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Department of Air Transport

Integrated safety data collection and processing for maintenance organisations

Master's Thesis

Study programme:	Technology in Transportation and Telecommunications
Study field:	Air Traffic Control and Management
Thesis advisors:	Ing. Andrej Lališ, Ing. Vladimír Plos

Bc. Katarína Szentkeresztiová

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Při zpracování diplomové práce se řiďte osnovou uvedenou v následujících bodech:

- Analýza taxonomií využívaných v oblasti údržby letadel
- Analýza procesů sběru a zpracování dat v systému řízení bezpečnosti organizací údržby letadel
- Návrh integrovaného sběru bezpečnostních dat a jejich systematické klasifikace
- Návrh implementace systému integrovaného sběru a zpracování bezpečnostních dat do reálních podmínek
- Vyhodnocení přínosu navrhovaného řešení

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HENDERSON-SELLERS, Brian a Bhuvan UNHELKAR. Open modeling with UML. New York: Addison-Wesley, 2000, 245 p. ISBN 0201675129.

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V Praze dne .... 1. července 2016

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Poděkování

Děkuji svým vedoucím, Ing. Andrejovi Lališovi a Ing. Vladimírovi Plosovi, za pravidelné poskytování cenných informací, rad a doporučení v průběhu psaní mé diplomové práce.

Také děkuji své rodině a přátelům za podporu během celého mého studia. Bez ní by byla má cesta vzděláváním daleko náročnější.

Abstrakt

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Tato práce je studií o integrovaném sběru a zpracování bezpečnostních dat pro organizace údržby letadel.

Klíčovým prvkem shromažďování a zpracování bezpečnostních dat obecně je jasně definovaná taxonomie. Z tohoto důvodu se tahle práce také pozorně zaměřuje na rozbor taxonomií vyvinutých pro účely sběru a zpracování dat v letecké údržbě, jako jsou MEDA nebo ECCAIRS.

Po shrnutí existujících způsobů sběru informací, postupů při jejich zpracování a taxonomií souvisejících s leteckou údržbou je navržena konkrétní forma integrovaného sběru a zpracovaní dat aplikovatelná pro organizace údržby letadel.

Abstract

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This thesis is a study on integrated safety data collection and processing for aircraft maintenance organisations.

The key element of safety data collection and processing is clearly defined taxonomy. Hence, this thesis also closely looks at existing aircraft maintenance taxonomies developed for data collection and processing purposes, like MEDA or ECCAIRS.

After the review of existing data collections along with data processing procedures and maintenance taxonomies, a particular integrated safety data collection applicable to maintenance organisations is proposed.

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Acronyms and abbreviations

CAA	Civil aviation authority
EASA	European aviation safety agency
ECCAIRS	European coordination centre for accident and incident reporting systems
FAA	Federal aviation administration
FOD	Foreign object damage
ICAO	International civil aviation organisation
MEDA	Maintenance error decision aid
MEL	Minimum equipment list
MOR	Maintenance occurrence report
MRO	Maintenance repair organisation
OFDM	Operational Flight Data Monitoring
QMS	Quality management system
REDA	Ramp error decision aid
SA	Safety assurance
SAFA	Safety assessment of foreign aircraft
SAG	Safety action group
SARPs	Standards and recommended practices
SDCPS	Safety data collection and processing system
SMM	Safety management manual
SMS	Safety management system
SPI	Safety performance indicator
SPT	Safety performance target
SRB	Safety review board
SRM	Safety risk management

Introduction

Air transport is undeniably one of the safest ways to travel around the globe. This is proved by many statistics taken each year. But despite this fact, when an aircraft accident occurs the consequences can be devastating and usually impact not only the lives of humans, but the whole aviation industry as it is. The safety should therefore never be underestimated.

Technology and materials used on aircraft are nowadays undoubtedly highly advanced and safe. Chances that the technology fails by itself are quite narrow. Even if it does, predictive systems designed to monitor its current and future state can grab this information in time. But even the most state-of-the-art technology does not ensure safe aviation environment. Aviation is still strongly impacted by humans and their actions. No matter how trained someone is, making errors is an inseparable part of human nature. As long as human interaction is involved, air transport can never be free of such errors.

ICAO, FAA or EASA understand this and initiatives to make flying even safer are taken each year by developing new ways to improve safety. One of those ways is developing and implementing an integrated safety data collection and processing system within an organisation. This system is founded on a common, well-developed taxonomy used for occurrence classification. Using such taxonomy is essential in improving quality of safety data collection and processing and hence improving aviation safety. Having uniform sets of terms and phrases helps providers gather relevant data about occurrences and see which occurrences cumulate and why. If unsure how to properly deal with such accumulation, exchanging safety data with providers from other states can be of great value. Other providers might have implemented useful measures to reduce the same occurrences and sharing this information could help others.

In spite of many benefits a common, uniform taxonomy offers, it was not widely recognized by the whole aviation industry yet. Although some taxonomies have already been developed, like the one ECCAIRS is built on, they are not applicable to all service providers. There is no doubt that aviation providers such as aerodromes, air transport operators and air navigation services are the key players in air transport and require the highest level of safety. But constant safety improvements should be desired in all sectors of aviation industry equally, as other players might affect the level of safety as well.

One of such players are approved maintenance organisations. Several papers and publications were issued in recent years on how to manage safety properly in approved maintenance organisations. This thesis can be considered as a follow-up on such publications.

Improving safety in maintenance organisations can be challenging. Maintenance providers are even more susceptible to human error, because the quality of aircraft maintenance is not dependent on technology as much as it is on the level of personnel expertise and their ability to perform safely. Human-error related occurrences are not easy to control and predict. Mistakes just happen, even to the best mechanics always following a checklist.

One way to achieve a safer environment in aircraft maintenance organisation is to follow other aviation service providers and develop and implement an integrated safety data collection and processing system. For such system in maintenance organisations, the use of a common taxonomy is of same importance as in any other aviation organisation.

Step by step, this thesis firstly reviews existing taxonomies that utilise terms applicable to aircraft maintenance. Further on, the thesis analyses means to collect and process safety data. After summarising the above, an enhanced system for safety data collection and processing applicable to maintenance organisations is proposed.

1 Analysis of taxonomies used in the domain of aircraft maintenance

1.1 Preface

In aviation, taxonomy refers to a set of definitions and descriptions used for gathering and reporting occurrence data into reporting tools. In aircraft maintenance repair organisations (MROs), taxonomies should contain specific terms that are applicable to MRO operation processes and that all persons required to report and analyse these data understand what these terms mean in order to correctly report and classify any occurrence.

Currently, there are two main sources of taxonomies intended for aviation maintenance. First taxonomy is contained in MEDA methodology; the second taxonomy comes from ECCAIRS.

1.2 MEDA

1.2.1 General philosophy

Maintenance Error Decision Aid, or MEDA, is "a structured process used to investigate events caused by mechanic inspector performance developed by Boeing [1]." It is an event-based investigation process meaning the investigation starts after the event occurred. Maintenance human error related events, approximately 80% of all maintenance related accidents [2], are either caused unintentionally (errors), intentionally (violations), or by combination of the two. Initially, MEDA was developed as an error investigation process, but since violations too play a role in causing a maintenance related event, MEDA is now described as an event investigation process.

MEDA stands on the philosophy that behind any event there is an error/violation, and behind any error/violation there is (are) contributing factor(s). Contributing factors are to be understood as conditions that contribute to an error/violation, which is basically anything that affects how a mechanic does his/her job. For one error/violation to occur several contributing factors might exist, and for these factors to occur another factors could have contributed. This causation model is displayed in *Figure 1* on the next page.

Probability is the main causation linking two occurrences in maintenance event investigation. This applies to contributing factors leading to error/violation or errors/violations leading to event. Experience has shown that there are approximately three to four contributing factors to each error.

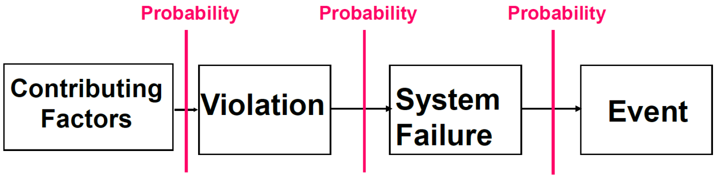

Figure 1. MEDA Error and violation model [1]

To give an example for the above model, a mechanic performing his job is considered. The mechanic does not use a torque wrench, which is a required procedure step, and therefore the mechanic violates the procedure. Factors that contributed to this violation might include torque wrench not being available in time, or not using torque wrench being a group norm. The violation then contributes to an incorrect installation (system failure) because of an under-torqued bolt, which eventually leads to an in-flight shutdown (event).

Experience has shown that most contributing factors in MROs nowadays are due to management of the organisation, not mechanics themselves. Therefore, MEDA views the MRO as a complex system with the mechanics being only one part of it.

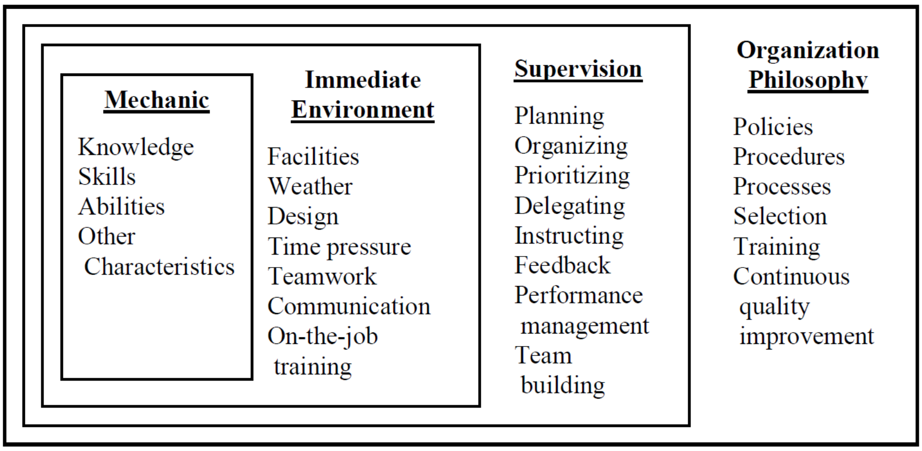

Figure 2. MEDA contributing factors model [1]

Figure 2 shows organisational levels of MRO in general. Each level has various areas that, if weakened, might likely provide a space for contributing factors to occur. *Figure 2* also indicates how upper organisational level might affect the lower one, from the organisation's philosophy down to mechanics on the shop floor.

1.2.2 MEDA Results form

MEDA investigation is used to help MRO see the factors that might later contribute to an error and correct them (either reduce or eliminate) to create safer environment and prevent incidents. To do so, the so-called MEDA Results form was developed based on the previous findings. It is the main investigation tool when doing the MEDA investigation in MRO.

The form (revision L) consists of several pages that cover the event history described in six sections. The sections are:

1. General information
2. Event
3. Maintenance system failure
4. Chronological summary of the event
5. Summary of recommendations
6. Contributing factors checklist

These sections and their subsections can be modified by respective MRO to best fit their needs. The whole MEDA Results form is attached to this thesis as *Appendix 1*.

1.2.3 Taxonomy

For the purposes of this thesis, sections II., III. and VI. of MEDA Results form are essential as they contain specific maintenance taxonomy used for event, failure and factors classification. Sections III. and III. are shown in *Figure 3* and *Figure 4*, respectively. *Figure 5* shows a part of Section VI.

1.2.3.1 Events

Figure 3, MEDA events taxonomy, classifies eight basic types of maintenance events depending on the area they affect.

The events are:

1. Operations process event
2. Aircraft damage event
3. Personal injury event
4. Rework
5. Airworthiness control
6. Found during maintenance
7. Found during flight
8. Other event

These event types are for general allocation of an occurrence, therefore an investigator may choose a more accurate classification within each event's type, as seen below.

Section II—Event		
Please select the event (check all that apply)		
1. Operations Process Event		**( ) 3. Personal Injury Event**
( ) a. Flight Delay _ days_ _ hrs._ _ min.	( ) f. Diversion	( ) **4. Rework** (e.g., did not pass Ops check/inspection)
( ) b. Flight Cancellation	( ) g. Smoke/fumes/odor event	( ) **5. Airworthiness Control**
( ) c. Gate Return	( ) h. Other (explain below)	**( ) 6. Found during Maintenance**
( ) d. In-Flight Shut Down		**( ) 7. Found during Flight**
( ) e. Air Turn-Back	**( ) 2. Aircraft Damage Event**	**( ) 8. Other Event (explain below)**
Describe the incident/degradation/failure (e.g., could not pressurize) that caused the event.		

Figure 3. MEDA events taxonomy [1]

1.2.3.2 Maintenance system failures

Terms used in Section III., maintenance system failures, represent error and violations that contributed to an event. This classification covers most of the failures that might occur during maintenance repair operation, therefore are applicable to any MRO worldwide.

The maintenance system failures include:

1. Installation failure
2. Servicing failure
3. Repair failure
4. Fault isolation/test/inspection failure
5. Foreign object damage/debris
6. Airplane/equipment damage

7. Personal injury
8. Maintenance control failure
9. Other

Section III—Maintenance System Failure

Please select the maintenance system failure(s) that caused the event:

1. Installation Failure
( ) a. Equipment/part not installed
( ) b. Wrong equipment/part installed
( ) c. Wrong orientation
( ) d. Improper location
( ) e. Incomplete installation
( ) f. Extra parts installed
( ) g. Access not closed
( ) h. System/equipment not reactivated/deactivated
( ) i. Damaged on remove/replace
( ) j. Cross connection
( ) k. Mis-rigging (controls, doors, etc.)
( ) l. Consumable not used
( ) m. Wrong consumable used
( ) n. Unserviceable part installed
( ) o. Other (explain below)

2. Servicing Failure
( ) a. Not enough fluid
( ) b. Too much fluid
( ) c. Wrong fluid type
( ) d. Required servicing not performed
( ) e. Access not closed
( ) f. System/equipment not deactivated/reactivated
( ) g. Other (explain below)

3. Repair Failure (e.g., component or structural repair)
( ) a. Incorrect
( ) b. Unapproved
( ) c. Incomplete
( ) d. Other (explain below)

4. Fault Isolation/Test/Inspection failure
( ) a. Did not detect fault
( ) b. Not found by fault isolation
( ) c. Not found by operational/ functional test
( ) d. Not found by task inspection
( ) e. Access not closed
( ) f. System/equipment not deactivated/reactivated
( ) g. Not found by part inspection
( ) h. Not found by visual inspection
( ) i. Technical log oversight
( ) j. Other (explain below)

5. Foreign Object Damage/Debris
( ) a. Tooling/equipment left in aircraft/engine
( ) b. Debris on ramp
( ) c. Debris falling into open systems
( ) d. Other (explain below)

6. Airplane/Equipment Damage
( ) a. Tools/equipment used improperly
( ) b. Defective tools/equipment used
( ) c. Struck by/against
( ) d. Pulled/pushed/drove into
( ) e. Fire/smoke
( ) f. Other (explain below)

7. Personal Injury
( ) a. Slip/trip/fall
( ) b. Caught in/on/between
( ) c. Struck by/against
( ) d. Hazard contacted (e.g., electricity, hot or cold surfaces, and sharp surfaces)
( ) e. Hazardous substance exposure (e.g., toxic or noxious substances)
( ) f. Hazardous thermal environment exposure (heat, cold, or humidity)
( ) g. Other (explain below)

8. Maintenance Control Failure
( ) a. Scheduled task omitted/late/incorrect
( ) b. MEL interpretation/application/removal
( ) c. CDL interpretation/application/removal
( ) d. Incorrectly deferred/controlled defect
( ) e. Airworthiness data interpretation
( ) f. Technical log oversight
( ) g. Airworthiness Directive overrun
( ) h. Modification control
( ) i. Configuration control
( ) j. Records control
( ) k. Component robbery control
( ) l. Mx information system (entry or update)
( ) m. Time expired part on board aircraft
( ) n. Tooling control
( ) o. Mx task not correctly documented
( ) p. Not authorized/qualified/certified to do task
( ) q Other (explain below)

( ) **9. Other** (explain below)

Did the Maintenance System Failure "fly" on the aircraft? ( ) Yes ( ) No

Describe the specific maintenance failure (e.g., auto pressure controller installed in wrong location).

