

# Safety Metrics Based on Utilisation of Resources

Alfred Roelen<sup>1,2\*</sup>, Robbert van Aalst<sup>1</sup>, Nektarios Karanikas<sup>1</sup>,  
Steffen Kaspers<sup>1</sup>, Selma Piric<sup>1</sup> and Robert J. de Boer<sup>1</sup>

<sup>1</sup>Aviation Academy, Amsterdam University of Applied Sciences, NL

<sup>2</sup>Netherlands Aerospace Centre, NL

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## Abstract

The objective of the study described in this paper is to define safety metrics that are based on the utilisation of resources. The background of this research is a specific need of the aviation industry where small and medium-sized enterprises lack large amounts of safety-related data to measure and demonstrate their safety performance proactively. The research department of the Aviation Academy has initiated a 4-year study, which will test the possibility to develop new safety indicators that will be able to represent safety levels proactively without the benefit of large data sets. The research team has reviewed the academic and professional literature about safety performance indicators and has performed surveys into 13 companies in order to explore what, how, and why safety performance indicators are used and whether there is a statistically linear relation between SMS process metrics and safety outcomes. The preliminary results showed that companies do not use data from all SMS processes in the development of safety performance indicators, they do not ground the selection of indicators on specific criteria, they implement SMS process in different ways, but they are eager to use alternative metrics, including ones potentially to be derived on the basis of contemporary safety models and views. As part of the development of alternative safety metrics, safety performance indicators were defined that are based on the difference between required resources and available resources. Resources are people, time, equipment and budget. This work is inspired by the general notion that a large gap between ‘work as

\*Corresponding author: Alfred.roelen@nlr.nl, +31 610012167

imagined' and 'work as done' has a negative influence on the level of safety. Work as imagined in this context is represented by available resources and work as done by required resources. The metrics were defined by a combination of literature research and semi-structured interviews with operational practitioners in the aviation industry. The suitability of the metrics will subsequently be tested in pilot studies within the aviation industry.

Key Words: Safety Performance; Safety Metrics; Resources

## 1 Introduction

Safety is typically managed through a risk management cycle which includes the stages of hazard identification, risk assessment, risk mitigation and safety assurance. Under this concept, a service provider's safety performance is verified in reference to safety performance indicators. The safety performance indicators are used to monitor known safety risks, detect emerging safety risks and to determine any necessary corrective actions (ICAO 2013). According to ICAO (2013), information used to measure the organization's safety performance is generated through its safety reporting systems. However, small sized organisations typically generate very little occurrence reports. This information alone is insufficient to provide a robust picture of safety performance. Therefore, there is a need for alternative, supplementary indicators of safety performance.

The performance indicators are to be used in the safety management cycle of aviation organisations, with an emphasis on medium and small-sized companies. The work presented in this paper was conducted in the context of the research project 'Measuring Safety in Aviation – Developing Metrics for Safety Management Systems', which responds to specific needs of the aviation industry where Small and Medium Enterprises (SME)<sup>†</sup> lack large amounts of safety-related data in order to measure and demonstrate their safety performance proactively (Aviation Academy, 2014). During the first phase of the project, the research concluded to the following findings:

- State-of-artacademicliterature, (aviation)industrypractice, and documentation published by regulatory and international aviation bodies jointly suggest

<sup>†</sup> The category of micro, small and medium-sized enterprises (SMEs) is made up of enterprises which employ fewer than 250 persons and which have an annual turnover not exceeding EUR 50 million, and/or an annual balance sheet total not exceeding EUR 43 million (EC, 2003).

that (a) safety is widely seen as avoidance of failures and is managed through the typical risk management cycle, (b) safety metrics can be, conventionally, split in two groups: safety process metrics and outcome metrics, (c) there is a lack of standardization across the aviation industry regarding the development of safety metrics and the use of specific quality criteria for their design, and (d) there is limited empirical evidence about the relationship between Safety Management System (SMS)/safety process and outcome metrics, and the link between those often relies on credible reasoning (Kaspers et al., 2016a).

