DO QUALITATIVE AND PROACTIVE SAFETY INDICATORS BETTER CONTROL RISK THAN THE USUAL QUANTITATIVE AND REACTIVE ONES ?

Thomas Novotny

LUND UNIVERSITY
SWEDEN

Date of submission: 2007-10-30

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Under supervision of Sidney Dekker

ABSTRACT

From the literature on safety indicators in high risk industries, it appears that whole business models rely on the use of numbers, these fitting well our Newtonian Cartesian way of thinking. Going a bit deeper the observation can be made that numbers are being used because it is sort of agreed that they offer a good insight into performance measurement, however the present thesis will demonstrate that this taken for granted consideration is questionable. A recent survey of several ATC safety managers within central Europe air navigation providers revealed dissatisfaction with current methods for counting and categorising incidents (mainly AIRPROX and serious incidents data). These numbers are used reactively and do not allow managers foresight into how a company works in the safety performance domain. This thesis begins with a literature review in order to find out first a definition for indicators in ATM. Then several arguments will be presented to show the limited value these offer an ANSP in terms of controlling safety. Some proposals will be made for improved indicators. To achieve this goal, it will be necessary to further explore the latest literature into the use of safety indicators and safety management systems.

GLOSSARY

AAIB	Aircraft Accident Investigation Bureau
ANS	Air Navigation Services
ANSP	Air Navigation Services Provider (e.g. skyguide)
AIRPROX	AIRcraft PROXimity
AIS	Aeronautical Information Services
ATC	Air Traffic Control
ATCO	Air Traffic Control Officer (controller)
ATFCM	Air Traffic Flow and Capacity Management
ATM	Air Traffic Management
ATS	Air Traffic Services
BSC	Balanced Score Card
CNS	Communication, Navigation, Surveillance
ECAC	European Civil Aviation Community
ESARR	EUROCONTROL Safety Regulatory Requirement
ETTO	Efficiency Thoroughness Trade-Off (Hollnagel, 2004)
EUROCONTROL	European Organisation for the Safety of Air Navigation.
FAB	Functional Airspace Block
FBC	Faster, Better, Cheaper (NASA's philosophy)
FHNW	Fach Hochschule Nord-West (Swiss high-school)
GASP	Global Aviation Safety Plan
HEIDI	Harmonisation of European Incident Data Initiative
HERA	Human Error Reduction in ATM

HRO	High Reliability Organizations
ICAO	International Civil Aviation Organization
IFATCA	International Federation of ATC Associations
KPI	Key Performance Indicator
NSA	National Surveillance Authority
MET	METeorological services
OIR	Operational Internal Report (compulsory at skyguide)
SAFREP	SAFety REPorting task force at Eurocontrol
SAR	Search And Rescue
SARD	Safety Assessment and Reporting Document (initial safety analysis report at skyguide when changes to system are required)
SES	Single European Sky
SIR	Safety Improvement Report (voluntary at skyguide)
Skyguide	Swiss Air Navigation Services, ltd
SMART	Specific, Measurable, Attainable, Realistic and Timely
SMS	Safety Management System
SMIS	Safety Management Information System (project launched in Switzerland by the FHNW high school to identify indicators across industries)
STCA	Short Term Conflict Alert

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1. INTRODUCTION

Air Traffic Control (ATC) is very safe. In fact, it is sometimes described as "ultra-safe" (Brooker, 2006, Perrow, 1984). Air transportation has reached the mythical barrier of one accident per 10 million (10^{-7}) flights. ATC has a direct contribution to less than 10% of these, which makes ATC even safer than the already very safe air transportation (Eurocontrol, 2005).

Ironically, this high level of safety (low "baseline accident rate") limits the use of statistical data for reasons of safety monitoring. (Amalberti in Hollnagel, Woods & Leveson, 2006; Brooker, 2006&2005, ICAO, 2005; Hollnagel, 2004; Amalberti 2001; Reason, 1997). The tendency among ANSPs is therefore to focus on incidents as an indirect indicator of safety performance (Aircraft Accident Investigation Bureau, 2005; Federal Office for Civil Aviation, 2005; Eurocontrol 2004, 2001; Direction Navigation Aérienne, 2001). It is a strong popular belief that incidents will offer an insight into the next accident. However the mechanisms that relate an incident to an accident are not easily understandable, if there is any relation at all in the first place (Brooker, 2006; Hollnagel, 2004). More is explained about this theme in chapter 3.2.3.Our ability to make predictions of future system risk using incident data is limited, at best. Dekker (2004) also argues that in the end everyone agrees on the fact that counting errors is a good way forward on safety because almost everyone seems to agree that it is a good way forward. Dekker further argues that it is already difficult to decide on what is an error or an incident in the first place.

Another issue is that "safety" as such is not an easy concept to be measured directly, or even indirectly. Many experts agree that many incidents reported do rather show a good reporting culture than the exposure at risk of the system analysed (Brooker 2007, Baumgartner, 2006; Dekker, 2004; Hollnagel 2004, Ruitenberg, 1997; Reason 1997). In this sense the assumption that the reduction of incidents is synonymous with safety (and vice-versa) is hardly defendable.

Moreover it is infinitely disputable if incidents are markers of resilience or rather of brittleness. Woods and Cook (in Hollnagel, Woods & Leveson, 2006) explain the basic ambiguity about incidents: are the cases that fall short of breakdown success stories (as the system coped with them) or anticipation of future failure stories (which is a generally agreed concept)?

In summary, the chief disadvantage of using incident data as safety indicators is that we are unsure of whether in fact an incident should be viewed as a success story or a failure story. But read more about this in chapter 3.2.5.

1.1 The context: Aviation and air traffic control

ATC systems are responsible for managing a complex mixture of commercial, general, corporate, and military aviation. Within this, ATC systems organize and decompose density into smaller units that all have a designated piece of airspace managed by in general 2 ATCOs. The task of ATC is to ensure a safe, efficient and orderly flow of traffic (ICAO definition). Safety is critical to both airlines and to ATC. Over the years, the airline industry has made impressive progress on reducing fatal accidents and incidents. In 1929, which remains the worst year on record in terms of safety, there was an accident rate of about one per <u>million</u> miles flown, compared to the 1997 rate of one accident per two <u>billion</u> miles. Many different initiatives have been introduced to improve safety. Many safety experts (Amalberti in Hollnagel, Woods & Leveson, 2006; Hollnagel, 2004; Amalberti, 2001; Perrow, 1984) recognize however that the global rate of accidents is stabilizing and, as a consequence, leverage points are harder to identify in order to break the asymptote. Today significant safety issues are being identified in various ways and actions are being taken (both proactively and reactively) to address problems and reduce their impact. Safety Management Systems (SMS) are part of nearly all ANSPs within Europe. EUROCONTROL by the way regulates the building of a Safety Management System (SMS), which is part of the ESARR3 requirement. In Switzerland the law enforces automatically any ICAO or EUROCONTROL rule and therefore makes them legally binding with direct applicability (no vote needed). Respecting the ESARRs is needed to obtain the Single European Sky (SES) certificate (a common requirement by European Commission) and is essential in the evolution to a European system based on Functional Airspace Blocks (FABs).