Figure 4. MEDA failures taxonomy [1]

1.2.3.3 Contributing factors

Lastly, there is a set of different factors that may contribute to failures above. These contributing factors are contained in Section VI. of MEDA Results form. Even though the factors' selection is quite comprehensive, there can always be other factors not included in the Form that had something to do with an occurrence. In this case a blank field is provided for investigator to define the factors that are not included within the Results form.

The categories of factors are:

1. Information
2. Ground support equipment/tools/safety equipment
3. Aircraft design/configuration/parts/ equipment consumable
4. Job/task

5. Knowledge/skills
6. Individual factors
7. Environment/facilities
8. Organisational factors
9. Leadership/supervision
10. Communication
11. Other contributing factors

Each category is made up of more detailed selection of the factors. *Figure 5* shows category *Leadership/supervision* and its subcategories.

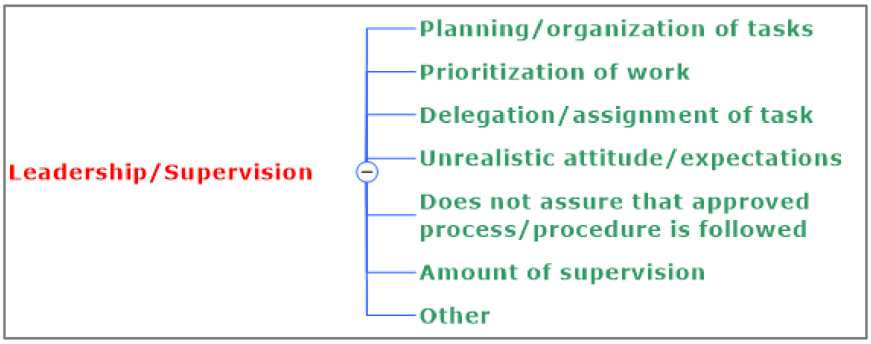

Figure 5. MEDA factors taxonomy

1.2.4 Benefits versus drawbacks

For the event-based investigation, MEDA provides a great tool with its comprehensive Results form. The investigation, if taken properly, is a process revealing mistakes that led to an event. By uncovering the contributing factors, with the help of mechanics or management, the organisation is able to better control them and to prevent adverse safety outcomes.

On the other side, the MEDA investigation can only be used as a reactive tool, meaning it can be applied after the event occurred. Plus, the investigation itself (the report) is still mainly focused on the mechanics/inspectors themselves. Therefore, it is important to keep in mind that the failures which are recognized on mechanic's part can be due to management's incorrect procedures, organisation's policy, etc. MEDA helps uncover these links and improves the safety at all levels of MRO.

As for the purposes of this thesis, the main benefit is the maintenance taxonomy developed by the MEDA team. It provides clearly defined event categories, system failures and quite detailed list of contributing factors.

1.3 ECCAIRS

1.3.1 General philosophy

ECCAIRS is a “co-operative network of European CAAs and safety investigation authorities. The project is being managed by the Joint Research Centre of the European Commission on request of the Directorate General for Mobility and Transport and in close co-operation with EASA.” [5]

The mission of ECCAIRS in general is “to assist national and European transport entities in collecting, sharing and analysing their safety information in order to improve public transport safety.” [4] As for the civil aviation, ECCAIRS aims to “improve air safety by bringing together the knowledge derived from the collection of incompatible occurrence reporting systems from various (member) States.” [3]

Based on the above, the main objective of ECCAIRS was to develop a common aviation language using a rich classification for reportable data. A lot of work has been done since the launch of the original project in 1989. The ECCAIRS taxonomy is already widely implemented among some aviation service providers. The results have shown that having a common definitions and terms with clear meaning for occurrence data reporting is of high value for safety data collection, exchange and analysis, not only on a state level but regionally or internationally as well.

1.3.2 Taxonomy

The ECCAIRS taxonomy covers extensive area of civil aviation operations and is being regularly updated. Within ECCAIRS taxonomy, any term, word or phrase (attributes) is assigned with a specific identification number, which helps prevent any substitution. Also, a short description is provided for most of the attributes to help classify occurrences more accurately and consistently.

The taxonomy development was mostly oriented on airlines, ATM suppliers and aerodromes. Below are some examples of occurrence categories being already used:

- AMAN: Abrupt manoeuvre
- ICE: Icing
- SYST: System failure/malfunction or defect
- LOC-G: Loss of control - ground

- RE: Runway excursion
- ATM: ATM/CNS
- F-NI: Fire/smoke (non-impact)
- FUEL: Fuel related

But in recent years, a lot of effort was and still is being put into creating a taxonomy better suitable for the area of maintenance. Even though a more general categorisation of occurrences similar to the one above is not officially established yet, a lot was done for events and factors classification.

ECCAIRS uses three levels coding structure for occurrences as shown in *Figure 6*.

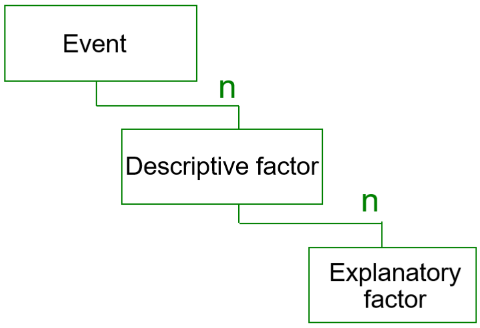

Figure 6. ECCAIRS occurrence level coding [6]

1.3.2.1 Events

Events are usually based on findings from reports and analysis. One occurrence can be described with several events that happened consequentially.

Several event types were identified among the existing ones in ECCAIRS taxonomy that are applicable to MRO. These are[1]:

1. Consequential events
2. Aircraft/system/component related event
3. Events of an operational nature
4. Personnel events
5. Organisational events
6. Any other events

[1] Event categories listed contain many subcategories, some relevant to maintenance, some not. Putting down all subcategories would extend the scope of this thesis, therefore only several were chosen.

1.3.2.2 Contributing factors

ECCAIRS utilizes two types of factors that contribute to events:

1. Descriptive factors (technical)
2. Explanatory factors (human)

Descriptive factors

Descriptive factors add detail to events, in other words, they provide extra information from technical point of view.

Again, for maintenance purposes only some descriptive factors were extracted from ECCAIRS taxonomy. The main categories of descriptive factors applicable for maintenance are[2]:

1. Operation and maintenance of the aircraft, its components and systems
2. Undefined

Explanatory factors

Explanatory factors incorporate organisational and personal issues. They adopt SHELL (software/hardware/environment/liveware) model philosophy on how different interactions of and between these interfaces affect the event.

ECCAIRS explanatory factors categories related to maintenance are[2]:

1. Liveware
2. Liveware (human) – environment interface
3. Liveware (human) – hardware/software interface
4. Liveware (human) – interface system support
5. Liveware (human) – liveware (human) interface

[2] ECCAIRS contributing factors categories listed contain many subcategories, some relevant to maintenance, some not. Putting down all subcategories would extend the scope of this thesis, therefore only several were chosen.

Figure 7 below sums up occurrence classification using ECCAIRS methodology that stands on its logic. It is obvious that adopting this structural and detailed approach means adding quality to data collection and processing.

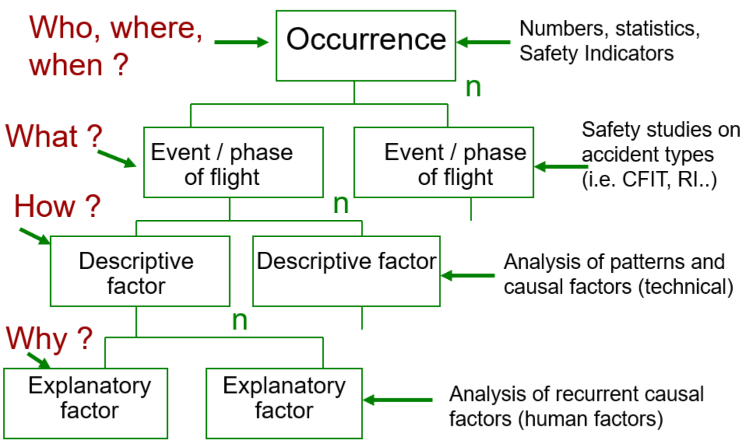

Figure 7. ECCAIRS occurrence classification [6]

1.3.3 Benefits versus drawbacks

ECCAIRS is a great tool for data collection and processing, which was already confirmed by positive feedback from organisations that already implemented ECCAIRS and use it for occurrence reporting. Moreover, along with the system itself comes a comprehensive aviation taxonomy, which is being regularly updated and improved. ECCAIRS adapts to changes and industry needs, hence its taxonomy renewal is an ongoing process. This is important for the future of maintenance occurrence reporting. To have common, clearly defined and applicable collection of terms and definitions is essential for creating safer environment within MRO and prevent incidents or accidents.

Still, a huge drawback of ECCAIRS taxonomy lies in its complexity. There is too much terminology defined, with some being related to maintenance, some not, that someone might find it confusing and hard to organise and suit for his/her organisation's needs. Because, as for any aviation organisation, each MRO is specific and focuses on different aspect of aviation maintenance. The terminology chosen to report and classify safety data has to be clear and understandable to all involved, whether it is mechanics or management.

1.4 Summary

Even though there are not many taxonomy sources designated for MROs, ECCAIRS and MEDA contain sufficient amount of attributes describing maintenance related events and contributing factors. Both MEDA and ECCAIRS work with similar terms definitions, whether speaking of events or factors description. ECCAIRS goes further and divides factors depending on whether the contribution is related to technical issues or human interaction issues.

Combining and adjusting the two, a consistent foundation of aircraft maintenance taxonomy is ready for further application and implementation in any MRO (as a part of SMS reporting tools, MRO audits, inspection, etc.).

2 Analysis of data collection and processing procedures in safety management system of maintenance organisations

2.1 Preface

Safety data collection and processing system (SDCPS) refers to "processing and reporting systems, databases, schemes for exchange of information, and recorded information [7]."

Methods for data collection and processing are similar in all areas of aviation operation and are usually at the heart of safety management system (SMS) of the organisation. The reporting quality (the amount of received data) via these systems varies from organisation to organisation, as it depends on many factors, especially related to reporting culture within the organisation. Reporting is mandatory for some types of occurrences affecting safety[3], and voluntary for those that do not affect safety directly. Voluntarily reportable occurrences might have a potential to affect safety, and should be part of data collection and processing to analyse them and prevent potential safety outcomes.

As for the MRO, the voluntary and confidential occurrence reporting has only started to be in the spotlight. This is mainly due to the fact that SMS for MRO is not yet regulatory, and as indicated previously, the SMS stands on the reporting. Because with low quantity of data (mandatory occurrences as the main source), its collection and processing is not sufficient for safety outcome prevention. Lately, the approach towards maintenance occurrence reporting has been positively changing.

2.2 Safety management system

Safety management system is a systematic approach for managing safety. SMS was developed particularly for organisations where the safety is of utmost priority, whether speaking about nuclear, chemical or aviation industry. Aviation safety needs to be managed proactively by all actors. Safety management benefits the total aviation system by strengthening traditional risk control practices and ensuring safety risks are managed in a systematic way.

[3] More on mandatory reporting can be found in EU Regulation No 376/2014

2.2.1 SMS implementation requirements

As per ICAO requirements, aviation service providers are responsible for establishing SMS, which is accepted and overseen by their State. Minimum SMS requirements for ICAO member states are defined in ICAO's Standards and Recommended Practices (SARPs). ICAO has also published guidance material on safety management principles and concepts to help providers with the implementation. These are contained in the ICAO's Safety Management Manual (SMM) Doc 9859.

As for the European Union and its member states, the first EASA SMS requirements were adopted in the form of authority (national CAAs) and organisation (service providers) requirements in the domain of air crew and in the domain of air operations (2006). Requirements are being progressively extended to other domains of the aviation system, and more are ahead. [9] Similar to ICAO, European service providers were given some extra SMS guidance material. EASA's current SMS rulemaking status regarding service providers can be seen in *Figure 8*.

Figure 8. EASA SMS requirements [10]

When implementing SMS in any organisation, it is suggested to adopt an integrated approach. This means that SMS should not stand alone as an extra supplementary system, but rather be implemented into already existing management system as one of its parts.

2.2.2 SMS components

SMS is comprised of four main pillars:

1. Safety policy and objectives
2. Safety risk management
3. Safety assurance
4. Safety promotion

Each pillar then consists of several elements related to the scope of the pillar. To stay aligned with the topic of this thesis, no deeper description of all four SMS pillars will follow. Rather, a brief explanation of those that have something to do with data collection and processing will take place. These are safety risk management and safety assurance.

SMS stands on well-developed safety risk management (SRM). To achieve that, it is essential to have a common and agreed-upon approach to risk. The organisation has to decide what is and what is not acceptable and how hazards have to be addressed. The key of SMS is to adopt principles of risk management into day-to-day operations.

