual-level change in behavior. Furthermore, most programs were successful in achieving passive behavioral changes suggested by their increased self-awareness regarding human performance issues, but not active changes in the sense that the participants were not overtly committed to *doing* anything different such as implementing mitigation measures to counter fatigue, distractions, stress, etc. In the future, interventions involving training programs could consider comprehensive models of training evaluation like Alvarez et al.'s (2004) integrated model of training evaluation and training effectiveness as well as Spitzer's (2005) Learning Effectiveness Measurement (LEM) methodology, which take a more active stance on transfer of learning into workplace behaviors and incorporate the role of extant organizational culture. Such an approach would not only make MRM-like training interventions more effective in achieving their outcomes, but also enable the managers (frontline through senior management) to be better prepared to support the organizational changes emanating from the implementation of the training intervention.

Another observation regarding the MRM programs is that the early generation programs were rooted in the corresponding CRM programs and customized for the maintenance application. Also, the early FAA InfoShare meetings were focused almost exclusively on flight-related issues and had no formal representation of the maintenance community. Over the years, both these conditions changed: the MRM training became more independent of CRM training and the InfoShare meetings had strong representation from the maintenance community. Thus, although one cannot claim that MRM was planned as a training intervention to influence safety culture in technical operations, it has certainly served that purpose. Learning from this experience, and drawing on relevant literature on training effectiveness, future interventions can be even more successful at achieving a large-scale cultural change.

13.6.4 Performance Outcomes

It has already been reported in this chapter that MRM training programs were effective in improving participant attitudes toward safety and there was a positive correlation between improvement in safety attitudes and improvement in safety performance related to ground damage and lost-time injuries. Also, these programs have achieved significant return-on-investment through cost savings associated with safety performance improvements. Thus, performance improvements have been noted at the individual and unit levels.

Theoretically, however, transfer of training into workplace behavioral change is a function of the extant organizational climate (Birdi, 2007;

Holton, 2005), and a shift in participants' behaviors, supported by feedback focused on task performance (Senge, 1990), can bring about a change in organizational climate and culture. Thus, one could argue that the training intervention serves as a specially designed shared experience, which could employ Spitzer's LEM, with specific operational goals as well as value-based goals. Birdi and Reid's (2013) Taxonomy of Training and Development Outcomes would be particularly helpful in formulating training outcome goals at the individual-, group-, organization-, as well as the entire aviation industry-level.

13.6.5 Artifacts

Schein (1988) defines artifacts as manifestations of the underlying culture and hence they can take the form of language, symbols, stories, as well as implementation mechanisms like policies and procedures. Since artifacts are *products* of culture, Patankar (2017) proposes the study of artifacts as outcomes or manifestations of culture rather than the culture itself. Vilnai-Yavetz and Rafaeli (2012) argue that artifacts are much more than evidence of organizational culture. They incorporate relevant literature and provide an expansive definition of artifacts:

Artificial products, something made by human beings and thus any element of a work environment...perceived by senses and that they have certain intentions, aiming to satisfy a need or a goal...include intangible notions such as names, language, and contracts, as well as tangible notions such as inanimate objects introduced by organizational members into their organizations. (p. 10)

Considering the broad range of tangible and intangible items that could be included within the scope of an artifact, Vilnai-Yavetz and Rafaeli present three dimensions from which artifacts should be analyzed: instrumentality, esthetics, and symbolism. Instrumentality refers to the utility (or lack thereof) of the artifact—many physical artifacts such as tools, checklists, policies and procedures would have a positive influence on the outcomes and hence would be considered to have positive instrumentality. Esthetics refers to the sensory reaction to the artifact—is it pleasing, is it appropriately used (graphic or symbolism in the context of local customs and traditions), or does it evoke generally positive emotional reactions? Symbolism refers to the meaning of the artifact—it could mean something entirely different to the ones that create the artifact versus those that see it or observe it. Thus, “artifacts can have both intended and unintended symbolic consequences” (p. 14).