Aviation is nowadays a deeply regulated industry and the future will probably lead ATC and the whole aviation system into more complexity and coupling. (Perrow, 1984).

Figure 1; highly complex operations, 24 HOURS of traffic at skyguide

1.2 Method, scope and aim of the thesis

<u>Method</u>

The effort began with a literature review into safety indicators. As expected, it was difficult to find any papers on safety indicators based on a somehow wider context or source than data based on incident solely. The second SAFREP report to the Eurocontrol Provisional Council (Eurocontrol, 2007) called "Roadmap for the development of safety key performance indicators in ATM" is a document that confirms that research for better indicators is needed. This document acknowledges that the present indicators based on incident monitoring lack more high level indicators. The paper proposes a first approach towards leading (proactive) indicators instead of lagging (reactive) indicators solely (more on that in chapter 2.3.3), which is totally in line with the way proposed in this thesis. However the roadmap still focuses mainly on reactive elements and it is due for 2009, therefore this thesis maintains its full raison d'être.

Scope

A shown below, ANS consists of a number of elements. Of these, a decision was made to address only ANS and CNS (i.e., the technical equipment used by controllers). Although AIS and MET elements might also be safety relevant, it was not considered feasible to address these elements. They are beyond the scope of this thesis.

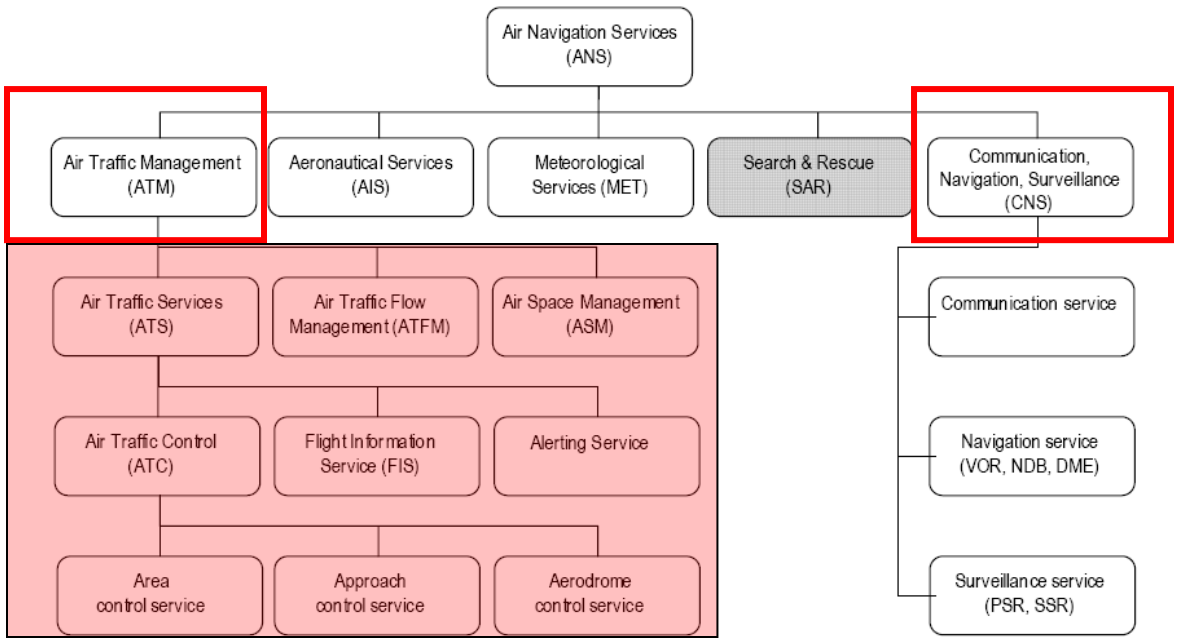

Figure 2: the elements needed to provide ANS (according to ICAO doc 9082/7)

ATM and CNS are purely internal to most ANSPs. An ANSP does not exist alone in a vacuum but is surrounded, obviously, by an environment and different stakeholders. According to the figure beside the sharp end is where the people work at the front, or production, meaning for an ANSP mainly

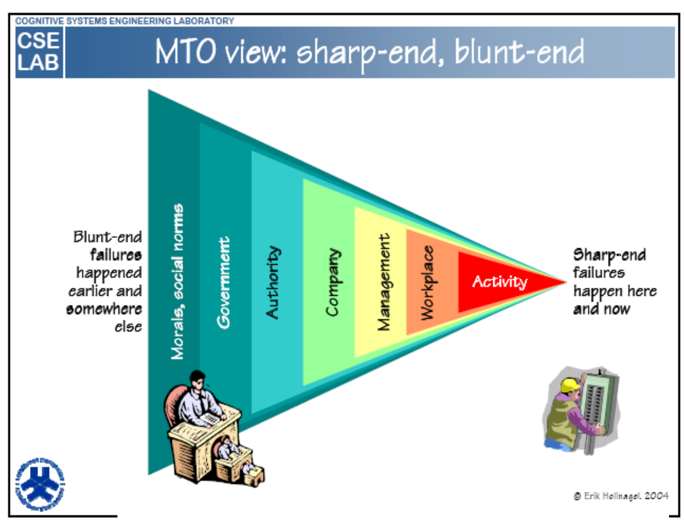

Figure 3: sharp-end vs. blunt end (Hollnagel, 2004)

controllers, but also other supporting staff like supervisors, maintenance personnel and Air Traffic Flow and Capacity Management (ATFCM) might be considered at the sharp end as well, or very close to it. The more we move from people at the front (through hierarchies commonly), the more we head towards the blunt end.

In this thesis the limit is fixed at the regulator's level, although of course international regulations extend far beyond. However the international requirements (ICAO, EUROCONTROL, EC directives, etc.) are almost invariably in the whole ATC industry enforced through the national regulatory bodies.

In summary, this thesis stated out from a literature review into the use of safety indicators in ATM and other domains. This lit review relied on:

- Books
- Articles
- Presentations
- Wikipédia
- ICAO
- IFATCA
- European ANSPs papers
- AAIB annual safety reports
- R&D seminars' material
- Magazines
- Journals
- Reports

The material is coming mainly from Aviation and ATC, although for example the car and maintenance industry have provided significant inputs also. Most of the safety indicators apply to various risky industries. Fricke-Ernst (2007) for example demonstrates the relevance, applicability and thus the transferability of indicators from the nuclear industry to various high potential of danger industries such as ATM. This makes the recent SMIS (safety management information system) project launched by FHNW (Swiss high school) in collaboration with the nuclear power plant Leibstadt, Swiss international airlines and skyguide. This project will try to establish a safety management indicators system. The results will however only be available well beyond this thesis's deadline.