Safety risk management includes:

- hazard identification processes (reactive, proactive, predictive)
- risk assessment and mitigation processes (analysis, assessment and control of risks)
- internal safety investigation following occurrences (either mandatory or voluntary)
- safety performance monitoring and measurement (safety reporting, safety studies, safety reviews, safety audits, safety surveys)
- management of change (changes with potential to adversely affect safety, assessing and managing existing risks)
- continuous improvement (evaluations via audits, surveys, …)

After SRM is developed and implemented, it is necessary to ensure that new processes are being practiced on a daily basis. This is called safety assurance (SA). SA’s function is basically to measure organisation’s performance by constantly evaluating SRM changes and deviations from standards (in terms of safety) that were established. Relations between SRM and SA processes can be seen in *Figure 9* on the next page.

To monitor and review organisation's performance in general, key performance indicators (KPIs) have to be defined. Likewise, indicators that reflect SMS performance are called safety performance indicators (SPIs).

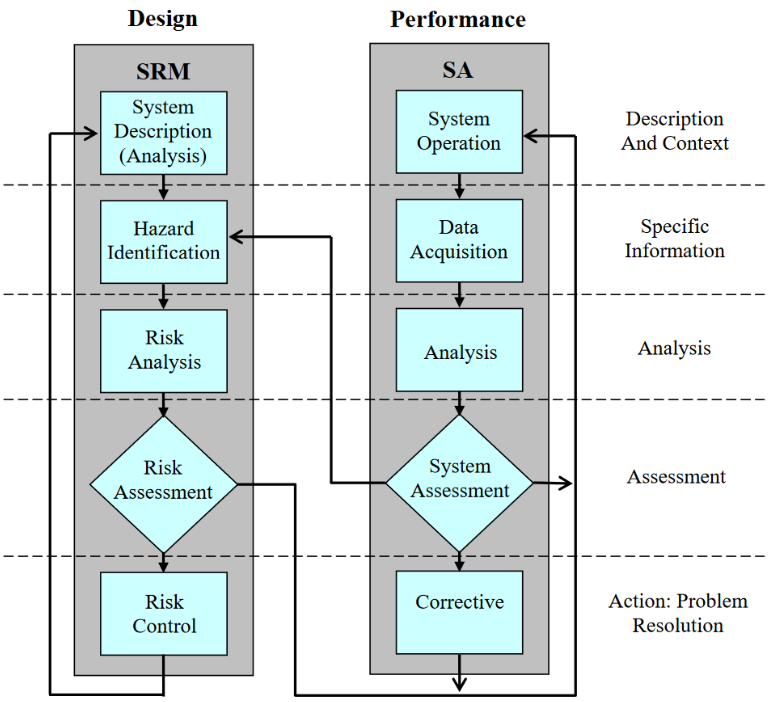

Figure 9. SRM and SA functions relation [12]

2.2.3 Safety performance monitoring and measurement

The core of SRM and SA is safety performance monitoring and measurement. There are two ways used for expressing safety performance that are compared to each other.

- safety performance indicators
- safety performance targets

2.2.3.1 Safety performance indicators

Safety performance indicators, or SPIs, are quantifiable measures representing each occurrence expressed in numerical terms. In other words, safety indicators are short and medium term objectives of an organisation's SMS and are linked to its major components. SPIs need to be meaningful and provide direction for action. Also, SPIs have to be defined in a way that everyone in the company understands what they represent.

Examples: rejected take-offs due to maintenance failures, average number of MEL items per aircraft per fleet, flight delays/cancellations due to maintenance, average number of days late out of letter check, maintenance write-ups for 10 days after D check

2.2.3.2 Safety performance targets

Safety performance targets, or SPTs, are long-term objectives of an organisation's SMS and are determined by weighing what is desirable and what is realistic for an organisation. Safety targets are, similarly to SPIs, expressed in numerical terms. By analysing SPIs and current level of safety performance and comparing it SPTs, one can determine if the organisation is doing fine or if more has to be done in order to achieve desired goals.

Examples: By 2018 reduce the average number of maintenance write-ups per aircraft for 10 days after D check to ≤ 5

2.3 Safety management for maintenance organisations

The maintenance domain is being considered for SMS adoption as well (see section Airworthiness in *Figure 9*) and some initiatives were already taken. EASA released Notice of Proposed Amendment (NPA) 2013-01 that proposes changes to the requirements for the embodiment of Safety Management Systems (SMS) in the quality system of Part M and Part 145 approved organisations [11]. These requirements have not been amended yet, but many maintenance organisations have already started implementing some SMS components into their managements systems.

For a long time, quality management system (QMS) was the way to interpret safety in MROs. Performing audits, inspections, analysing reports filled out by mechanics, it is all part of QMS. But compared to SMS, QMS is geared towards production rather than safety. To put it simply, QMS manages quality of processes and SMS manages safety risk in processes. It is important to realise that this difference exists.

2.4 Safety data collection and processing for maintenance organisations

Safety data collection and processing is a system used to ensure the capture, storage and aggregation of data on accidents, incidents and hazards obtained from safety data sources.

SDCPS is not necessarily computer based software (like ECCAIRS). In some MRO, several different maintenance reports and forms shall exist separately and MRO might not have any integrated software[4] that would comprehend all these forms and process them. If this is the case, all reports containing safety data have to be manually linked together, looked for duplicates and assorted – for example in excel sheets or access databases. Then, the processing results can be visualised via graphs, charts, tables, etc. However, it is advised for organisations to move from this old disarranged way to a more sophisticated manner to collect and process safety data.

2.4.1 Basic requirements

Similar to any other efficient SDCPS, the one designated for MRO must comprise certain necessities:

1. The system is specifically adapted to MRO operation
2. The system is accessible to all relevant subjects (mechanics, supervisors, management)
3. The information within the system (taxonomy) is clear and understandable to all relevant subjects
4. The system collects safety data from various sources (reports, MEDA forms, email notices/complaints, audit findings, inspections, surveys, etc.).
5. The system contains various means of reporting (mandatory/voluntary/confidential reports, electronic/paper reports, etc.)

2.4.2 Safety data collection

Safety data can be collected from many different sources. The key is to utilise as many as possible, because the more we know about occurrence the more we can do to prevent it from happening again.

This subsection reviews basic types of safety data and how data are reported.

[4] The reason most MRO do not have integrated SDCPS software implemented yet is that those available are quite costly.

2.4.2.1 Data types

For the purpose of data reporting in aviation industry, there are three types of safety data - reactive, proactive and predictive.

Reactive data

These are events that already occurred, like incidents or accidents. These events could have had a direct impact on safety. Reactive data sources are incidents and accidents reports (mandatory/regulatory occurrences mostly), MEDA and REDA.

Proactive data

Proactive data are usually received from safety audits, surveys, check rides, and inspections. Voluntary reporting and internal hazard reporting from personnel (pilots, mechanics, ramp staff, cabin crew) also fall under this category.

Predictive data

These data reflect real-time system performance in daily operations to identify future problems with a potential to cause harm. Examples for maintenance include maintenance and ramp line operations safety assessments, digital flight data recorder analysis, etc.

In general, safety data come from internal or external sources. Internal sources include voluntary or mandatory reporting systems, safety surveys, internal audits, feedback from training, investigations of accidents or incidents. External sources include industry accidents reports, state oversight audits, customer audits, SAFA inspections, information exchange systems.

2.4.2.2 Reporting

Reports, as stated above, are one way to move forward an information about occurrences or hazards. For states and their service providers in European Union, reporting falls under Regulation (EU) No 376/2014 of the European Parliament and of the Council of 3 April 2014 on the reporting, analysis and follow-up of occurrences in civil aviation. Reports can be mandatory (regulatory) or voluntary.

Mandatory reporting

Mandatory reporting requires personnel to report accidents and certain types of incidents by law. ICAO defines [13] mandatory reporting as reporting of certain types of events or hazards. This necessitates detailed regulations outlining who shall report and what shall be reported.

Some mandatory reportable occurrences from maintenance are:

- structural defects
- system malfunctions
- maintenance and repair problems
- propulsion problems and auxiliary power unit problems

Voluntary reporting

Voluntary reports are vital for accident and incident prevention, and all employees should be encouraged to report any event or hazard with a potential to cause damage. Voluntarily reportable data could be:

- excessive duty times
- rushing through checks
- poor communication between operational areas
- lack of planning
- inadequate tool or equipment control
- expiration of chemicals
- lack of up-to-date technical manuals

Report forms should be simple, quickly fillable and user-friendly. This features are important since in MRO, most reports come from employees on the shop floor, who best can identify what potential hazards are from years of practice. And if the report takes too much time to fill in or contains unclear sentences or complex taxonomy, the amount of voluntary reports received will not be very high.

Before the report is used it should be consulted with respective employees for any mishaps or uncertainties. Knowing what to report plays a key role in an active reporting program. Report submission procedures should be well documented and should include the information on where and to whom they should be submitted.

2.4.3 Safety data processing

Any occurrence or event is an opportunity to learn new safety lessons. For employees and management to understand what and why went wrong, all events have to be precisely analysed for contributing factors. Occurrences and related events and factors have to be correctly classified to match selected SPIs that can be used for further safety performance measurements and predictions (see *Figure 10*). This whole philosophy stands on the well-developed taxonomy, as without the proper taxonomy the classification of events and factors would stumble.

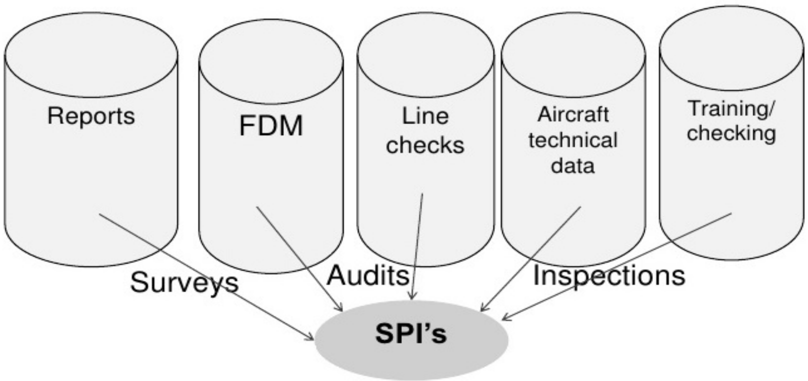

Figure 10. Relationship between safety data sources and SPIs [8]

After the analysis, all findings should be exchanged between relevant parties and feedback should be provided to those that reported safety data. Once hazards are analysed for the risk they represent to their environment and overall operation, organisation should try to mitigate or eliminate the risk they represent.

2.5 Summary

Chapter 2 showed what a typical SDCPS for MRO should look like and what basic requirements it should have. These systems are usually very similar among all aviation service providers.

Data processing is as important as its collection, because if the analysis of data lacks the quality or enough time it may not reflect what was or is really going on and where the attention should be directed. This way the risk from unrevealed hazards cumulates and, if still neglected, results in accidents or incidents. Therefore, it is necessary not only to promote safety and reporting culture among employees, but to have personnel trained for working with lot of different safety data and identify any discrepancies.

3 Proposal for integrated safety data collection and their systematic classification

3.1 Preface

Chapter 3 is the practical part of this thesis and combines the facts from two previous chapters. Existing aircraft maintenance taxonomies (MEDA, ECCAIRS) discussed in chapter 1 are used as the main source to propose a new, adjusted taxonomy for aircraft maintenance data classification. However, it is important to point out that besides utilising these taxonomies, some new terms are added. This is because ECCAIRS and MEDA do not fully cover all maintenance related terms that would fit any type of data. Means of collecting safety data were analysed in chapter 2. Chapter 3 does not utilise all these data sources, as the data in MRO mostly comes from reports[5]. Therefore, only various types of reports are proposed.

Based on the above, a redesigned safety data collection applicable to maintenance organisations is proposed. More specifically, section 3.2 proposes various types of reports to be used for data reporting. Section 3.3 then explains what it means to have an integrated safety data collection and how safety data should be stored. Lastly, section 3.4 underlines the importance of a systematic way to classify the data.

3.2 Aircraft maintenance reports and their classification

Data that go to safety database come from different sources, either electronically or on paper. The first step is therefore to divide the incoming data depending on its origin. *Table 1* shows some basic report types used for data collection in MRO.

Table 1. Basic types of reports in MRO

Type of report	Description
Maintenance occurrence report	*mandatory, voluntary reporting*
Audit report	*internal, external audits*
Personnel self-assessment report	*self-assessment related to workplace conditions*
Hazard report	*voluntary reporting of hazards*
Complaint	*voluntary reporting related to MRO operation*

[5] Other means of data collection (like safety surveys) are not used on a daily basis and are usually created for specific purposes.

The form and complexity of these reports varies. Following subsections describe each report type individually and pick out their main features.

3.2.1 Maintenance occurrence report

Maintenance occurrence report (MOR) should be one of the primary sources of data in any MRO. Used mostly by mechanics, the report provides information on what happened and why it happened during aircraft maintenance. It should be used when reporting mandatory occurrences like accidents, significant incidents or incidents, but it can also be used to report other occurrences related to maintenance (known as occurrences without safety effect).

The fields to be filled in MOR should include:

1. Headline
2. Type of maintenance
3. Phase of operation
4. Occurrence class
5. Occurrence category
6. Events and contributing factors
7. Effects on operation
8. Narrative
9. Comments

1 Headline

Headline should include some basic facts about the occurrence, like date and time, location of occurrence (hangar, on-stand, in-flight, apron), aircraft type, operator, component specification, P/N, S/N, ATA code, etc. Also, it should include the information on when the occurrence was noticed (during inspection, audit, airworthiness control, etc.)

2 Type of maintenance

MOR should have an option for a mechanic to select the type of maintenance that is related to an occurrence (see *Table 2* on the next page).

As more reports are filled out and some statistics can be made, it is easier to directly see which type of maintenance is weaker and needs more attention.

Table 2. MOR: Types of maintenance

Type of maintenance	Description
Aircraft maintenance	*overhaul, inspection, replacement*
Application of SB/AD	*application of service bulletin or airworthiness directive*
Un-scheduled maintenance check	*hard landing, bird strike, turbulent air, lightning strike*
Aircraft modification	*aircraft modification by maintenance personnel*
Aircraft major repair	*as defined by ICAO, FAA or EASA*
Aircraft scheduled check	*aircraft scheduled check by maintenance personnel*
Aircraft minor repair	*as defined by ICAO, FAA or EASA*
Aircraft installation	*aircraft installation by factory personnel*

3 Phase of operation

If known, reporting personnel should provide information on when the problem occurred. *Table 3* divides general operation into five phases.

Table 3. MOR: Phases of operation

Phase of operation	Description
In transit to/from stand	*occurrence during aircraft transit on apron*
Maintenance	*occurrence during base or line maintenance*
Parking	*occurrence during aircraft parking*
Towing	*occurrence during aircraft towing*
Flight	*occurrence during aircraft flight*

4 Occurrence class

The very basic occurrence classification should include whether the occurrence was an accident, significant incident, incident or had no safety effect (see *Table 4* on the next page). Reporting personnel should be trained to correctly assign occurrences. If unsure, an option -not determined- should be provided. This information can be later clarified by safety manager or civil aviation authority.