In the case of MRM programs in technical operations, numerous items could be considered cultural artifacts. Some examples of such artifacts are as follows:

- The Dirty Dozen posters (available at <http://aviationknowledge.wikidot.com/aviation:dirty-dozen>)
- The ASAP Advisory Circular (AC 120-66B) (available at https://www.faa.gov/documentLibrary/media/Advisory_Circular/AC120-66B.pdf)
- MEDA Form (available at https://www.faa.gov/about/initiatives/maintenance_hf/library/documents/media/media/meda_results_form_rev1.pdf)
- Fundamentals of SMSs Video (available at <https://www.youtube.com/watch?v=IdRwNZ-7s4Y>)
- ASAP Memorandum of Understanding (available at http://www.iamdl142.org/wp-content/uploads/2017/09/127-AA_2017a.pdf)
- Safety Awards (e.g., available at <https://www.tn.gov/workforce/news/5552>)

Most of these artifacts have a very high level of instrumentality—they were designed to be used to convey a message or used as references/tools for specific tasks. Some of them, like the Fundamental of SMSs video, have a good esthetic appeal as well. Other artifacts like the ASAP MOU have a very high degree utility as well as symbolism. The public display of names and signatures on the MOU have a very high symbolic value, expressing the joint commitment toward the shared value of safety and the operating principles agreed upon in the document. Such documents serve as authoritative license for frontline personnel to hold each other accountable for agreed upon behaviors. Finally, safety awards, as symbolic artifacts, play a critical role in recognizing individual and group-level achievements as well as in encouraging others to engage in similar behaviors. Overall, all these artifacts seek to reinforce shared values and beliefs regarding safety.

13.7 CONCLUSIONS

The story of MRM for technical operations provides an interesting roadmap for a large-scale cultural change. In the case of MRM programs, three catastrophic maintenance-related accidents (Aloha Airlines, Air Ontario, and British Airways BAC 1-11) served as the defining moments or trigger events. In response to these events, there was a flurry of responses. First, there was an organized series of symposia to gather industry-wide input in determining the nature of the work environment and general challenges like aging aircraft, workforce development, and human fallibility. Almost concurrent with these symposia the previously successful CRM training was adapted to the maintenance environment and the first generation of MRM training program was launched. Over the years, both the series of industry symposia and the MRM training programs evolved through six generations, they survived multiple economic challenges, and adapted to meet the emerging regulatory and economic needs. Thus, today's MRM programs tend to be embedded in the broader SMS program.

In response to the needs identified by the industry symposia, and in partial support of the ongoing MRM training programs, the FAA funded a number of research programs that enabled serious action research in collaboration with aviation companies and labor unions. This research program is also possibly the only example of large, industry-wide collaboration across the US FAA, NASA, TC, and UK CAA. Such multinational collaboration allowed for many of the research results to be translated into guidance materials, policies, and regulations in the United States, Canada, and the United Kingdom, as well as on a global scale through the International Civil Aviation Organization. Thus, it helped infuse a common language across the world's leading regulators and create a shared platform for long-term, cultural change. The findings from these research projects clearly demonstrate that the training programs were effective in improving participant attitudes toward safety and those attitudinal improvements were positively correlated with improvements in safety performance outcomes like ground damage and lost-time injuries.

In addition to the training programs and tangible artifacts like policies and regulations, the MRM program also reinforced the importance to interpersonal trust. In the early years, it was acknowledged that trust among technicians, company management, and the regulatory representative was critical to the success of MRM programs. This recognition served as the key to the subsequent success of ASAPs, the development of just culture, and it is well-integrated in the expectations of the current SMS program as well as maintenance and ramp LOSA programs.

Moving forward, there is growing interest in preventive and predictive measures. Thus, there is no doubt that MRM programs will continue to evolve and their impact will also grow. The adoption and use of an MRM program could be viewed along a maturity continuum with reactive programs on one end and predictive programs on the other. As aviation organizations become comfortable with one generation of MRM programs, they may move to the next generation along the continuum toward predictive programs. The ability to move along the maturity continuum will likely be a function of interpersonal trust, management commitment, availability of fiscal and human resources, and the overall state of the industry.

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