2. What is understood as a "safety indicator"

2.1 A little history about performance indicators in general

Traditionally, measures of performance have been used by management to check business' capabilities. These measures are used to assess the performance, and secondly to identify if performance has met objectives. That is, performance indicators are metrics used to quantify objectives to reflect strategic performance of an organisation.

Metrics in their turn are understood as a system of parameters or ways of quantitative and periodic assessments of a process that is to be measured, along with the procedures to carry out such measurement.

Obviously the indicators differ depending on the nature of the organisation and its strategy. The overarching principle of an organisation is first to stay in business and this concern has logically put the focus on productivity first. However it is not recent knowledge that other aspects like quality for example, rather than the productivity itself, can have a much better leverage on an organisation's efficiency (Fatzer & Stora, 1990).

Logically indicators are used to assess the present state of the business and to prescribe a course of action. Therefore the monitoring of these indicators is typically tied to an organisation's strategy (as exemplified through techniques such as the Balanced Scorecard (BSC; Kaplan & Norton, 1992)).

The BSC is a concept for measuring a company's activities in terms of its vision and strategies, and in turn allows managers to look beyond merely financial issues, for instance to human issues that also drive the business' outcomes. An organisation can therefore focus on the future and act in its long-term best interest. Here the transition is made towards the safety indicators that are of concern is this thesis.

It has to be the view of any potentially dangerous industry that there will be no business without safety and that there will be not safety without business. This simply means that a sound business cannot exist unless the organisation's operations are safe. A lack of safety will be detrimental to business because it jeopardises continued operations, and hence long term sustainability.

ATM being of no exception to other industries, its performance indicators in early days rather focussed on capacity, cost-efficiency, environment, flexibility, inter-operability, predictability before going into safety and security (Baumgartner,2006; ICAO, 2005 relating to Doc 9854; Ruitenberg, 1997). Nowadays the concern has changed and more people are interested in "safety indicators".

2.2 Choosing the right expression

The review made about the "indicators" topic showed many different expressions used all over the world (Brooker, 2007, 2006, Eurocontrol, 2007, 2006, McNeeney, n.d.):

- (safety) indicators
- (safety) metrics
- (safety) performance indicators
- (safety) key performance indicators

For the sake of being concise without losing any vital information the expression "safety indicators" (which is also the one that appears most often in ATM), is the one that will be used throughout this thesis work. ICAO (2005) defines a safety indicator as:

a measure (or metric) used to express the level of safety performance required or achieved in a system.

2.3 The way to build safety indicators

2.3.1 Short introduction

Many different theories exist in the way to proceed to identify indicators. What follows is the choice amongst the most valuable theories, which additionally show a good compatibility for the ATM domain.

2.3.2 Safety targets / goals

First of all a safety indicator has to rely on a defined safety process, which in turn must have clear goals/performance requirements.

ICAO (2005) defines Safety Performance Targets as:

The required level of safety performance for a system. A safety performance target comprises one or more safety performance indicators, together with desired outcomes expressed in terms of those indicators.

For example ICAO (2005) has set a global safety performance target in the specification of the objectives of the Global Aviation Safety Plan (GASP), as follows:

a) to reduce the number of accidents and fatalities, irrespective of the volume of air traffic; and
b) to achieve a significant decrease in worldwide accident rates, placing the emphasis on regions where these remain high.

The ECAC Strategy for ATM 2000+ sets a high-level safety objective:

" …. To improve safety levels by ensuring that the number of ATM induced accidents and serious, or risk bearing, incidents do not increase and, where possible, decrease"

Basically as the system is already very safe in the first place, the average targets might be sumarised like this: do not get worse, and where possible improve.

2.3.3 The features of a safety indicator

Once the goal is set the indicators need to identified, which will help in assessing whether the goal has been reached or not. Interestingly enough ICAO (2005) says:

" in order to set a safety performance target, first of all it is necessary to decide on an appropriate safety performance indicator, and then to decide on what represents an acceptable outcome"

It seems therefore that it is possible both to fix targets first and then identify the indicators or vice-versa. Eurocontrol (2007) proposes the setting up of the safety targets to be done only in conjunction with a sound and reliable safety indicator framework. For practicality reasons it is considered in this thesis that fixing the targets first will be of little help (because too high level) and that the determination of indicators has to be done first

2.3.3 a) SMART

Going across several industries it is understood that an agreement exists that the indicators need to be **SMART** (Eurocontrol 2007, 2006, McNeeney, n.d):

Specific	clear and focused
Measurable	can be quantified and compared to other data
Achievable/Attainable /Ambitious/Actionable	are in organization's control to effect change
Realistic	fits in organisation's constraints and is cost effective
Timely	doable within the time frame

In addition they have to be:

-simple

-reproducible

-reliable

-pertinent

(Brooker, 2006; Brachet & Thibault, 2005, Fatzer & Stora, 1990, McNeeney, n.d)

2.3.3 b) Absolute vs. relative

The safety indicators are essentially of two types (Brooker, 2006; Brachet & Thibault, 2005):

- **Absolute** (are the targets met this year?) or ;
- **Relative** or directional (is safety improving or not, e.g. year by year)

2.3.3 c) Lagging vs. leading

Two additional essential features also distinguish safety indicators (Eurocontrol, 2007; skyguide, 2007; Wreathall in Hollnagel, Wood & Leveson, 2006)

- **Lagging indicators (reactive)**

  Lagging indicators are used in conjunction with past events (e.g. safety occurrences, such as accidents, incidents, system outages, etc.). They also help determine whether safety improvement activities have been effective in mitigating identified risk. As such, they are an indicator of the outcome of the service delivery.

- **Leading indicators (proactive)**

  Leading indicators are identified principally through the comprehensive analysis of the organisation (audits, safety surveys, occurrence management, reporting systems). They are designed to help identify whether the safety processes are effective in lowering the risk.

The leading indicators are considered the "drivers" of lagging indicators. There is an assumed relationship between the two that suggests that improved performance in a leading indicator will drive better performance in the lagging indicator.

2.4 The indicators in a wider context

The Deming cycle (from W. Edwards Deming, teacher) helps to put the indicators in a wider context. The indicators, in order to serve a company's management, are often aggregated in a "cockpit", which displays several indicators in a simple and understandable manner. The cockpit usually presents indicators in a table, histogram or pie chart and enables the monitoring of the chosen indicators. The indicators and the cockpit also feed the BSC.