Table 4. MOR: Occurrence classes

Occurrence class	Description
Accident	*as defined by ICAO*
Significant incident	*as defined by ICAO*
Incident	*as defined by ICAO*
Occurrence without safety effect	*occurrence had no safety outcome*
Not determined	*further guidance on occurrence classification required*

5 Occurrence category

ECCAIRS divides occurrences into several occurrence categories. The problem with this framework is that it was developed to suit the needs of only some types of service providers (ATM, aerodromes, etc.), where occurrence reporting uniformity among and within states was of utmost importance, and therefore excluding aircraft maintenance providers. The idea is to create similar model applicable to MRO. *Table 5* shows a proposal for occurrence categorisation in MRO. These categories should cover any occurrence that is likely to happen during aircraft maintenance.

Table 5. MOR: Occurrence categories

Occurrence category	Description
ACFT: Aircraft/aircraft component damage	*physical damage to body, engine, landing gear, propeller, flaps, etc.*
MAT: Aircraft material	*aircraft material (age, handling, marking)*
SYST: System failure/malfunction or defect	*aircraft systems failures (hydraulics, pneumatics, electronics)*
FAC: Facilities	*facilities damage as a result of maintenance*
PERS: Personnel injuries	*any injuries to maintenance personnel when performing their job*
FOD: Foreign object damage	*any occurrence caused by foreign objects*
F-NI: Fire/smoke (non-impact)	*fire or smoke as a result of maintenance*
OTHR: Other	*any other occurrences not mentioned above*

Table 6 shows proposed types of occurrence categories in comparison to those from ECCAIRS. There are only two occurrence categories that were adopted from ECCAIRS – SYST and F-NI.

Table 6. Comparison of existing vs. proposed taxonomy (occurrence categories)

ECCAIRS occurrence categories	Proposed occurrence categories
AMAN: Abrupt manoeuvre	ACFT: Aircraft/aircraft component damage
ICE: Icing	MAT: Aircraft material
SYST: System failure/malfunction or defect	SYST: System failure/malfunction or defect
LOC-G: Loss of control - ground	FAC: Facilities
RE: Runway excursion	PERS: Personnel injuries
ATM: ATM/CNS	FOD: Foreign object damage
F-NI: Fire/smoke (non-impact)	F-NI: Fire/smoke (non-impact)
FUEL: Fuel related	OTHR: Other

6 Events and contributing factors

These are events and factors that might contribute to an occurrence. Initial information received depends on knowledge or assumptions of personnel who reported the occurrence (which for MOR are mechanics or line supervisors). As investigation proceeds, events and factors can be added or adjusted based on the findings.

Occurrence report should not be very long or hard to fill in. Personnel reporting an occurrence usually wants to fill in the report quickly, which means that the information received will often be very brief. Therefore, events and factors selection in MOR is top level selection. This means that there are few general categories of events and contributing factors and mechanic should be able to choose the right category. Later, safety manager or someone who works with safety database can add more specific events and factors by reading narrative of the report or after interviewing mechanics.

Events

Table 7 on the next page combines MEDA and ECCAIRS event related taxonomies and proposes their top level classification with some examples.

There are five event categories proposed:

Table 7. MOR: Events

Event category	Description
Maintenance technical events	*specific aircraft parts/components (damage, loss, ...)*
Maintenance operational events	*fault isolation, FOD control, acceptance/storage of tools, maintenance inspections/controls/planning*
Personnel events	*experience, knowledge, performance*
Organisational events	*organisation's documentation, publications, management events, non-compliance with regulations*
Other events	*any other event*

Contributing factors

Table 8 suggests top level classification of contributing factors for MROs.

Table 8. MOR: Contributing factors

Contributing factors category	Description
Aircraft maintenance instructions/directives	*application of SB, AD, maintenance repair documentation*
Aircraft maintenance procedures	*insufficient, unfollowed, not supervised*
Aircraft/system/component	*all systems and components of aircraft*
Communication	*improper/lack of communication, misunderstanding*
Environment/facilities	*physical/psychosocial aspects of environment and facilities on performance*
Ground equipment and hardware support	*old/dirty/lack of equipment*
Maintenance tools and equipment	*tools/chemicals, their cleanliness, numbering*
Knowledge/skills/training	*personnel knowledge of tasks, procedures*
Leadership/supervision	*lack of leadership, pressure, no oversight*
Organisational factors	*organisation's policies, decisions*
Physiological factors	*fatigue, illness/incapacitation*
Psychological factors	*learning, personality, memory issues*

Again, both ECCAIRS and MEDA contain a solid inventory of factors terms. ECCAIRS divides factors into two categories, namely descriptive and explanatory factors. Descriptive factors represent technical issues, whilst explanatory factors focus on human interactions. This general selection is not necessary when determining what caused an occurrence, as usually both technical and human factors have their share in an occurrence and they do frequently overlap. General contributing factors proposed in *Table 8* are therefore not divided into these two categories.

Also, it can be noticed that an event category *Personnel events* in *Table 7* (e.g. experience or knowledge) and factors category *Knowledge/skills/training* in *Table 8* basically cover the same content. The fact is that many top ECCAIRS events and contributing factors are quite similar in their content[6]. And although taxonomy that was proposed for MOR is unique when speaking of selecetion of categories (some being from ECCAIRS, some from MEDA, some as a combination of the two), its logic (i.e. requirement to pick both an event and a contributing factor for an occurrence) is still rather based on ECCAIRS as it is the main reporting tool in aviation worldwide.

7 Effects on operation

The proposal for effects selection is shown below in *Table 9*.

Table 9. MOR: Effects on operation

Effect on operation	Description
Aircraft not ready for operation	*delay due to maintenance*
Fire services	*fire services assistance was required*
Security services	*security services assistance was required*
Flight delayed/cancelled	*flight was delayed or cancelled*
Maintenance action	*extra maintenance was required*
No effect on operation	*no consequential events*

[6] ECCAIRS events and contributing factors are already being grouped together. After the merger, there will be only one huge group of terms representing all kinds of possible contributing events/factors that can cause an occurrence.

Proposed effects on operation in *Table 9* are basically consequential events. Some of these events might already be included in MOR as event categories (see *Table 7*)**.** Though, basic selection of possible (common) effects should still be an extra part of MOR as the personnel reporting an occurrence can usually directly answer what were the consequences of an occurrence. For someone who later works with the report itself, this information is an instant feedback on what happened due to occurrence and how severe it was.

8 Narrative

Narrative is a brief description of an occurrence provided by someone who reported it, in his/her own words. This field can contain information on whether any corrective action was taken immediately and which events and factors probably contributed to the occurrence. This field is likely to include a more personal view of an occurrence and mechanic's opinion on the probable cause.

9 Comments

At the end of MOR, a reporting personnel shall provide a positive comment related to the occurrence. Personnel can describe what was done correctly, what was done differently (and not necessarily wrong) compared to a standard procedure, what helped to prevent other events from occurring, etc.

Personnel can also provide their own ideas on fixing the problem and preventing it from occurring again.

3.2.2 Audit report

Audit reports represent another source of data in aircraft maintenance. These reports are filled out by auditors who perform MRO audits. The areas that are usually audited depend on MRO's scope of operation and can include maintenance planning, technical records, maintenance manuals, etc. Audit itself is performed with some checklist questions suited for each area that needs to be audited. Depending on audit results, an audit report should be filled out along with information on what corrective actions have to be taken to eliminate discrepancies.

Audits are performed internally by company's auditors, or externally by CAAs or customer's auditors. They reflect on company's current performance and show its strengths and weaknesses. Therefore, it is essential to look at audit results properly as any space for improvement should be welcomed.

Checklist questions will not be discussed in this chapter. The reason is that many different checklists can be used for aircraft maintenance audits. On the other side, an audit report (containing the actual results of an audit) can be uniform and applicable nearly to all MROs no matter what their operation involves (landing gears, aircraft body, engines, etc.)

There is one more thing to clarify before looking at the form of audit report itself. Internal audit report is created and maintained by respective company. MRO cannot affect the way external audit reports look like, therefore the forms of such audit reports will not be discussed. What MRO can do is to adjust its own database where all data are stored, so that it can utilise the information coming from external sources and compare it to its own audit data.

The fields to fill in aircraft maintenance internal audit report should include:

1. Headline
2. Audit scope
3. Audit findings
4. Corrective actions
5. Conclusions

1 Headline

Headline should contain information like audit number, audit date, subject of the audit and auditor's name.

2 Audit scope

Scope of audit is an area of MRO operation that is subject to audit (in relation to EASA Part-145 approved organisations).

For each audit area in *Table 10* below its respective Part-145 section is provided.

Table 10. Audit report: maintenance audit areas [18]

Audit scope	Description
Facilities	145.A.25
Personnel	145.A.30
Certifying staff	145.A.35
Equipment, tools, material	145.A.40
Acceptance of components	145.A.42
Maintenance data	145.A.45
Production planning	145.A.47
Certification of maintenance	145.A.50
Maintenance records	145.A.55
Occurrence reporting	145.A.60
Safety and quality policy, maintenance procedures and quality system	145.A.65
Maintenance organisation exposition	145.A.70
Privileges of the organisation	145.A.75
Limitations on the organisation	145.A.80
Changes to organisation	145.A.85

3 Audit findings

Auditor's specification of discrepancies that were found during the audit. Each area of audit from above covers the whole process or procedure, and the auditor should provide an information on what specific component of that procedure was found insufficient. Auditor can also provide some information on what contributing factors were likely to be the reason for the discrepancies.

4 Corrective actions

Corrective actions that were already taken as an immediate response to the findings, and any corrective actions that will be taken in the near future.

5 Conclusions

Auditor's conclusions on audit findings, information on whether the audit report is finalised or left open for future modifications as investigation proceeds. Any other remarks related to the audit.

3.2.3 Personnel self-assessment report

Personnel self-assessment report is voluntary reporting on personnel's work environment, actual conditions, health, training, etc. Personnel should be encouraged to check and report on these issues on a daily basis, even if no deficiencies are observed. Having this information and watching its trend is an instant feedback on how personnel's performance changes and what is behind these changes, as degraded performance does not necessarily mean it is due to employees themselves. Lack of training, off-shift time, insufficient oversight, these are just some examples of how performance can be degraded due to other contributing factors than human error.

3.2.4 Hazard report

The process of hazard risk evaluation and risk management is a great way to prevent undesirable safety outcomes. But to start measuring the risk that hazards represent to safe operation they need to be identified and collected first.

Hazard reporting should be voluntary and anonymous. There are many ways to report hazards, and hazard report is one of them. It is the main tool to report recognized hazards and should be available to anyone within a company. Besides, hazards can be reported orally or electronically (email, web/mobile application form), and are also sometimes revealed by audits and MORs (contributing factors).

The purpose of hazard report is to directly point out hazards that exist in an organisation. Nature of these hazards can vary, some can be related to workplace conditions, some to inadequate procedures or lack of training. To help MRO keep track of hazards being reported and identified, a hazard register should be created. Here, all hazards can be gathered and risk can be managed.

As concluded from the above, a general hazard report does not need to contain a lot of fields to fill in. For someone to report a hazard, he or she can directly name what might endanger a normal, safe operation. After such report is acquired, respective manager will place the hazard under the category that it belongs to. As hazards are basically factors contributing to occurrences, factors categorisation in MOR (see *Table 7*) can be used for categorisation of hazards as well. Using the same taxonomy helps uncovering relations between separate occurrences and findings that are coming from different sources.

Personnel reporting hazards should be also provided with space to explain what is the source of the hazard, how often it occurs and what are possible consequences. Responsible manager will then add the hazard into hazard register and start risk assessment process. After defining the risk, manager should suggest means to control it, and add this information back to hazard register.

The risk that a hazard can represent is related to whether it is a hazard occurring regularly or rarely (likelihood of a hazard) and it also depends on how severe its consequences could be. *Figure 11* on the next page shows hazard's risk assessment matrix used by many high-risk industries, aviation included.

	Hazard Categories			
Frequency of Occurrence	**1 Catastrophic**	**2 Critical**	**3 Serious**	**4 Minor**
(A) Frequent	1A	2A	3A	4A
(B) Probable	1B	2B	3B	4B
(C) Occasional	1C	2C	3C	4C
(D) Remote	1D	2D	3D	4D
(E) Improbable	1E	2E	3E	4E

Unacceptable **High** **Medium** **Low**

Figure 11. Hazard's risk assessment matrix [14]

It is essential to provide feedback on hazards and associated risks to all personnel, via regular meetings or any other way. Personnel should be given extra knowledge on how to deal with risky hazards and what actions should be taken. As an example, there can be a certain job which procedure is hazardous and the risk associated with it is too high. If the job procedure itself is not that crucial and only the job result is, then the means of performing the job should change. If the job procedure has to be done a certain way that is risky, then other action should be taken (job done by well-trained personnel only, less regularly, under supervision, etc.) to mitigate the risk when performing such procedure.

3.2.5 Complaint

Complaint is a form of voluntary reporting. An option for someone to submit a complaint should be available. Complaints have to be treated differently than occurrence or audit reports, and can be related to anything that has something to do with MRO's operation. Some of them could be related to safety and therefore complaint is discussed here as another source of safety data.

Complaints can come internally or externally, whether from mechanics, managers, cleaning staff or public. They should be anonymous and confidential. If the reporting person wants to be contacted back to know what actions were taken in response to his/her complaint, he or she can provide contact information. Complaint submission should be available via different methods: public email address designated specifically for complaints, a paper, or mobile application form. Sometimes, complaints can be passed on orally between personnel.

3.3 Integrating safety data collection – a joint safety database

3.3.1 Integrated: what it means and why adopt it?

Making safety data collection integrated means that all incoming safety data are not to be perceived separately. Although they come from different sources and their flow varies a bit, all data come to one joint safety database where they should be processed the same way (see *Figure 12* on the next page).

The reason to adopt an integrated safety data collection is to reveal existing connections between safety data coming from different sources. Same factors can contribute to occurrences initially reported via MOR or to those that were uncovered by audits, SAFA inspections, or MRO personnel. The next paragraph demonstrates this by giving a specific example.