- Results from surveys by 13 aviation companies (i.e. 7 airlines, 2 air navigation service providers and 4 maintenance/ground service organizations) showed that (a) current safety metrics are not grounded in sound theoretical frameworks and, in general, do not fulfil the quality criteria proposed in literature, (b) a few, diverse and occasionally contradictory monotonic relationships exist between SMS process and outcome metrics (Kaspers et al., 2016b, 2016c).

The researchers with the support and reviews from academic and research institutions, subject matter experts and through pilot studies in aviation companies have developed a set of five new safety metrics. These metrics are based on the premise that the greater the gap between system design (Work-as-Imagined; WaI) and operation (Work-as-Done; WaD), the lower the safety/system performance (Dekker, 2011, Leveson, 2015). The metrics regard: (1) assessment of Safety Management Systems by addressing their design, operation, quality of delivery and internal and external interfaces and dependencies, (2) planning and implementation of safety culture prerequisites, (3) system complexity and coupling, (4) measurement of risk control effectiveness, and (5) utilisation of resources.

The objective of the research presented in this paper is to explore safety performance indicators that are based on the utilisation of resources. The researchers aimed at designing indicators of resource utilisation that are based on the distance between required and available resources. Resources in this context are equipment, people, time, and budget.

## 2 Theoretical background

No organisation operates in complete isolation. Every organisation operates in an environment that has constraints, such as the amount of capital available and the qualifications of available employees (Dekker 2011). Rasmussen (1997) suggested that there are three types of constraints, economic, workload

and safety. These constraints surround the operation from three sides, and the organisation may migrate towards (or across) a boundary as a result of pressure from the other constraints. The concept that organisations may exchange performance in key areas as a result of internal or external pressures is also reflected in several other views that are described in the literature. Hollnagel (2014) states that availability of resources (time, manpower, materials, information, etc.) may be limited and uncertain, and therefore people adjust what they do to match the situation, and performance variability is inevitable, ubiquitous, and necessary. The Efficiency Thoroughness Trade-Off (ETTO) concept reflects the idea that people usually sacrifice thoroughness for efficiency due to conflicting goals. These sacrifices are normal, necessary for system functioning, and usually, result in success. However, occasionally they contribute to an accident (Hollnagel, 2009). Lack of resources possibly leads to such trade-offs to be made. Safety and production compete for resources: this means that investments in safety are seen as costs, and therefore, sometimes, hard to justify or sustain (Hollnagel, 2013). This is a possible cause of conflicting goals for the allocation of resources within a company. A relation between the allocation of resources and safety is also suggested by Rasmussen and Svedung (2000) who state that accidents are the effect of a systematic migration of organisational behaviour under the influence of pressure towards cost-effectiveness in an aggressive, competitive environment.

Hollnagel (2015) also suggests that a large gap between work-as-imagined and work-as-done has a negative influence on the general level of safety. Work-as-imagined is what designers, managers, regulators, and authorities believe happens or should happen. Work-as-done is what people do to get the job done in the actual situation. Work-as-imagined is the basis for design, training, and control (Hollnagel, 2015). Understanding the gap between system-as-imagined and the system as actually operated requires understanding how the system really works, but also how it is imagined to work (Hollnagel et al., 2006). Historically, Work-as-imagined is represented as the most efficient way of doing something (Hollnagel, 2017), and this is exemplified in concepts such as 'lean' that focus on avoiding 'waste'. However, if we do not really know how the system really works, it may be difficult to differentiate between 'waste' and required resources. A gap between work-as-imagined and work-as-done may in such cases be reflected in a lack of resources required to get the job actually done. In other words, the difference between planned resources and actually required resources is symptomatic of a gap between work-as-imagined and work-as-done and may influence safety.