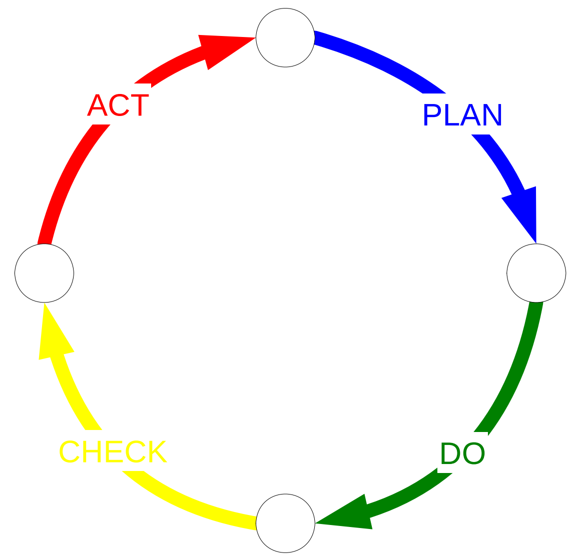

Figure 4: the Deming cycle (Eurocontrol, 2005)

The indicators' process maps well the framework proposed by the classical Deming cycle:

The cycle is to be interpreted as follows:

- **Plan** – Determine goals and methods to reach these;
- **Do** – Implement the plan and measure its performance;
- **Check** – Analyze the measurements and report to decision-makers; and
- **Act** – Decide on changes needed to improve

As described in Eurocontrol (2005) the 2 last stages of the process are identified as being traditionally the weakest. It is eventually <u>what</u> is decided upon the new existing knowledge available that is interesting in order to achieve progress after all.

2.5 Typical aviation and ATM safety indicators

Safety indicators are generally expressed in terms of the frequency of occurrence of some event causing harm. Typical indicators include the following: (ICAO, 2005; AAIB, 2005; Eurocontrol 2004, 2001):

- fatal aircraft accidents per flight hour;
- fatal aircraft accidents per movement;
- fatal aircraft accidents per year;
- serious incidents per flight hour;
- fatalities due to aircraft accidents per year

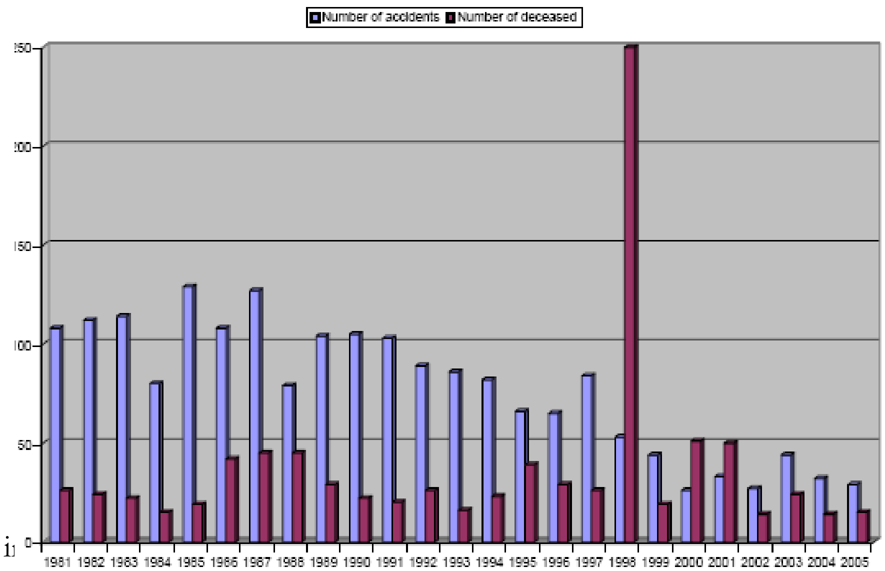

Figure 5: typical aviation safety indicators
(Swiss AAIB, 2005)
(graphical overview of accidents and serious incidents involving Swiss-registered aircraft, inventory of the aircraft and list of deceased)

ATM typically relies on the following i

- Number of AIRPROX
- Number of separation minima infringements
- Number of safety alerts (e.g. STCA) etc
- Number of e.g. airspace infringements, level-busts, runway incursions
- The ratio when ATC was involved

Figure 6: Number of AIRPROX encounters in Switzerland (FOCA, 2005)

Jahr	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Total Airprox	**11**	**20**	**14**	**22**	**20**	**29**	**46**	**47**	**49**	**65** (+18)*	**77**	**75**
Risiko A	6	2	2	2	4	12	22	13	15	25 (+3)*	16	9 **
Risiko B	4	12	6	9	8	6	14	10	6	10 (+6)*	12	22
Risiko C	-	4	6	5	6	11	7	24	28	30 (+9)*	45	39
Risiko D	1	2	0	6	2	0	2	0	0	0	4	5
Total Instrumentenflüge	976'680	1'024'919	1'069'424	1'119'826	1'224'425	1'266'204	1'352'319	1'324'578	1'287'862	1'287'665	1'328'054	1'370'437
Anzahl Airprox pro 100'000 Flüge	1,1	2,0	1,3	2,0	1,6	2,3	3,3	3,5	3,9	5,0 (6,4)*	5,8	5,5

3. Challenging the actual use of indicators

3.1 Introduction

As seen before data based on incidents form a quantitative level for managerial decisions, forgetting for example about the context that nurtured the evolvement of the error. Error classification disembodies data (Dekker, 2004).

In chapter 2.5 several safety indicators are exemplified through two charts. They do represent well what is used across the majority (and perhaps all) of ATM providers around the world. The goal in this chapter will be to clearly demonstrate why the use of such indicators is limited and why we should search for additional new ways to find a better source of knowledge.

3.2 Limitations of actual indicators

3.2.1 Incident data are reactive, negative and context less

The first limitation that appears clearly is the fact that actual safety indicators are based on past data and are therefore very reactive. Waiting for something unwanted to happen in order to make progress on safety does not sound good. Moreover there might be a two-year gap between investigation (of accidents and other serious events) and any resulting indicators. This limits their use in quickly detecting trends (de Jong et al., n.d).

Rochlin (1999) explains that safety is much more than the management of error; he argues that safety is not something that is out there ready to be measured, but is a constructed human concept that is more easily judged than defined. Additionally the negative interpretation (no accident, no error) is not sufficient to build an appropriate safety picture. Safety stands in the same relationship to error and risk, as health does to illness and the potential for being unwell (Rochlin, 1999). ICAO has a brilliant statement to illustrate this point:

"Assessing safety health based solely on statistical safety performance indicators may not provide a valid predictor of safety performance. Reviewing the past does little to assist organizations in their quest to be proactive; putting in place those systems most likely to protect against the unknown. (ICAO Doc 9859 Ch 10,Section 10.2.7)

As such the view of safety as being simply the opposite of risk is hardly defendable. Rochlin (1999) argues that safety is in some sense a story that a group or organization tells about itself and its relation to its task environment. The origins of both do not lie solely with indicators or performance; automation and other technical strategies aimed at reducing the rate of operational error are reductionist and probably overly objective, not paying attention to representations, social constructs and other more subjective collective behaviour.