During Part-145 maintenance audit of *Equipment, tools, material* an unmarked material (few screws) was revealed. In the database, this has to be classified with a respective contributing factors (i.e. why the material was not marked). Later, safety manager might be processing MOR stating there was an occurrence that resulted in aircraft damage, therefore should be classified as *ACFT: Aircraft/aircraft component damage*. MOR can also contain information on what was the cause of occurrence. In this case, let's assume that a mechanic used wrong screw to attach the component to aircraft. It is later found out that the screw used by mechanic was unmarked. Despite realising this, the mechanic used this screw because it looked very similar to all the other screws and was placed in the same pack. Again, in the safety database, this occurrence should be classified accordingly with the same contributing factor as was the audit finding from above. Now, when a safety manager looks at the database, he can see that same contributing factor was revealed several times (unmarked material) and this should be an impulse for MRO to take actions, i.e. eliminate the presence of an unmarked material, provide recurrent training to mechanics.

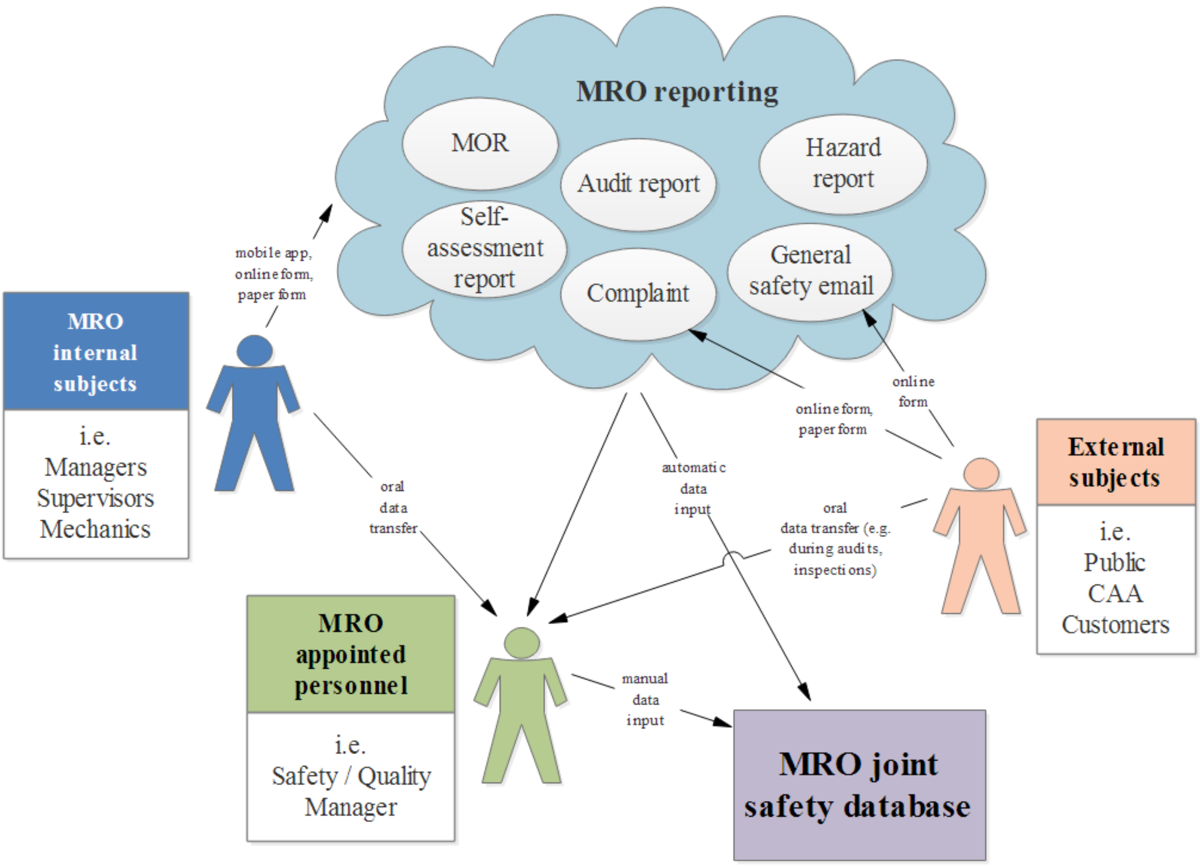

Figure 12. Integrated safety data collection

3.3.2 Safety database

There are different ways to store the data. Using excel sheets for storing all safety data is one way of doing the job. This could be an option for smaller-sized MROs with lower number of reported data. Other, more efficient way, is to have the database included in a software used for data processing. All bigger-sized MROs should go for this option, as with huge quantum of information to deal with one can easily overlook existing connections between occurrences, hazards, etc. Analysis and processing of data would be a lot easier and faster this way. Instant feedback via graphs, statistics, accumulation of events and contributing factors, these are just some benefits of software safety database rather than using excel sheets with limited features for later data processing. More on adopting SDCPS as a software is discussed later in chapter 4.

Safety database itself is usually managed by a safety manager of company. If MRO does not have one, quality manager or any other appointed personnel should be trained to manage the database. It is not advised to have too many persons working with database as this could cause data duplication.

Data input can be manual or automatic. If manual, one has to read all reports and fill in the information that is essential for analysis. If automatic, MRO needs to create electronic data reports by transferring information from paper forms into mobile applications or online forms. These would be then automatically transferred into software database ready for classification of extra attributes and later analysis. To adopt electronic report forms, the taxonomy in reports has to be identical with the one used in the software database.

MRO hazard register should be part of safety database as well. Here, all hazards present in MRO operation are gathered through hazard reporting forms (electronic, paper) and assessed for risk. As mentioned before, some hazards get revealed by MOR or audit reports. When manager deals with such reports he or she can directly transfer revealed hazard to a hazard register, as all would be stored in one database.

Besides collecting data from internal reports, an integrated safety database should also incorporate external data, like audit reports from CAAs, customers, SAFA inspections, etc. This means integrating the whole SDCPS not only internally, but with external subjects as well. Having all this information at one place provides a space to compare the results between all audits, no matter if discrepancies were observed from inside or outside the company.

3.4 Systematic classification of safety data as part of data processing

Systematic classification means that each occurrence in the safety database is assigned specific attributes. Some of these attributes are mentioned in the report form itself (like occurrence date, location, type of maintenance). However, reporting personnel does not know SDCPS taxonomy and cannot provide exact classification of attributes like occurrence category, events or contributing factors in the report. This is the task for safety manager.

But even safety managers from CAAs or from various service providers often struggle when trying to properly classify safety data by assigning correct events and factors to each occurrence [21]. As required by law, they must use attributes from ECCAIRS taxonomy for data classification. ECCAIRS contains a very detailed taxonomy with lots of events and contributing factors that can be just slightly different from each other. Besides similarities in content, events and contributing factors usually contain other set of factors.

Figure 13 shows some groups of ECCAIRS contributing factors *Experience, knowledge and recency.*

Experience, knowledge and recency (Experience & knowledge)	105000000
Factors related to experience, qualifications, knowledge and recency. N.B. details should be recorded elsewhere; the keywords should only be used if inexperience, inadequate qualifications, poor knowledge or for example, lack of recency are considered to have been contributory factors (irrespective of whether the regulations were met or not).	
Inadequate or inaccurate knowledge (Adequacy of knowledge)	105030000
Factors related to inadequate or inaccurate knowledge.	
Aeronautical knowledge (Aeronautical knowledge)	105030400
Factors related to aeronautical knowledge (applicable to flight crew, controllers and maintenance engineers).	
Aircraft systems knowledge (Aircraft system knowledge)	105030500
Factors related to the knowledge of aircraft systems (aircrew and maintenance engineers).	
Lack of up-to-date knowledge (Current knowledge)	105030200
Factors related to up-to-date knowledge.	
General knowledge (General knowledge)	105030100
Factors related to general knowledge.	
Knowledge of flight rules (Knowledge of flight rules)	105030700
Factors related to the knowledge of flight rules (flight crew and controllers.)	
Knowledge of procedures (Knowledge of procedures)	105030600
Factors related to the knowledge of procedures, e.g. existence, content or where to look them up.	
Knowledge of aerodrome procedures (Aerodrome procedures)	105030604
Factors related to the knowledge of aerodrome procedures.	

Figure 13. ECCAIRS contributing factors correlation [20]

As seen, contributing factor *Experience, knowledge and recency* is a top level category factor (like the categories proposed in MOR *Events and contributing factors* in section 3.2.1). This factor contains few more categories of other factors, which then contain even more detailed contributing factors. Based on this, a safety manager is able to choose either more general (top) category of a contributing factor, or if enough data were provided (narrative of report states what exactly happened), a manager can choose a more in-depth factor. The problem is that sometimes, when managers deal with same types of occurrences to which same factors contributed, they might classify it with a more general category of contributing factor, like *Inadequate or inaccurate knowledge*, as they do not get more information from the report to be more specific. On the contrary, let's assume the same occurrence happens again. When the report is well filled in and one of the contributing factors is known to be *Knowledge of procedures*, then this is the one that is used for classification. Due to this, there is not enough accuracy in data classification and accumulation of specific factors might not reflect directly about on-going issues. This means that no matter how detailed the taxonomy is, if uniformity and accuracy are not maintained, the quality of data processing and analysis is low.

The following is an example on the similarity in meaning or content coverage of events and contributing factors that safety managers have to face with ECCAIRS taxonomy. Contributing factor *Knowledge of procedures* in *Table 13* can be used when ATM personnel contributed to occurrence by not knowing a specific procedure when guiding an aircraft. Using ECCAIRS taxonomy, a manager has an option to choose between too many event types and contributing factors that, in their content, overlap even between different top categories (in this group, another possibility for classification of contributing factor that someone would likely consider is *General knowledge*).

Due to this complexity of ECCAIRS taxonomy, safety managers can be unsure if the classification they choose is the right one or detailed enough. What can happen is that a specific factor can regularly contribute to independent occurrences, but might be classified as a different factor when putting it into database. Analysis and measurements are then based on incorrect data and could misdirect management when making a bigger picture of what is going on.

To solve this problem, ECCAIRS taxonomy should either be adjusted and contain less similar events or contributing factors, or safety managers should be provided training on how to work with such a complex database. Otherwise, ECCAIRS taxonomy will hardly ever be utilised for 100% as personnel will often choose only the basic options for data classification in order not to misuse different factors.

3.5 Summary

Chapter 3 gave a proposal on how an integrated safety data collection should look like in a bigger-sized MRO by providing particular types of data report forms with specific taxonomy they should contain. Certainly, this is not the final look of such collection for all aircraft maintenance organisations. Each MRO may adjust their report forms to exactly match its operational needs. But chapter 3 of this thesis can serve as a good template.

Each report form proposed in this chapter contains a specific taxonomy. The idea was to create a taxonomy that derives from ECCAIRS (to the extent that ECCAIRS offers for aircraft maintenance purposes), because this can help MROs speak the same reporting language as all the other aviation service providers. And uniformity in data classification is essential. Also, it is very likely that in future, ECCAIRS taxonomy itself will be extended to cover all aviation maintenance areas. But, due to the coverage of ECCAIRS taxonomy valid now, MROs have to adopt their own taxonomy that can stand on ECCAIRS, but still needs to be enhanced and more detailed to fully cover all aircraft maintenance areas. Therefore, besides utilising ECCAIRS existing taxonomy in report forms in chapter 3, several terms (of which some are from MEDA Reports Form) were added.

Final sections of chapter 3 emphasized that it is not just a relevant taxonomy that matters in SDCPS. To benefit from a well-developed taxonomy an accuracy during data classification process is necessary (ability to choose the right terms for all attributes). Besides classifying attributes correctly, it is more than necessary to mark all existing connections between occurrences/events/factors. As without one event/one factor the other would probably not occur. By marking their relations, it is easy to see what events usually lead to what consequences and prevent harm in future.

Chapter 3 also analysed different ways to store safety data. For big maintenance organisations, the best way to store all data is in a safety database that is part of a data processing software.

Lastly, safety managers should know how to work with the maintenance taxonomy used for data classification and they should be aware of its complexity. It is more than necessary to use correct and precise terms when classifying either the occurrence itself (assigning general category) or any contributing factor and still be as detailed as possible. Quality of safety information depends on it.

4 Proposal for implementation of integrated safety data collection and processing system into real-operation environment

4.1 Preface

Previous chapter proposed means to collect and systematically classify safety data in MROs. This chapter moves to the next step and proposes how SDCPS can be implemented into real-operation environment. Moreover, the chapter discusses what needs to be overcome to achieve high quality of safety data processing and what it means to integrate the whole SDCPS within MRO. While chapter 3 was more focused on practical points, chapter 4 complements it by suggesting implementation principles that are based on theory and experiences from other high-risk industries.

SDCPS implementation relies on many different factors and is usually related to the phase of SMS implementation in which an organisation currently is. SMS for MROs alone is not yet a regulatory requirement, therefore any initiatives taken by maintenance organisations are voluntary and there is almost no support for them due to lack of experience with such dedicated systems from the industry. This affects the quality and effectiveness of MRO's safety data collection and processing.

Though, MRO's should move forward regardless of EASA's SMS regulation and try to improve their safety processes to enhance safety, protect their employees and increase reputation among its customers. One way to do so is to improve their safety data collection and processing and integrate it into their daily operation.

4.2 Assigning responsibilities related to safety

It is necessary to appoint a person responsible for managing SDCPS. If company does not have a safety manager, it shall delegate such responsibility to any other qualified personnel. This person has to be trained for working with huge amount of safety data, classify it, store it and analyse it. Also, such person should know his/her company and its operational scope well in order to see relations between reported data.

Though, not all work related to safety improvements should lie on one's shoulders. Ensuring high level of safety and its daily promotion should be responsibility of everyone, beginning with MRO's accountable manager and top management. Employees need to see that company puts safety first and fully supports all initiatives taken to improve it.

When following SMS implementation steps and having enough resources, a company should also appoint a group of selected top management employees to form Safety Review Board (SRB). According to ICAO's SMM, "SRB is a very high-level committee, chaired by accountable manager and composed of senior managers, including line managers responsible for functional areas. Safety manager participates in the SRB in an advisory capacity only." [13] In other words, SRB's main objective is to meet occasionally to discuss high-level issues in relation to policies, resource allocation and organisational performance monitoring. SRB meets infrequently, unless exceptional circumstances dictate otherwise.

Once SRB develops a strategic direction, implementation of strategies across the organisation must take place. This is the role of the Safety Action Group (SAG). "SAG is a high-level committee, composed of line managers and representatives of front-line personnel, and chaired in turn by appointed line managers." [13] The group deals with implementation of ideas proposed by SRB and is managed by safety manager.