### 3 Design of the indicators

Exploratory interviews were held with representatives from four different aviation companies (i.e. two aviation maintenance organisations, a helicopter operator and a non-complex aircraft operator) to obtain further insights regarding the way in which resources are planned, the way in which the differences between planned and required resources are identified and the types of data that are collected regarding planned and required resources. The design included semi-structured interviews and each interview lasted approximately two hours. The interviewees indicated that resource planning is difficult because of fluctuating demands that may not be predictable and therefore creates uncertainty. Resource planning mainly concerns man-hours. A short-term lack of man-hours is solved by allowing delays or by hiring temporary staff. For the companies that were interviewed, the equipment that is available to perform the main activities is considered to be fixed; in case of equipment shortages work is outsourced due to an unexpected temporary increase in demand (Haastert, 2017).

Based on the results of the exploratory interviews, it was decided to consider four types of resources: Time, People, Money and Equipment.

#### 3.1 Time

Time can be expressed as the total duration of an activity (i.e. runtime) or as the number of person-hours involved in an activity. The latter combined the resource 'time' with the resource 'people'. The runtime may or may not be affected by the availability of personnel. Runtime is the turnaround time of a task and is a measure of task duration; person-hours is a measure of total task effort. If an activity allows tasks to be executed in parallel, the runtime can be reduced if more people are working simultaneously, but obviously, such personnel must be available. For the purpose of this research, we will consider the runtime that has been made available for a specific activity compared to the runtime that is required to perform the activity adequately. Similarly, we consider the number of person-hours that have been made available compared to the number of person-hours that are required to perform the activity adequately. Available/required runtime and person-hours are to be calculated for a task or a combination of tasks.

#### 3.2 People

Human capital theory suggests that the accumulation of firm-specific human capital in a workforce determines workforce performance (Strober, 1990).

Human capital is seen as the primary determinant of productivity, and because voluntary turnover diminishes human capital, productivity is weakened as turnover increases (Dess and Shaw, 2001). Voluntary staff refers to an employer's decision to terminate the employment relationship. It occurs when an individual decides to leave a job for reasons other than retirement. It generally occurs when an individual anticipates more attractive work alternatives available. Involuntary turnover occurs when organisational actions are taken to relieve an individual from their position (Ring, 2011). Since the determinants of voluntary and involuntary turnover may differ (Shaw et al., 1998), and most published work on the relationship between turnover and performance concerns voluntary turnover, we choose to restrict the metric to voluntary turnover. Voluntary turnover eliminates an organisation's return on investment in an employee and reduces the firm-specific human capital (Shaw et al., 2005). It is associated with an outflow of experience and knowledge from the company and can, therefore, be seen as a knowledge-based resource rather than a property-based resource such as equipment. This is important because knowledge-based resources are more difficult to protect against loss than property-based resources (Dess and Shaw, 2001). Results from a meta-analysis conducted by Park and Shaw (2013) confirm the proposition that increased turnover rates damage organisational performance.

### 3.3 Money

A negative correlation between the availability of monetary resources and safety performance is one of the implicit assumptions of the 'drift into failure' concept as discussed by Rasmussen (1997) and Dekker (2011). Such an assumption is supported by the observation that there is a strong inverse relation between aircraft accident rates and gross domestic product across world regions (Roelen et al. 2000, Visser 1997). Karanikas (2015) demonstrated an association between expenditure per employee (including wages, salaries, compensations and allowance expenditures) and the rate of accidents attributed to human error. A logical indicator of monetary resources for a company is the profit as a percentage of total turnover. However, if the profit goes directly to the company shareholders and is not invested back in the company, an effect on (safety) performance is not expected. Therefore, we propose to consider the budget invested in the organisation or parts of it relative to the budget spent by the organisation or its parts as an indicator for the 'money' resource. Effects of safety investments on safety performance have been demonstrated (Feng, 2013), albeit that the effectivity of safety investments varies across safety culture levels. For the purpose of this

research, however, invested and spent budget is not necessarily restricted to safety activities but applies to all investments and expenses related to a particular activity or group of activities.

### 3.4 Equipment

Almost all activities in aviation require the use of tools or equipment, varying from common equipment such as laptop computers and smartphones, to special tools used for one specific maintenance task and personal protection equipment to prevent occupational injuries. A risk model developed by RIVM (2008) based on accident data includes equipment as one of eight management delivery systems that define the precursor events of accidents. The effect of scarcity of personal protection equipment is one of the most dominant factors affecting occupational safety performance (Sawacha et al., 1999). For this metric, however, we consider all specific equipment on which the execution of the tasks is critically dependent.