The indicators based on incidents do also focus on the sharp end essentially and as such offer little help in the way to addressing systemic vulnerabilities. In other words, to collect data from the sharp end prevents the search for second stories, which are the ones which can help to identify trouble deeper in the system, and therefore a more complete and systemic picture.

Brooker (2007, 2006), who probably went as far as possible in the reactive indicators' issue (using "scientific methods") had to invariably conclude in his own words:

" indicators are very useful things to have, but they are not solutions to safety problems"

and ends up with the following advice:

"identify good, simple indicators, based on significant kinds of events or states of system control, and try to ensure that reporting rates are high'. This conclusion leaves a strong feeling of unachieved search in this topic. No clear demonstration of the usefulness of incident-based indicators has been presented throughout the documents in my view. Saying that indicators are useful is almost a folk model in some sense (more in chapter 3.2.4).

3.2.2 Error counting might be counterproductive

In our effort to remove errors from the system we might overlook some important consequences to the overall safety of the system. The easiest to understand here is that technical solutions for errors will introduce new errors, like automation or engineered safety devices (Dekker, 2002; Perrow, 1984).

The negative connotation of error counting leads to negative formulated measures; the few incidents are never compared to the huge amount of operational hours that were conducted safely. The safe operations remain unanalyzed by the way. Snook (2000) in his explanation of the shoot down of friendly Blackhawk helicopters in northern Iraq shows how the accident might appear different if compared to the previous 50,000 hours of safe operation.

It is not proven if the counting of negatives can say anything about safety, what does the quantity measured have to do with the quality managed? Reason (1997) argues that adverse events provide an unreliable indication of a system's intrinsic safety. The same Reason (1997,p.114) suggests that:

"rather than struggling vainly to exercise direct control over incidents and accidents, managers should regularly measure and improve those processes-design,…,goal conflicts,…"

Past success was never and will never be a guarantee for future safety. Similarly, absence or low levels of incidents should not be taken as an absence of hazards or threats.

3.2.3 Are incidents really precursors of an accident or AIRPROX?

Another model that is often seen is the accident pyramid (e.g. Eurocontrol, 2007).

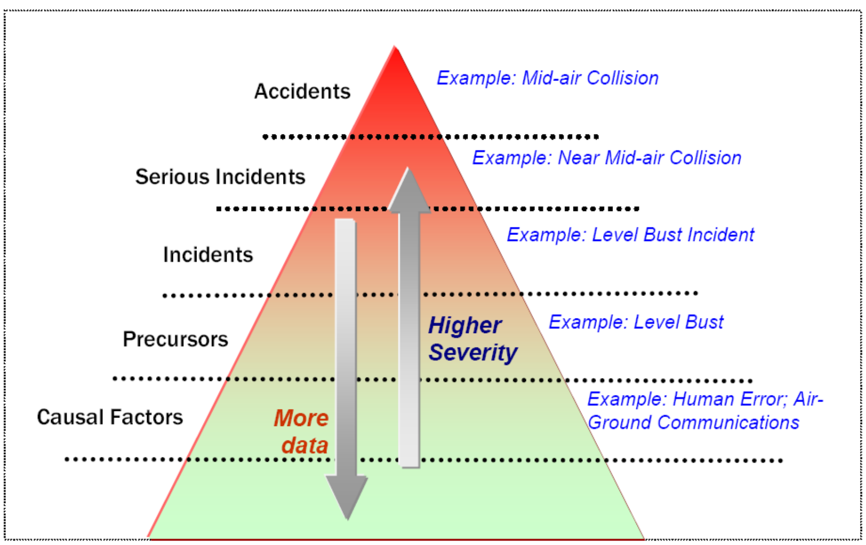

Figure 7: the accident pyramid according to Eurocontrol (2007)

The accident pyramid, even if used often, is yet another agreed upon model that is used everywhere but that leads to profound misunderstandings as it is suggested that incidents of lesser severity are precursors to more severe ones. Connections between the layers are strongly suggested in this figure but not every accident follows many serious or less serious incidents. The categories displayed in the pyramid are mutually exclusive, therefore making associations between them is false. Focusing on eliminating the bases of the pyramid will not remove the top! The definition of the categories displayed is very vague in the first place. Accident or AIRPROX have seemingly clear definitions, but it does not make them interpretation proof at all. A Qantas B747 made a runway excursion implying lots of damage. It was the company's decision to repair the craft at a greater cost than a new one in order not to make it appear as a hull loss in international statistics.

AIRPROX is yet another interesting term. In Europe there are not two countries which apply the term AIRPROX in the same way (although regulated by ICAO!). It goes from the simple and total dismissal of it to the very free interpretation that it applies to pilots and not to controllers, to a disproportionate application of the term AIRPROX to all separation minima infringements (as was still the case in Switzerland until fairly recently). There is no proper foundation whatsoever for this concept. AIRPROX is often used by ATM as a principal indicator, and some articles were published in the press benchmarking Switzerland with France and Germany on the basis of AIRPROX. Obviously Switzerland applying a much more restrictive rule appeared very unsafe in comparison to others which rely only on pilot reports to "upgrade" an event to an AIRPROX. In Switzerland for years the percentage of AIRPROX from the pilots' side has never reached 10% compared to the more than 90% from the ATM side. If we here add the quote from Reason (1997) or Hollnagel (2006) that near misses are only rarely reported and unsafe acts are as a rule not reported at all, we perceive that we have an issue here, to say the least.

On top of that a Fight Safety Foundation article (2005) explains how five "commercialized" ANSPs have generally reduced their AIRPROX numbers since privatisation. The private companies showed a better safety record than the "previous" ones, whereas having no financial support any longer.

When knowing how interpretable the data are and how it is possible to downgrade an incident, the conclusions of this paper are remarkable, and suggest that some companies have in fact made NASA's Faster Better Cheaper (FBC) model come true.

3.2.4 Culture of objectivity and illusion of control

Feldman (2004), in his paper about the culture of objectivity derived from his studies about NASA, demonstrates how organisations use scientific methods to accomplish their goals. What is more objective than counting incidents? But counts acknowledge an apparent simplicity and fail to respond to the actual complexity of a system like ATC for example. Objectivity is often a constructed human artifact to balance all kinds of pressure, for example the anxiety that uncertainty creates. Great amounts of data legitimize knowledge, but uncertainty cannot be measured, human factors cannot be explained easily by scientific methods either. Managing safety by numbers can create a false impression of rationality and managerial control (Dekker, 2004). People prefer to stick to something fallacious than evolve in a world of uncertainty. This quote is appropriate to close this point:

> *"There is a tendency, then, to use only*
> *what can be measured as a criterion.*
> *That is, the spirit of the man,*
> *the way he feels towards things,*
> *may be difficult to measure"*

Richard Feynman (**The Meaning of it All**)

3.2.5 Incidents: markers of resilience or brittleness?

The incidents-based indicators invariably need to have quantitative measures. Every document found (see chapter 2) proposes a measurement of some sort. Then the quantity found always means, if big, that safety is in danger:

More incidents = less safety

Fewer incidents = more safety

In 3.2.3 the limitations of such concepts is already explained. However in addition to that, it has to be said that reporting is the absolute main source of all incidents known (at least in ATM). Reporting is far from reliable and depends on many aspects, like the safety culture and the just culture for example (Reason, 1997). Then it is quite easy to understand that organisations with a poor safety culture, where operators fear retribution for example, will lack reporting, then:

Poor safety culture => few reports => good safety??