Mainly, SAG [13]:

- oversees operational safety performance within the functional areas and ensures that hazard identification and safety risk management are carried out as appropriate, with staff involvement as necessary to build up safety awareness
- coordinates the resolution of mitigation strategies for the identified consequences of hazards and ensures that satisfactory arrangements exist for safety data capture and employee feedback
- assesses the impact of operational changes on safety
- coordinates the implementation of corrective action plans and convenes meetings or briefings as necessary to ensure that ample opportunities are available for all employees to participate fully in management of safety
- ensures that corrective action is taken in a timely manner
- reviews the effectiveness of previous safety recommendations
- oversees safety promotion and ensures that appropriate safety, emergency and technical training of personnel is carried out that meets or exceeds minimum regulatory requirements

Actions should be taken after SAG meeting. However, first meetings of SAG may not be very efficient. It is important to understand that people need time to cope with change and comprehend it. Some things were done a certain way for many years and now personnel are required to meet regularly and discuss what never had to be discussed in such a complex manner. Once managers understand why the change is needed and what benefits it brings, it is much easier to convince all the other personnel to do the same.

Figure 14. Safety accountabilities relations (airlines example) [15]

Figure 14 gives an idea on how safety responsibilities are assigned in a bigger airline. For a maintenance organisation alone some units would be changed to fit its operational scope.

4.3 Personnel training

All employees should be trained regularly on issues regarding safety. Each group of employees, depending on the scope of their job, should have a training that is related to their part of the safety system. This means that mechanic does not need to know how to analyse safety data. He needs to be trained on how to identify and report the safety data to someone who will later analyse it. Therefore, MRO should make sure that an appropriate training will be provided to all personnel, whether it is on SMS principles, reporting procedures (paper, electronic[7]), explanation of reporting forms and when to use them, hazard identification and reporting, etc.

Also, instructors have to teach employees that safety training is not just about what one learns, but mostly why he or she learns it and how the training received can be later utilised in practice. Simply passing a final test is not the aim of such training. Maintenance staff should understand, like management has to, that safety must be perceived with the highest priority.

Feedback from employees regarding training is necessary too, mostly when MRO is just starting integrating safety management system into their operation. Training has to be provided one step at a time, making sure each part of the training was understood well. If not, training should be adjusted and repeated.

4.4 Enhancing positive safety culture: why and how?

Reporting policy is developed, report forms are available to all employees, employees are trained to fill out the reports properly, and yet, the only safety data that enter the system come from mandatory reporting. Why? One reason might likely be an insufficient safety culture.

One has to understand that integrating safety database and processing into daily operations is not a stand-alone process. It goes hand in hand with company's safety culture. If one develops and implements means to collect safety data, it does not necessary mean the data will be collected. If safety culture is low and personnel do not see and understand why safety related data should be reported and exchanged, the reports themselves are useless.

Therefore, following subsections review what safety culture is and what effective tools can be used to improve it.

4.4.1 Safety culture principles

A safety culture within an organisation is generally thought to be a set of beliefs, norms, attitudes or practices which reduce the exposure of all people in and around the organisation to conditions considered dangerous or hazardous.

[7] If company decides to implement an electronic form of reporting, then all personnel should have access to electronic device in the working environment.

According to ICAO (1993), the characteristics of a 'safe culture', which should guide decision-makers in modelling corporate safety culture, include the following [16]:

- senior management places strong emphasis on safety as part of the strategy of controlling risks
- decision makers and operational personnel hold a realistic view of the short- and long-term hazards involved in the organisation's activities
- those in senior positions do not use their influence to force their views on other levels of the organisation, or to avoid criticism
- those in senior positions foster a climate in which there is a positive attitude towards criticism, comments and feedback from lower levels of the organisation
- there is an awareness of the importance of communicating relevant safety data to all levels of the organisation (and with outside entities)
- there is promotion of appropriate, realistic and workable rules relating to hazards, to safety and to potential sources of damage, with such rules being supported and endorsed throughout the organisation
- personnel are well trained, and fully understand the consequences of unsafe acts.

Safe organisations generally [16]:

- pursue safety as an organisational objective and regard it as a major contributor to achieving production goals
- have appropriate risk management structures, which allow for an appropriate balance between production and risk management
- enjoy an open and healthy corporate safety culture
- possess a structure which was designed with a suitable degree of complexity
- have standardised procedures and centralized decision-making consistent with organisational objectives and surrounding environment
- rely on internal responsibility, rather than regulatory compliance, to achieve safety objectives
- put long-term measures in place to mitigate latent safety risks, as well as acting short term to mitigate active failures

Safety culture is composed of five components: flexible culture, learning culture, informed culture, just culture and reporting culture. Each component is explained below in *Figure 15*. The amount of safety data reported to management is closely related to company's reporting culture and mostly, to its just culture. Therefore, when trying to get personnel to report and exchange more safety data, management and leaders should show their employees that their company acknowledges the principles of just culture and stands behind them.

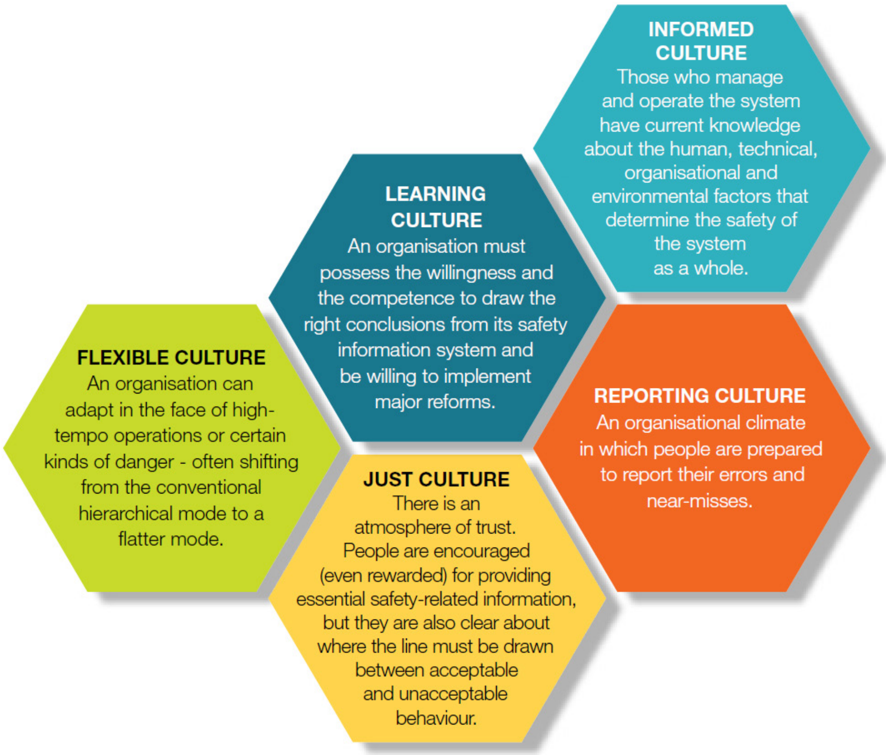

Figure 15. Safety culture key components [16]

4.4.2 Safety culture improvement tools

It is not easy to build an effective safety culture. As discussed before, personnel usually like doing things the 'good old way' and do not adapt to change on a day-to-day basis. Improving safety culture is a challenging process that requires a lot of time and mostly, a lot of effort from all participants. However, there are tools to help management and employees cope with such a big change.

Besides providing appropriate safety training to personnel, management should ensure a regular stream of safety information to all employees. This is a good way to show personnel that it does not end with a training, that safety is not a one-time thing to discuss few times a year and then move on.

Disseminating safety information is often referred to as safety promotion. The ways to promote safety depend on size of MRO and some can be more relevant than others.

Internally, safety can be promoted via safety bulletins, safety cartoons, safety notices, posters, CDs or DVDs, company's newsletter, regular briefings or toolbox talks, recurrent trainings, emails, intranet information, etc.

Externally, company can organise meetings, workshops or networking events, update their website to include safety information, provide online forums to talk about safety issues, etc.

Figure 16 gives an example on how to increase awareness among personnel in hangar using a safety cartoon. "The Dirty Dozen" is a well-known set of twelve common human factors representing threat to aircraft maintenance personnel on a daily basis.

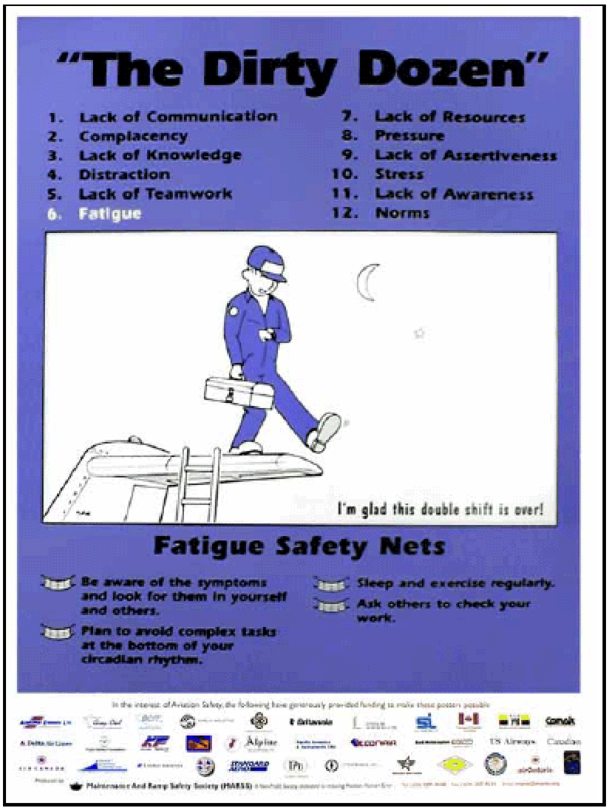

Figure 16. "The Dirty Dozen" in aircraft maintenance [17]

The twelve factors are:

1. Fatigue
2. Stress
1. Complacency

2. Communication
3. Awareness
4. Distraction
5. Lack of knowledge
6. Teamwork
7. Lack of resources
8. Pressure
9. Lack of assertiveness
10. Norms

Each factor of the twelve should be periodically shown on a visible place in hangar, making personnel more aware about their condition and surrounding environment.

When personnel constantly come across safety information like this, it gets into their minds and integrates into their daily tasks. Putting safety first then becomes employee's basic principle when performing his/her job. Surely, it takes time until such level of safety culture is achieved, but promoting safety is a good start.

4.5 Integrating SDCPS

Previous sections of chapter 4 proposed how to create an appropriate environment for SDCPS implementation. But there is one more important step to take in order to achieve an efficient implementation – SDCPS integration.

SDCPS as a whole, similarly to safety data collection, should not be considered a separate system. Rather, it should be inherent to most MRO systems, because it interacts with all employees and processes. After all, safety is everyone's responsibility. The best way to start integrating SDCPS within the whole MRO operation is to clearly define the roles and responsibilities of all entities interacting with SDCPS – what, why and how they are required to do.

Employees of all MRO departments should have access to internal reporting forms, e.g. personnel from marketing or finances should be at least allowed to access a hazard report form, self-assessment report form and to submit a complaint. Also, a general email regarding safety issues should exist and be available to all personnel from all departments. To this email address, personnel can send any safety related information, and any hazards, complaints, or maintenance occurrences as well. Although staff should be advised to use appropriate reporting forms, sometimes they might lack enough time to fill in the whole report. And the objective is to get as much existing safety data as possible, regardless the way they are reported. Besides internally connecting all relevant organisational units to reporting forms, some form of access has to be permitted to external subjects as well. For example, an option to report via public MRO website containing reporting form for public or again, a general email designated for safety purposes only. In *Figure 17*, all this is incorporated in *Occurrence reporting* rectangle.

The above part of an integrated SDCPS was already illustrated in *Figure 12* of chapter 3 and focuses mostly on safety data input from different internal and external sources into joint safety database. But integrating SDCPS also covers safety data output (see *Figure 17*).

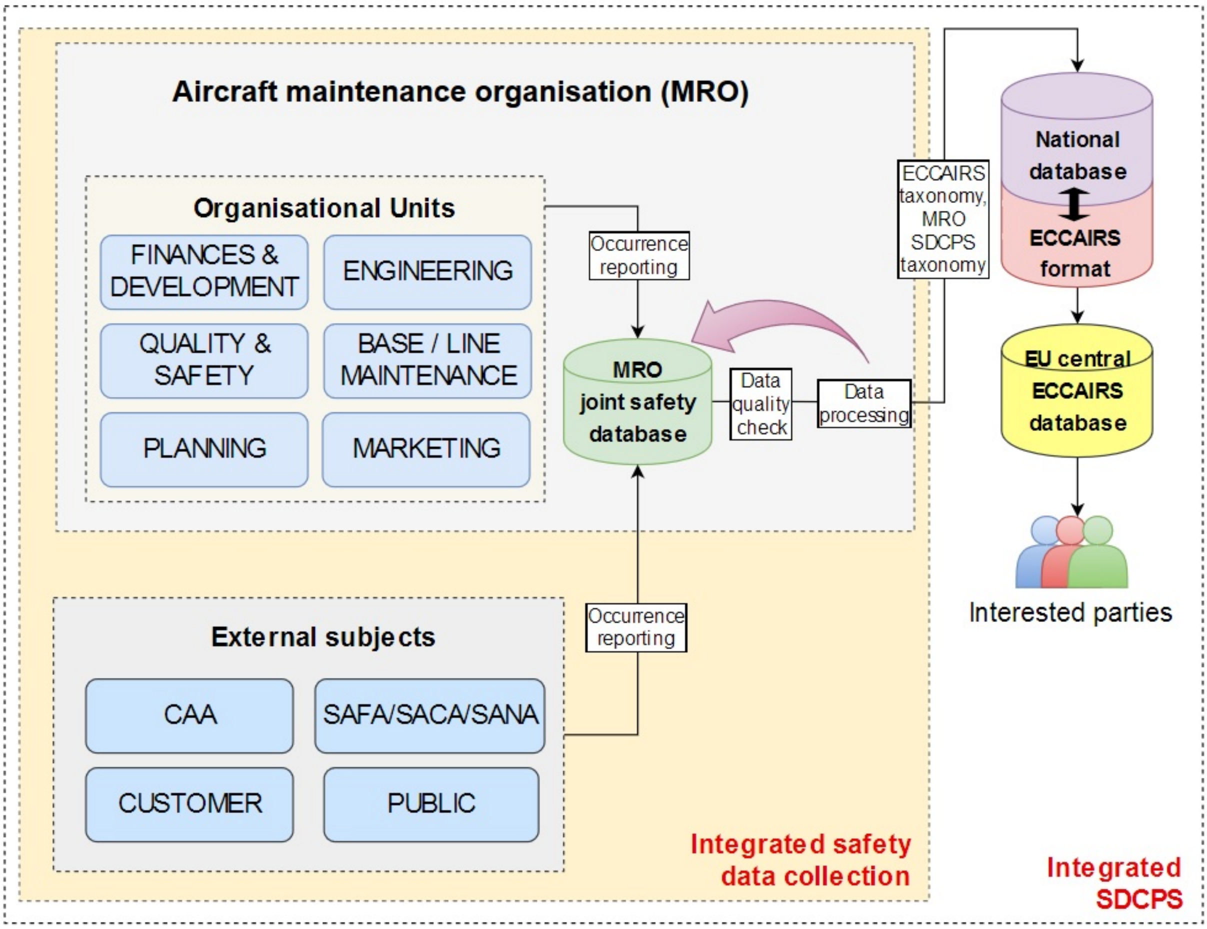

Figure 17. Integrated SDCPS

Not only MRO can utilise the safety information processed by its SDCPS, but national authorities as well. MRO's SDCPS should therefore be linked to national safety database to pass relevant safety information onward, either in its own SDCPS taxonomy or ECCAIRS taxonomy. National authorities collect safety information similarly from all aviation service providers and maintain the national aviation safety database. They use this information to assess aviation safety on a national level. Besides, in their own database, they might be able to find connections between occurrences received independently from MROs, aerodromes, airlines, etc.