## 4 Discussion

Based on the theoretical background and results from the exploratory interviews and the expected availability of data at SMEs, the following performance indicators were defined:

- Available runtime / required runtime

Runtime is the turnaround time of a task and is a measure of task duration. Available run-time is the runtime that is scheduled for a specific task or group of tasks. Required runtime is the time that was actually needed to perform the task. Generally speaking, if the required runtime is longer than the available, there will be some sort of delay. If the required runtime is shorter than the available runtime, there is some sort of slack. Available short-term runtime is usually determined during activity planning and can be found in planning documentation. Actual run-time can be found in operational service records.

- Available person hours / required person hours

Person hours are a measure of total task effort. Available person-hours are the number of person-hours that are scheduled for a specific task or group of tasks. Required person-hours are the number of person-hours that were actually needed to perform the task. Generally speaking, if the required person-hours are more than the available person-hours, there will be a

delay unless additional staff are made available. Available person-hours are usually determined during activity planning and can be found in planning documentation. Actual person-hours can be found in operational service records.

- Voluntary staff turnover

Voluntary staff turnover is defined as the percentage of employees in a workforce that voluntarily leave the organisation during a certain period of time (e.g., one year). Voluntary staff turnover data are usually recorded by the Human Resources department.

- Budget invested / budget spent

Budget invested/spent should be calculated for a specific activity or group of activities in a certain time period. Information on invested and spent budget can usually be found at the finance department.

- Number of equipment available / number of equipment required

Equipment available refers to the number of equipment that is actually available to perform the task under consideration. To be available, the equipment must be in working condition. Equipment required refers to the number of equipment that is actually required to perform a task. If equipment required is less than the equipment available there is a shortage of equipment.

It is noted that available/required runtime and person-hours are to be calculated for a task or a combination of tasks depending on the system under study. Also, in the indicators above that are calculated through ratios, the nominator corresponds to the WaD and the denominator to the WaI. The metrics collectively provide broad coverage while being individually rather specific. This is considered a desirable attribute of performance indicators (Fitzgerald et al. 2011).

The metrics described here are considered to be pro-active indicators, using the definition of Rasmussen et al. (2000) who defined pro-active indicators as indicators before an accident. Moreover, they are considered predictive in the sense that they are predictive of the likelihood of occurrence of unsafe events, as opposed to monitoring indicators that use actual events as a measure for the likelihood of unsafe events (Körvers, 2004).

It has been noted that there may be interactions among these indicators, for example, that voluntary turnover could affect financial performance (Shaw et al., 2005) and hence that there is a relation between the 'people'



and ‘money’ indicators’. Whether such interactions can be observed from available data will be one of the research questions for the next stage (see section 5).

## 5 Industry review and next steps

The proposed metrics for the effectiveness of risk control measures were distributed among academia and industry with a request to provide feedback. The material constituted of a one-page description of the background, the proposed indicators and a note on information that must be available in order to apply the metrics. Comments were received from eight organisations (i.e. three airlines, two aviation consultants, a maintenance organisation, a ground support organisation and an airport). Reviewers were asked to assess the proposed indicators according to quality criteria that were developed in an earlier part of the study (Kaspers et al., 2016a). In general, the response was positive in the sense that the organisations indicate that the metrics as defined are meaningful and that the metrics can be applied to organisations with different sizes and type of activities. Most respondents suggested that data required to apply the metric can be obtained relatively easily, although the frequency and methodology for capturing and documenting data will differ amongst companies and throughout different departments and that would define how easy it would be to obtain.

As a next step, the metrics description will again be distributed among aviation service providers with a request to apply the metrics. The purpose is to test the practical applicability and to validate an association between the metrics and safety performance. During this process, the researchers will examine the criterion, predictive and statistical conclusion validity of the metric. However, the researchers contemplate that the limitations encountered during the previous research phases (Kaspers et al. 2016, Kaspers et al. 2016c) might impede the execution of valid tests.

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