This demonstrates well enough that the foundation for indicators is very fragile in the first place. At skyguide many efforts have been made recently towards establishing a just culture and the reporting has almost doubled! It can be argued confidently that safety has not decreased twofold.

Incidents can show how the system in question can stretch given disruptions and show its adaptive capacity. Incidents occurring often might well show that that the system perfectly copes with these imperfections, and even could help to keep the operators in the loop. The incidents happening very rarely might well be the dangerous ones. But indicators trigger actions on the basis of their quantity. If we have 100 similar incidents then we will logically tend to find a remedy to these instead of the one which happened once only. The rationality and control that are agreed upon (and inherited trough Newton and Descartes) seem to be close to an illusion, and they offer neither real insight nor productive route for progress on safety (Dekker, 2004).

3.2.6 Data overload

Because the ATM system is ultra-safe and very few accidents are induced by ATC, the conventional approach is to look for near-collisions in order to reach some statistical significance—that is, to "telescope" backward from serious incidents, then to incidents, to quasi-incidents, and eventually to the precursors of quasi-incidents. The result of this approach is bloated databases from which one can extract any supportive and confirming elements (e.g. decision making or poor communication), but this might be more a drift than a step in the right direction (Amalberti, 2001). More information does not necessarily mean better prediction. This is the paradox: the high severity events are to infrequent, and the more reliable indicators are so numerous that the computational capacity required to make something out of them is probably out of reach.

3.2.7 Incidents, errors and indicators, are they really factual data?

Following Kant's ideas we know that the act of observing or perceiving objects is not passive, but that the observer is active in the way he perceives things. This relativism creates the epistemological uncertainty we see in error counting methods (Dekker, 2004). To count incidents we need to agree first that they exist. In the words of Einstein, it is the theory that determines what can be seen, facts are not available out there, independent of theory (Dekker, 2004). In some sense measuring errors becomes the proof of their existence. In the end, everyone agrees that counting errors is a good way forward on safety because almost everyone seems to agree on it (Dekker, 2004). Brooker's conclusions to his articles (2007, 2006) very much sound like that. Scientists and other communities are reluctant to renounce the paradigm that has led them into a crisis, until there is a viable alternative ready to take place instead. There is none yet.

3.2.8 Use of incidents in ultra-safe systems and emergence vs. deconstruction

Dekker (2004) explains that to understand failures in ultra-safe systems (read beyond 10^{-7}) we need to stop to look for failures as it is normal work (Perrow, 1984) which results in disasters. Failure and success are both sides of the same coin. Safety has to be seen as an emergent property. The whole is greater than the sum of its parts (Pariès in Hollnagel, Woods & Leveson, 2006), in other terms safety has properties that cannot be deduced from its components' properties. Therefore the deconstructionist approach suggested by the various categorisations of incidents appears far too linear and static. As Weick wrote: "Safety is a dynamic non-event". Dekker (2004) even suggests that the learning from incidents in ultra-safe systems may well be impossible!

4. New indicators

4.1 New safety knowledge and theories

Criticism of actual indicators has been extensive but it is not the purpose here to dismiss them completely. There is modern safety knowledge available which definitely offers new insights in order to make progress on safety indicators, and safety in general. The point is that the actual indicators strongly need to be seconded by another set of indicators. Hollnagel, Woods & Leveson's (2006) book on resilience engineering is presenting a new safety paradigm, however many of its co-authors still confirm that incidents are useful learning tools. It is the goal of this chapter to offer an insight in safety precepts which are proposed to be used as background knowledge in order to find new safety indicators. It is not the aim of this thesis to present new indicators in nice graphs. Instead, the real substance of the thesis will be, with the help of decades of progress in safety management, to ask the right questions to identify the appropriate indicators. It would be very much presumptuous to argue that new safety ideas are presented here, rather it is said that all that the modern safety knowledge can offer was not necessarily transposed yet into the way safety organisations use safety indicators. The following sub-chapters describe in a melting pot of modern safety ideas the ones that will bring the indictors' issue a step further. The questions that will finally help to extract the indicators are presented in a table in chapter 5.

4.2 Learning from incidents

In the reactive part of safety we should at least not embrace the prevailing fascination in cataloguing frailties, but should aim to abstract general patterns from specific cases instead. In other terms we should try to identify concurrences in the incidents instead of separate causes or categories. Moreover we should avoid the "distancing through differencing" problem which does not allow us to learn from the "external to the service" incidents.

Let's also forget about the quick fix illusion. Whatever capacity the system had to improve easily has been used already, there are no more low hanging fruits on the tree. The measures applying solely to the sharp end also show limited effect. Modern accidents show that they are no longer preceded by failures but by normal work, as such the view that humans contribute to safety needs to be preferred to the one where humans are seen as the weak part of the system, undermining safety.

"Responsibility for errors lies with the organization as a whole, rather than with a task group or an individual (Weick 1987, Weick and Roberts 1993)"

To speak more concretely, instead of counting the number of separation minima infringements (e.g.) we should rather have a look on the proportion of incidents having a similar pattern, like implying that two aircraft were on separate control frequencies as the procedure required, for example. But more ideas are to be found on the table in chapter 5.

4.3 From reactive to proactive safety

Scholars advocate that a shift from reactive to proactive safety needs to be made. Safety indicators need to follow the same trend. In the same way the Swiss cheese accident model (or rather metaphor) is not enough to give a good account to proactive safety, as the different barriers and layers that in retrospective are discovered has having holes. In this respect the lagging indicators that are well developed need to be seconded by leading indicators. In ATC the world is changing fast, as such waiting several months or even years to extract trends from incidents is weak. Lessons from a given incident might eventually apply to a quite different system than the one in which the incident actually took place. Therefore the assessment of the changes proposed to the system logically presents an advantage due to its proactive characteristic. Then the progressive uncoupling from the system as imagined to the system as exploited needs to be monitored, as every system is "living" and adapts.

4.4 Safety is dynamic and emergent

Traditional thinking based on the complex linear accident model (Swiss cheese) fails to address the way different barriers interact, therefore displaying an apparent simplicity and overly static view. New knowledge makes the point that safety is a dynamic non-event and is an emergent phenomenon. Indicators need to be more flexible than incident counts to address that. Safety is something an organisation does, rather than has (Hollnagel & Woods, 2006).