Figure 17 also illustrates that national aviation safety database is linked to central ECCAIRS database that collects data from national aviation authorities of all EASA members.

4.6 How to process safety data

4.6.1 Quantity versus quality

Assigning safety responsibilities, establishing and implementing principles regarding safety culture, reporting and collecting safety data, providing appropriate training to personnel and constantly working on enhancing the safety culture, it does not end here. Now, when the data are reported and enter MRO's safety database, measurements and analysis take over.

Safety manager's main responsibility at this point is to go through all the reported data, analyse them and make conclusions. Even though this might look like an easier part of the whole implementation process, data processing requires a reliable person able to see and understand why there was an occurrence and what could have been done to prevent it.

The processing starts after data were received. If reported occurrence does not provide enough data, safety manager should personally interview personnel that reported it to get more information. When reporting works well, a quantum of safety data come in. It is essential not to lose the track of what was reported and secure quality data output. One way to do this is to use correct terms for data classification. But with the current maintenance taxonomy used for data classification it is often hard to classify each occurrence and its contributing factors correctly (3.4). Therefore, MROs should adopt such taxonomy that is complex enough to cover all possible safety events but still easy to use. This means that boundaries between definitions of contributing factors are exactly defined so that safety managers will not be confused when classifying data.

But data processing, it is no just about taxonomy or correct classification. Data processing is a complex process that, in the end, has to provide clear feedback on safety matters. Other essential parts of data processing cover:

- processing data that come from sources outside MRO's SDCPS (e.g. OFDM)
- classification, assessment and control of risks that hazards might present
- increasing data relevance and data completeness
- creating timeline of events or contributing factors (to see the time sequence of contributing factors and events)
- regular safety issues (same, regularly repeated occurrences) and analysis of methods to reduce them

The above parts of data processing are important and MRO should focus on their implementation within SDCPS as well. But since MROs are a little behind in SDCPS development compared to some other aviation service providers, a good start is to firstly develop an integrated safety data collection, along with a good taxonomy and data processing basics.

4.6.2 SDCPS as a software program

There are ways to improve quality of data processing. One of them, and probably the most efficient one, is to transfer from manual data processing to software data processing. In other words, digitalising SDCPS.

This program, if developed well, can be of great assistance especially for safety managers and other personnel appointed to work with safety data. A well-developed SDCPS software is built on all SDCPS principles, i.e. it:

- adopts an integrated (joint) safety database with ability to import and work with both internal and external data
- uses a unique taxonomy that SDCPS stands on – for automatic transfer of data (submitted report form directly displayed in the software database)
- provides user-friendly interface (e.g. easy orientation, quick occurrence search)
- offers automatic search for existing connections between occurrences based on previous classification

- analyses and graphically illustrate safety trends in different maintenance areas based on data analysis
- guides managers processing data to precise classification (e.g. when a contributing factor is related to use of maintenance procedures, manager should be able to easily look up all existing factors related to maintenance procedures, read their description if provided, and then decided and choose the right one)
- gives top management the most current picture (an instant overview) of safety in MRO
- shows current safety performance, e.g. using some safety indicators chosen by MRO management to assess the safety performance

Digitalised SDCPS can be of great aid to data processing. It can help managers see what they would not be able to see on paper or in excel sheets. Accumulation of certain hazards and factors can be captured in time and harm can be prevented. And by preventing harm, whether speaking about physical damage to aircraft parts/components or personnel injuries, an organisation does save money.

4.7 Summary

Developing and implementing integrated SDCPS are two very different processes. Although a good data collection and processing system takes time to develop, organisations usually have access to guides and templates related to development of such system, as introduced in this thesis. Making it work in practice is a bit different.

The speed of implementation process may differ between MROs and depends on various factors. Usually, MRO’s safety culture is the factor that impacts the implementation process most. Ideal safety culture supports staff and systems, recognises that errors will be made and believes blaming staff will not solve problems, but more likely decrease the number of reported data. A positive and supportive safety culture encourages open and honest reporting, seeks to learn from its failures and is open and fair in dealing with those involved.

Several tools exist that can help MRO improve its safety culture. Each MRO should consider which tools are the most suitable for their operation and will positively affect the safety culture. Then, these tools should be progressively integrated into daily operations. If employees are exposed to many new procedures to comply with at once, these tools might have the exact opposite effect and even worsen the safety culture. Therefore, a step by step approach to implementation is essential.

SDCPS is not to be understood as a separate system. Integrating it into MRO operation is an essential step of successful SDCPS implementation. Its principles, mostly those related to data reporting, should be natural to all departments, whether it is a safety department, quality department, base/line maintenance, or even administration and finances (for hazard identification/reporting).

Safety data processing is an inseparable part of any SDCPS. The way that data processing is done has a major impact on data output and its quality. MRO management has to understand that the quality of data is even more important than its quantity. In other words, high data quantity with poor quality will not improve MROs safety and will not save money.

Safety data processing often lacks adequate resources, e.g. enough data sources, relevant taxonomy or trained personnel. To improve quality of safety data processing, chapter 4 proposed that MROs start using a software program based on SDCPS principles. If maintained well, such program can be of great aid to those that process safety data.

5 Contribution evaluation of the proposed solution

5.1 Preface

Chapter 5, the last chapter of this thesis, evaluates how this thesis contributed to development and implementation of SDCPS applicable to aircraft maintenance organisations.

The whole evaluation is divided into three segments to clearly demonstrate to which areas of SDCPS for MROs this thesis contributed and in what extent. These segments include SDCPS maintenance taxonomy, safety data collection and safety data processing.

5.2 Contribution to aircraft maintenance taxonomy

Taxonomy, as underlined many times throughout this thesis, is the cornerstone of any SDCPS. Common, uniform terms are essential for data measurements, analysis and safety data exchange between different parties. Therefore, terms used for classification of occurrences and all their attributes have to be precisely chosen to cover any potential event or contributing factor.

ECCAIRS taxonomy that is related to aircraft maintenance operation, as detailed as it is, is currently not sufficient enough as it does not cover the whole MRO operation. On the contrary, MEDA taxonomy, although developed directly for MROs, is not detailed enough when speaking about some specific events or contributing factors. Still, when combining ECCAIRS and MEDA taxonomies, they offer a solid foundation of maintenance related terms. The new, proposed taxonomy for MRO’s SDCPS therefore utilises some of ECCAIRS and MEDA terms, and adds some extra in the areas they do not fully cover.

This thesis contributed to aircraft maintenance taxonomy applied within the whole SDCPS, as terms proposed in reporting forms are later used for data processing as well.

As for safety data collection, this thesis enhanced the taxonomy related directly to reporting maintenance occurrences, and was hence applied in MOR. The reason for this is that maintenance occurrence reporting in most MROs nowadays lacks support and sufficient promotion, and safety data are mostly gathered from only one or two sources (e.g. revealed by audits or reported via email). Another reason is that, for example, taxonomy used in audit report is similar to the one used in MOR (mostly in events and contributing factors categories by which audit findings should be classified).

For some sections of MOR, several completely new terms were proposed. This is the case of occurrence categories. ECCAIRS has a special taxonomy used to divide occurrences on a very general level. This category assignment is based on the area that occurrence is related to. If an occurrence is related to air traffic services, then its respective general classification would be, according to ECCAIRS, ATM: ATM/CNS. There are quite a few general occurrence categories that ECCAIRS currently uses, but only two of them are applicable to MRO operation: system failure/malfunction or defect and fire/smoke (non-impact). Following the logic of ECCAIRS for this general occurrence categorisation, several categories were added to match the operational scope of MROs.

As for processing safety data, this thesis proposed that taxonomy used in report forms should be same (especially for electronic reporting) or at least similar to the one applied later in data processing. This way, classification of occurrences during data processing is less demanding and requires less time. Data processing itself then uses taxonomy that is a lot more complex than the one in reporting forms. It does not offer just a very basic selection (i.e. top level categories in MOR events and contributing factors), but a very detailed terms that each top category contains and that safety managers work with. Listing all these detailed events and contributing factors would extend the scope of this thesis, therefore only the top level selection was proposed.

The proposed taxonomy tried to follow ECCAIRS basic logic of systematic data classification by adopting a similar concept for general occurrence categories (see *Table 6*) and by utilising those ECCAIRS terms that fit aircraft maintenance operation (mostly events and contributing factors). This is because ECCAIRS (with its specific taxonomy) is still the main occurrence reporting tool used nowadays among all aviation subjects.

5.3 Contribution to safety data collection in MROs

There are several ways to collect data in MRO. These were discussed mostly in chapter 2 of this thesis. Receiving information from more sources is important, as it helps uncover problems that would not be very likely uncovered by one information source only. The current situation of data collection in MROs needs to get more attention. When speaking about MRO voluntary data reporting, it is just at its roots. The objective is to achieve high quantity of data input, from both mandatory and voluntary reporting. The fact is that managers often struggle with getting enough data from different sources – they mostly receive only data they find themselves (e.g. during audits). Therefore, MROs should direct some of its resources to improve this situation.

This thesis picked out reports and their forms as the main tool to be used for safety data reporting. The reason is simple – besides practicing a word-of-mouth, reports are a classic way of passing information forward. Personnel should know them and understand them. As MROs are only being considered for SMS and its implementation, there is no need to rush and establish all elements that SMS stands on, like for example, utilising several means to report safety data with reports being just one of them. At the beginning of SDCPS development or enhancement, personnel might be facing too many new procedures to comply with. Having just a few report forms that are simple and easy to fill out is a good start to improve internal company reporting. Taking a step-by-step approach will ensure full implementation and adoption of new principles.

Due to reasons mentioned above, proposal in chapter 3 focused mostly on different forms of reports applicable to maintenance organisations. These are namely maintenance occurrence report, or MOR, audit report, self-assessment report, hazard report and complaint. Each of these report types contains several sections that have to be filled in by reporting personnel. It is necessary that personnel understand the meaning of all terms used in respective report form.

MRO's safety data collection (the reporting forms) does not necessarily have to be electronic. Whether data come on paper report form or through electronic report form, or via general safety email, the fact is that it comes. MRO shall decide which way is going to be more user-friendly for staff. MRO can adopt paper reporting only, electronic reporting only, or a mixture of both. This means that paper forms are digitalised and personnel can fill them in using a mobile application or MROs website. Electronic report must use the same taxonomy as the paper one.

Chapter 3 also underlined the importance of making safety data collection integrated. Only integration of all data (internal and external) in one joint safety database can reveal existing connections between occurrences reported from different sources. Otherwise, these connections could easily be overlooked and could make safety space more vulnerable.

5.4 Contribution to safety data processing in MROs

Safety data processing is the process that follows after data are gathered. This process can be done by specially appointed personnel or by safety or quality manager. Data processing covers many processes that are linked together, like data classification, quality check, increasing data relevance and completeness, assessment and control of risks, or assessment and control of typical safety issues. Not all these processes were discussed in this thesis. The reason is that MROs are not that further ahead to be developing and implementing a fully advanced data processing within their SDCPS. Instead, they should firstly focus on the very basics of data processing – such as using a good taxonomy and precise data classification that clearly defines data. In order to do this well, this thesis proposed to adopt a software designed for data processing. Integrated safety database should be an inseparable part of such software. A software that helps managers process safety data offers many benefits. It keeps track of what is going on presently. Not only it helps improving safety processes, it also helps MROs stand out on the market. New aircraft types are built using the latest and most sophisticated technology that works with huge amount of data. Operating a modern fleet requires modern approach to repairing and maintaining these fleets. Air transport operators are very well aware of this fact and prefer those MROs that are able to adapt to this change. It is very likely that big data and the way MROs deal with them will determine the future of their business. According to The Lufthansa Technik Group Magazine [19], "the challenge is to have the ability to collect the data, to evaluate them and to react accordingly. This capability will characterize the successful MRO provider of the future."

5.5 Summary

Chapter 5 evaluated the contribution of an SDCPS for MROs that was proposed in this thesis. The evaluation was brought down to three segments. When looking at a contribution of each segment individually, one does not might see the scale of its value. The fact is that an enhanced maintenance taxonomy and integrated safety data collection alone do not help MROs decrease occurrences or grow their business. Neither does adopting a data processing software without good data collection procedures or appropriate taxonomy. But when perceiving the contribution to all these segments altogether as the contribution to one integrated SDCPS for MROs, the contribution value is indisputable.

SDCPS is all about integration and it has to be perceived this way from the very beginning. This thesis proposed that all MRO departments should have access to reporting forms, whether it is a mechanics or personnel from finances. Anyone should be able to report safety information. Moreover, processing data and getting valuable safety information is not useful just for MROs. SDCPS integration means passing safety information to external subjects, like national authorities. They might use it to make their own analysis and propose different corrective actions.

To sum up, all parts of SDCPS are important and linked together. Data collection (quantity of data) and data processing (quality of data) go hand in hand, and they both stand on a well-developed taxonomy. The following explains it best: the better the reporting and collection procedures, the more data get in. The better the processing procedures, the more valuable safety information is obtained. Maintaining high data quality with high data quantity can be challenging. But for businesses like MROs, it is exactly what needs to be achieved.

Conclusion

The aim of this thesis was to propose a concept of an integrated safety data collection and processing system applicable to aircraft maintenance organisations. Before peeking into the proposal itself, current means for data collection and processing were reviewed. An efficient SDCPS is built up using a taxonomy that is related to the operational scope of an organisation. For aviation areas other than maintenance, like aerodromes, air navigation services or air transport operation generally, a solid taxonomy is already developed and is being used among these providers. For aircraft maintenance providers, the development of such taxonomy is still in the process.

Chapter 1 looked at existing taxonomies related to aircraft maintenance. Namely, the chapter went through taxonomies developed for MEDA and ECCAIRS. For the purposes of data classification, MEDA Results form used during MEDA investigation process represents a great source of terms related to aircraft maintenance. Another taxonomy reviewed in chapter 1 comes from ECCAIRS. The problem with ECCAIRS taxonomy is, paradoxically, that it was created as a response to regulations asking national authorities and certain service providers to report and exchange safety data. As a result, taxonomy development followed mostly needs of CAAs and those service providers required to report by law. This strongly affected the taxonomy development in areas like aircraft maintenance. Despite, ECCAIRS does contain a lot of valuable terms of which some can be utilised in SDCPS of an MRO.

In chapter 2, a general SDCPS was analysed. SDCPS of various providers have a lot in common and the taxonomy they stand on is usually the only significant difference among them. Besides analysing specific ways to collect and process safety data, chapter 2 discussed current state of SMS regulation regarding MROs. As MROs are not yet required to implement SMS into their operation, data reporting lacks the support and oversight from a regulatory body, but mostly it lacks the support of external sources. There is no documentation or publications related to SMS implementation in approved maintenance organisations that would directly guide MRO's top management on how to integrate such a complex system into their daily operation. Sources like ICAO's SMM (Doc 9859) offer general guidance on how to develop safety policies, assign responsibilities, perform risk management, assure safety and promote it. But, as explained before, to perform risk management and assure safety is maintained, safety data need to be reported regularly and classified uniformly. In this direction, MROs are yet on their own.

In chapter 3, based on the previous know-how, a particular safety data collection applicable to MROs was proposed. The proposed collection focuses mostly on reports as the main source of safety data in MROs. Reports were divided into several types that are likely to be used in aircraft maintenance. MOR, audit report, personnel self-assessment report, hazard report and complaint are the reports proposed for collecting safety data in MROs. Each of these reports has specific features and uses specific taxonomy related to the scope of the report. MOR, for example, is used for occurrences related directly to aircraft maintenance. The common feature of all these reports is that a uniform taxonomy for data classification should be used, especially when talking about factors contributing to occurrences. Same factors can be revealed by MOR, audit report or hazard report. In order to see which of them cumulate and could cause harm in the near future, all these contributing factors have to be classified using the same taxonomy. Moreover, MRO should make safety data collection integrated to be able to collect and store safety data from different internal and external sources in one joint safety database.

Chapter 4 proposed how SDCPS as a whole can be implemented into real-operation environment. There are various factors that could affect how well SDCPS will be welcomed. Firstly, to increase the quantity of reported data, a good safety culture has to be developed within the whole organisation. Chapter 4 therefore discussed ways how to increase the overall safety culture in MRO. But safety culture is not the only factor that makes SDCPS functioning. Safety culture can increase the quantity of data received, but it does not affect the way data will be processed. Data processing is an inherent part of any SDCPS and it is that part of the system that should show the results and make management act on them. Thus the main task of data processing is to transform reported data into a valuable safety information that shows management a full picture of safety performance in their organisation. Several ideas were proposed to achieve high data quality, speaking mostly about well-developed taxonomy, precise data classification and a software for data processing. Because it is not just the quantity of safety data received from employees that matters. Eventually, it is the quality of data processing that decides how much money organisation saves.

In chapter 5, the last chapter of this thesis, a contribution of the proposed SDCPS was evaluated. This proposal is by no means the final look of SDCPS. MROs differ from each other, whether speaking of their size or types of maintenance they perform. The idea was to create a general template to help MROs develop or enhance their own SDCPS, focusing mostly on common taxonomy.

This thesis contributed to the field of aircraft maintenance taxonomy development and provided a template of SDCPS for aircraft maintenance. There are many other initiatives to improve safety in MROs. A big move forward will come when SMS becomes regulatory for approved maintenance organisations. This will not only enhance data reporting, collecting and processing procedures, but it will make MROs environment and operation a lot safer. Few years will pass until SMS regulations will be extended and valid, but MROs can and should work on improving their operational safety without a law. The fact is that a proper safety management is not about compliance, it is mostly about protecting employees, creating trust among customers, and making business grow by ensuring safety is always put first. And these beliefs should not be enforced, they should be natural to any organisation.

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Figures

Tables

Appendix 1 – Maintenance Error Decision Aid (MEDA) Results form

Maintenance Error Decision Aid (MEDA) Results Form

Section I—General Information

Reference #: ___ ___ ___ ___ ___
Airline: ____
Station of Maintenance System Failure:_________________
Aircraft Type: ______________________________________
Engine Type: _______________________________________
Reg. #: ___ ___ ___ ___ ___ ___ ___
Fleet Number: ___ ___ ___ ___ ___ ___
ATA #: ___ ___ ___ ___
Aircraft Zone: ______________________________________
Ref. # of previous related event: ___ ___ ___ ___ ___

Interviewer's Name: __________________________________
Interviewer's Telephone #: __ __ __ __ __ __ __ __ __ __ __
Date of Investigation: __ __ / __ __ / __ __
Date of Event: __ __ / __ __ / __ __
Time of Event: _ _: _ _ am pm
Shift of Failure: ____________________________________
Type of Maintenance (Mx) (circle one):
1. Line -- If Line, what type? ___________________
2. Base --If Base, what type? ___________________
Date Changes Implemented: __ __ / __ __ / __ __

Section II—Event

Please select the event (check all that apply)

1. Operations Process Event
( ) a. Flight Delay _ days_ _ hrs._ _ min.
( ) b. Flight Cancellation
( ) c. Gate Return
( ) d. In-Flight Shut Down
( ) e. Air Turn-Back
( ) f. Diversion
( ) g. Smoke/fumes/odor event
( ) h. Other (explain below)

( ) 2. Aircraft Damage Event
( ) 3. Personal Injury Event
( ) **4. Rework** (e.g., did not pass Ops check/inspection)
( ) **5. Airworthiness Control**
( ) 6. Found during Maintenance
( ) 7. Found during Flight
( ) 8. Other Event (explain below)

Describe the incident/degradation/failure (e.g., could not pressurize) that caused the event.

Section III—Maintenance System Failure

Please select the maintenance system failure(s) that caused the event:

1. Installation Failure
( ) a. Equipment/part not installed
( ) b. Wrong equipment/part installed
( ) c. Wrong orientation
( ) d. Improper location
( ) e. Incomplete installation
( ) f. Extra parts installed
( ) g. Access not closed
( ) h. System/equipment not reactivated/deactivated
( ) i. Damaged on remove/replace
( ) j. Cross connection
( ) k. Mis-rigging (controls, doors, etc.)
( ) l. Consumable not used
( ) m. Wrong consumable used
( ) n. Unserviceable part installed
( ) o. Other (explain below)

2. Servicing Failure
( ) a. Not enough fluid
( ) b. Too much fluid
( ) c. Wrong fluid type
( ) d. Required servicing not performed
( ) e. Access not closed
( ) f. System/equipment not deactivated/reactivated
( ) g. Other (explain below)

3. Repair Failure (e.g., component or structural repair)
( ) a. Incorrect
( ) b. Unapproved
( ) c. Incomplete
( ) d. Other (explain below)

4. Fault Isolation/Test/Inspection failure
( ) a. Did not detect fault
( ) b. Not found by fault isolation
( ) c. Not found by operational/ functional test
( ) d. Not found by task inspection
( ) e. Access not closed
( ) f. System/equipment not deactivated/reactivated
( ) g. Not found by part inspection
( ) h. Not found by visual inspection
( ) i. Technical log oversight
( ) j. Other (explain below)

5. Foreign Object Damage/Debris
( ) a. Tooling/equipment left in aircraft/engine
( ) b. Debris on ramp
( ) c. Debris falling into open systems
( ) d. Other (explain below)

6. Airplane/Equipment Damage
( ) a. Tools/equipment used improperly
( ) b. Defective tools/equipment used
( ) c. Struck by/against
( ) d. Pulled/pushed/drove into
( ) e. Fire/smoke
( ) f. Other (explain below)

7. Personal Injury
( ) a. Slip/trip/fall
( ) b. Caught in/on/between
( ) c. Struck by/against
( ) d. Hazard contacted (e.g., electricity, hot or cold surfaces, and sharp surfaces)
( ) e. Hazardous substance exposure (e.g., toxic or noxious substances)
( ) f. Hazardous thermal environment exposure (heat, cold, or humidity)
( ) g. Other (explain below)

8. Maintenance Control Failure
( ) a. Scheduled task omitted/late/incorrect
( ) b. MEL interpretation/application/removal
( ) c. CDL interpretation/application/removal
( ) d. Incorrectly deferred/controlled defect
( ) e. Airworthiness data interpretation
( ) f. Technical log oversight
( ) g. Airworthiness Directive overrun
( ) h. Modification control
( ) i. Configuration control
( ) j. Records control
( ) k. Component robbery control
( ) l. Mx information system (entry or update)
( ) m. Time expired part on board aircraft
( ) n. Tooling control
( ) o. Mx task not correctly documented
( ) p. Not authorized/qualified/certified to do task
( ) q Other (explain below)

( ) **9. Other** (explain below)

Did the Maintenance System Failure "fly" on the aircraft? ( ) Yes ( ) No

Describe the specific maintenance failure (e.g., auto pressure controller installed in wrong location).

IV. Chronological Summary of the Event, including how some Contributing Factors lead to additional Contributing Factors

V. Summary of Recommendations

Section VI—Contributing Factors Checklist

N/A __

A. Information (e.g., work cards, maintenance manuals, service bulletins, maintenance tips, non-routines, illustrated parts catalogs, etc.)

__ 1. Not understandable
__ 2. Unavailable/inaccessible
__ 3. Incorrect
__ 4. Too much/conflicting information
__ 5. Update process is too long/complicated
__ 6. Incorrectly modified manufacturer's MM/SB
__ 7. Information not used
__ 8. Inadequate
__ 9. Uncontrolled
__ 10. Other (explain below)

Describe specifically how the selected <u>information</u> factor(s) contributed to the system failure.

Recommendations to correct the Contributing Factors listed above.

N/A __

B. Ground Support Equipment/Tools/Safety Equipment

__ 1. Unsafe
__ 2. Unreliable
__ 3. Layout of controls or displays
__ 4. Out of calibration
__ 5. Unavailable
__ 6. Inappropriate for the task
__ 7. Cannot use in intended environment
__ 8. No instructions
__ 9. Too complicated
__ 10. Incorrectly labeled
__ 11. Not used
__ 12. Incorrectly used
__ 13. Inaccessible
__ 14. Past expiration date
__ 15. Other (explain below)

Describe specifically how selected <u>ground support</u> <u>equipment/tools/safety equipment</u> factor(s) contributed to the system failure.

Recommendations to correct the Contributing Factors listed above.

N/A __

C. Aircraft Design/Configuration/Parts/Equipment/Consumables

__ 1. Complex
__ 2. Inaccessible
__ 3. Aircraft configuration variability
__ 4. Parts/equipment unavailable
__ 5. Parts/equipment incorrectly labeled
__ 6. Easy to install incorrectly
__ 7. Not used
__ 8. Not user friendly
__ 9. Consumable unavailable
__ 10. Wrong consumable used
__ 11. Expired consumable used
__ 12. Other (explain below)

Describe specifically how the selected <u>aircraft design/configuration/parts/equipment/consumables</u> factor(s) contributed to system failure.

Recommendations to correct the Contributing Factors listed above.

N/A __

D. Job/Task

__ 1. Repetitive/monotonous
__ 2. Complex/confusing
__ 3. New task or task change
__ 4. Different from other similar tasks
__ 5. Other (explain below)

Describe specifically how the selected job/task factor(s) contributed to the system failure.

Recommendations to correct the Contributing Factors listed above.

N/A __

E. Knowledge/Skills

__ 1. Technical skills
__ 2. Task knowledge
__ 3. Task planning
__ 4. Airline process knowledge
__ 5. Aircraft system knowledge
__ 6. English language proficiency
__ 7. Teamwork skills
__ 8. Computing skills
__ 9. Other (explain below)

Describe specifically how the selected knowledge/skills factor(s) contributed to the system failure.

Recommendations to correct the Contributing Factors listed above.

N/A __

F. Individual Factors

__ 1. Physical health (including hearing and sight)
__ 2. Fatigue
__ 3. Time pressure
__ 4. Peer pressure
__ 5. Complacency
__ 6. Body size/strength
__ 7. Personal event (e.g., family problem, car accident)
__ 8. Task distractions/interruptions
__ 9. Memory lapse (forgot)
__ 10. Visual perception
__ 11. Assertiveness
__ 12. Stress
__ 13. Situation awareness
__ 14. Workload/task saturation
__ 15. Other (explain below)

Describe specifically how the selected individual factors contributed to the system failure.

Recommendations to correct the Contributing Factors listed above.

N/A __

G. Environment/Facilities

__ 1. High noise levels
__ 2. Hot
__ 3. Cold
__ 4. Humidity
__ 5. Rain
__ 6. Snow
__ 7. Lighting
__ 8. Wind
__ 9. Vibrations
__ 10. Cleanliness
__ 11. Hazardous/toxic substance
__ 12. Power sources
__ 13. Inadequate ventilation
__ 14. Markings
__ 15. Labels/placards/signage
__ 16. Confined space
__ 17. Other (explain below)

Describe specifically how the selected <u>environment/facilities</u> factor(s) contributed to the system failure.

Recommendations to correct the Contributing Factors listed above.

N/A __

H. Organizational Factors

__ 1. Quality of support from technical organizations (e.g., engineering, planning, technical pubs)
__ 2. Company policies
__ 3. Not enough staff
__ 4. Corporate change/restructuring
__ 5. Union action
__ 6. Work process/procedure
__ 7. Work process/procedure not followed
__ 8. Work process/procedure not documented
__ 9. Work group normal practice (norm)
__ 10. Team building
__ 11. Other (explain below)

Describe specifically how the selected <u>organizational</u> factor(s) contributed to the system failure.

Recommendations to correct the Contributing Factors listed above.

N/A __

I. Leadership/Supervision

__ 1. Planning/organization of tasks
__ 2. Prioritization of work
__ 3. Delegation/assignment of task
__ 4. Unrealistic attitude/expectations
__ 5. Does not assure that approved process/procedure is followed
__ 6. Amount of supervision
__ 7. Other (explain below)

Describe specifically how the selected <u>leadership/supervision</u> factor(s) contributed to the system failure.

Recommendations to correct the Contributing Factors listed above.

N/A __

J. Communication

__ 1. Between departments
__ 2. Between mechanics
__ 3. Between shifts
__ 4. Between maintenance crew and lead
__ 5. Between lead and management
__ 6. Between flight crew and maintenance
__ 7. Other (explain below)

Describe specifically how the selected <u>communication</u> factor(s) contributed to the system failure.

Recommendations to correct the Contributing Factors listed above.