4.5 Practical drift/normalization of deviance/ drift into failure

Another phenomenon that leads to accidents is the slow incremental deviance or drift from norms, rules, regulations etc. This is called normalization of deviance by Vaughan (1996), or practical drift by Snook (2000), and drift into failure by Dekker (2006, 2005). Dekker even says (2006) that this is the most important threat remaining in very safe systems. Obviously safety indicators need to address this topic in order to make progress on safety. Often it seems that middle management is confronted with decisions implying ETTOs (efficiency-thoroughness trade-offs, explained in Hollnagel, 2004). In this view progress needs to be made in order to give to the middle managers the requisite authority to take the sacrificing decision, implying that a decision "for safety" will usually undermine capacity.

4.6 3 Cs: commitment, competence, cognisance

Reason (1997) presents his three-pillar concept which are concepts that need to be evaluated regularly in a risky industry: The commitment (motivation and resources), the competence, and cognisance are very important to be assessed regularly (not only at sharp end) in order to identify if these components are being eroded under the different other priorities pushing the organisation. Many questions proposed in the chapter 5 table address these issues.

4.7 4 Is: independent, involved, informed, informative

Woods (in Hollnagel, Woods & Leveson, 2006) proposes the 4 I's speaking about a safety organisation: independent, involved, informed and informative. These terms are self-explanatory and obviously need to be checked against at all levels of the firm, then safety indicators will help to identify if the trend is appropriate or not.

Let's take just the example about "communication" (also addressed by Reason, 1997, preceding sub-chapter under 'competence'), in HRO (high reliability organisations) studies (e.g. Rochlin, 1999), all operational teams that were interviewed pointed out the importance of maintaining a free flow of information at all times. The communication on safety needs to be addressed as a safety indicator.

4.8 Safety, reporting, just, learning and flexible cultures

Reason (1997, p 195-222) exposes all the 'sub-cultures' embedded in the more general safety culture notion. Again the communication is addressed, the reporting of problems must be welcome (in any case not be a source for retribution), the 'just' culture must be functioning; learning has to take place, etc. The reporting is encouraged, even rewarded (Rochlin, 1999; Reason, 1997). In particular, one point that seems important: *"do not forget to be afraid"*, fear is a normal feeling helping for survival, and should not be discarded.

Generally the compliance mentality needs to be fought against, the respect of regulations solely can never be an adequate driver of safety, we should look for "excellence" rather than compliance. Safety is something an organisation does for itself first, not for the regulator.

4.9 Human factors in indicators

Fatzer & Stora (1990) suggest that indicators themselves should not be used by management as a justification for negative sanctions. The indicators are often perceived negatively because of that. The indicators, depending on the management's use of them, can be a source of frustrations, conflicts and fear. On the other hand indicators can be an object of valorisation and consensus. It is the task of a company's safety management to make the use of the indicators going into the right spirit; anyway these issues are very much linked to the safety culture in general as explained in the preceding sub-chapter.

4.10 Short summary on the added value proposed

From the preceding sub-chapters the "old view" concepts are presented with their opposite, or rather complementary expressions, which should help in the search to have a better grasp on safety indicators. The "new view" items have to be seen as complementary and are not supposed to replace entirely older views.

OLD VIEW ideas	**NEW VIEW concepts**
Reactive	Proactive
Lagging	Leading
Quantitative	Qualitative
Sharp end focussed	Blunt-end considerations
Person approach	System approach
Blame culture	Just culture
Deconstructive approach	Emergence to consider
Static linear accident models	Systemic accident model
Safety is something an organisation has	Safety is something an organisation does
The safety level is reached	Never stop questioning safety standards
Negative outcomes	Positive outcomes
Categorising of failures	Assess whole socio-technical system
Failures lead to accident	Accident is result of normal work

4.11 Why are the "new view" indicators more promising?

The incidents are actually nothing but the visible outcome of the safety process taking place in an organisation. If we embrace the sequential thinking it is not sensible to measure only the end of the chain as the safety process takes place at all organisational levels, blunt end having certainly more leverage because all the decisions that eventually influence the working place conditions are taken there.

We naturally tend to focus on the easiest or more visible part but it does not make this practice wise therefore. It is hardly arguable that an operator himself could give an appropriate account on the whole organisation surrounding him. It is strongly acknowledged by scholars that incidents are systemic in nature, and therefore do not happen somewhere in a vacuum at the sharp end. The front line operator hardly defines the conditions under which he works; the design of the HMI, sector manning etc. are not in his hands to decide on. In this sense it seems logically more appropriate to measure the management's performance in safety rather than the one of an operator in the first place. Toyota, a world leading company in safety (and business!) measures the management's behaviour in safety and strongly enforces functional leadership in safety, meaning that safety is built in every function of the business (Saunders & Lawry, 2005). As such it is recognised that safety has a top-down effect and therefore proactive measurements need to be taken as well. It is argued here that leading indicators will predict in advance what will happen in the lagging ones. For example a management decision to reduce staff at the sector (which may be tracked with a negative trend in a leading indicator) might have an effect on incidents later on (then showing a negative trend on lagging indicators as well).

To summarize in using a few lines, if an organisation:

- ensures safety resources and an appropriate safety organisation
- keeps discussion about safety alive

- holds safety meetings, give safety goals to each managers
- listens to the bad news
- cherishes its just culture
- understands the safety learning as an essential process
- ensures safety communication at any price
- gives the middle managers the authority to privilege safety in face of constant goal conflicts pushing towards production
- holds an independent safety management and keeps it involved in strategic decisions
- understands that accidents often results from an incremental drift and commits to fight against
- etc , etc

then it is firmly argued here that the positive signs in these leading indicators will have positive repercussions on the lagging ones. The indicators proposed can not all be counted and will have to rely partly on subjective feelings, but safety is not something that can be measured easily in the first place, as addressed before.

5. "OLD VIEW" INDICATORS VS. "NEW VIEW" INDICATORS

The list on the next page is not meant to be exhaustive but represents the essential indicators an ANSP should look for. The level of detail achieved could be further elaborated but would make the list unreadable and too long. The spirit of the indicators that are proposed is explained in the two preceding sub-chapters (4.10 & 4.11); the table presented here has the purpose to make the indicators look more concrete. The indicators proposed are numerous; a selection of around 10 to 20 of them should be privileged and used over several years. Then a new selection of indicators might be appropriate as the company and its environment evolves and new threats appear. It would be the task of the company safety management to initiate such measures.

Source	"OLD VIEW"	"NEW VIEW"
OIR (operational internal report) Mandatory confidential human reporting (confidential under some constraints)	• Number of AIRPROX: critical • Number of AIRPROX total • Number of incidents (skyguide) critical • Number of incidents (skyguide) total As a ratio to movements In comparison to: Previous year Other organisations By unit/to total. Etc…	The underlying factors looking more for systemic concurrences leading to incidents are used in order to achieve progress on safety. Average time taken to complete investigations/compared to norm Are the recommendations given an appropriate response in due time? Is the communication between line management and safety department seamless when talking about internal investigation reports? Is the incident data base routinely analysed to determine trends? An increase in reporting is seen as positive Is the communication about OIR free?
SIR (safety improvement report) Voluntary confidential human reporting (100% confidential)	Number of SIRs accepted Number of SIRs with high classification (requiring immediate action)	An increase in reporting is seen as positive Look for the number of SIR left unanswered and the time of resolution of these Does management consider SIR as a useful tool to help them? Number of SIRs with recurring themes Number of SIR recommendations/tasks not completed by agreed due date Is the data base routinely analysed to determine trends Is the communication about SIR free?
ALANIS (based on STCA)	Accepted alert sets: all Accepted alert sets: less than 50% separation achieved Accepted v OIR: all (critical??) Accepted v OIR: less than 50% separation achieved Number accepted compared to: Previous year	The ration of filtered alert in comparison of number of submitted OIR is great data to identify the company's reporting culture Is the data base routinely analysed to determine trends? Are ATCO's questioned back on non reported incident welcoming such intervention? Is the free flow of information ensured about all STCAs?

	Unit/total As ratio to movements	
Technical incidents and maintenance	Number of major system faults/failures Average time taken for reparation of major faults/failures Number of **minor** system faults/failures Average time taken for reparation for minor faults/failures Percentage of scheduled maintenance occurrences: -Delayed/deferred -Went longer for scheduled period -Not communicated to ATS staff timely or effectively Total number of hours where provided ATS service was affected by technical issues or problems (scheduled v unscheduled)	Are safety related data welcome and treated as priority? Is the free flow of information ensured at all times? What is the trend in the ratio between planned actions and pure reactive (surprise) ones? Is the repetition of identical shortcomings addressed appropriately? Is attention devoted to the understanding of shortcomings? Is the incident data base routinely analysed to determine trends?
Audits (internal, regulator, external)	Number of critical (or major) findings Number of critical compared with total number of findings	How is management dealing with audits findings? Are they considered helpful or rather additional workload? Are the findings assessed and given an adequate response in due time? Is audit data base routinely analysed to determine trends?
System safety assessment	Number of Units with Operating Safety Case Number of above vs. total units (Later indicator could be number of Operating Safety Cases reviewed per annum) Total number of SARDs conducted	Is the process understood and accepted by line management and executive staff? Is the procedure described always followed? Are reasons for non-compliance sought to give a positive input back in the process? Is top management giving a full support to this resource demanding task? Is excellence sought rather than compliance solely?

Projects	Number (or percentage) of **major** projects achieving safety milestones on time Number (or percentage) of **minor** projects achieving safety milestones on time Number of projects directly related to safety improvement Number of projects detailed or cancelled with safety impact	Are project having a safety interest as first objective being launched? Are project leaders encouraged, trained and understanding the added value safety offers, in particular the proactive safety assessment procedure?
Safety culture survey		Is the need for one accepted? When results appear, is management willing to address changes in the regard of results obtained? Is a survey planned regularly? Are results communicated? Are intentions given following a survey?
Resource for safety		Money spent for training safety staff, the trend needs to be analysed regularly
Communication about safety	-	Is the discussion kept alive? Is it a theme on each manager's agenda? Is there a formal system for regular communication of safety information between management and employees?
Procedures and service orders	The company relies on procedures to give a frame from which ATCOs should not depart, therefore expecting more safety	The number of procedures is beyond the cognitive capacity of ATCOs to manage, is there and effort in order to reduce the number of procedures and service orders?
Management of safety (new view only here)	Does the safety steering group (SSG) meet as foreseen? Is the board of management understanding what is meant by safety and are decisions taken with having always safety as overarching principle? Is the role of safety as essential for sustainable business been understood? Is the safety manager part of the decision process? Is the safety manager given the power he should? Is the manager continuously invited into the high decisional meetings? Does it happen that safety management is ignored or circumnavigated for some business decisions? Are the managers in general given a safety objective in their duty statement? Do management meetings in general have safety as a top bullet point in their agenda? Do senior managers take the lead role in driving the company focus on safety?	

	Is safety talk encouraged and hiding of safety issues discouraged? Does the board visibly demonstrate its commitment to safety? Is everybody in the company made of his contribution to safety? Is there visible senior management support for enacting/enabling the commitments detailed in the Safety Policy document? Are in-depth safety studies conducted? Are safety-related initiatives implemented before FOCA direction to do so, i.e. is the *skyguide* organisation proactive in this regard? Do safety-related implementations get "pushed through" without due respect of existing safety processes? Do new management personnel receive formal safety indoctrination and training? Are higher safety standards than those required by regulator? Development of a constructive, cooperative relationship with regulator Timely Compliance with International Organisations, beyond compliance mentality Are specific safety programmes launched that adress national safety issues? Is safety documentation checked as approapriate ?

6. CONCLUSION

It has been argued extensively in the thesis why the actual use of safety indicators in ATM and other industries is problematic. It is very much a widely shared concern among ATC safety managers that counting failures is unsatisfactory. This thesis aimed to elaborate and expand this view, as it applies to the ANSP community. The pathway for additional indicators has been traced with the help of the new safety knowledge available.

The views expressed in the thesis will serve to counterbalance the use of indicators made so far.

Safety is not a value that can be measured out there. It is not the claim that a way to measure safety has been found here. What is argued here is that new ways are presented on how to widen the scope out of the limited area from where the data have been extracted so far. The excitement of objectively cataloguing frailties identified at the sharp end has been offered a counterbalance of more qualitative systemic consideration lying further from the front line activities.

A presentation of Toyota (Saunders, J & Lawry, P, 2005) shows that a company with excellent safety records uses blunt end indicators to achieve its success, but this only one example. If a trend in the count of incidents is a mere indication, not more, the counting of the trend in the number of high-level safety meetings held per year (e.g.) shows much more sensible and usable data, which can be tackled much more efficiently by the way. Therefore the expectations on leading indicators having a much better leverage for safety improvement than the lagging ones are high.

6.1 Further research directions

One limitation of the present thesis is that many of its claims, although supported in the theoretical literature, have yet to be tested in practice. Actually the question any manager would like to be answered (*"is the system safe?')'* will probably never get a really suitable answer anyway. But what would be interesting to see is if indicators identified with the use of the "new view" proposed here will be more satisfactory to the managers than the ones used before. After implementation of new indicators a survey could probably show if managers prefer the new ones, and why, and if the fact that these offer a much clearer picture of which way pathway safety seems to follow has an influence on it.

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