# Heinrich Triangle for Ground Operation

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*"Only airborne aircrafts return a profit; aircraft on the ground cause costs and underlie various risks" [Ref. 1].*

This quote describes the actual drive to examine occurrences and accidents within the air traffic domain. During the last few decades, ticket prices for air transport services declined enormously; therefore, the cost pressure from the airlines — especially low-cost carriers — has led to a fierce competition. Hence, this pressure rolled off to the handling agents and suppliers.

The effect becomes manifest in short turnarounds, less ground time (and, therefore, less time for ramp processes), more distinctive peaks with complex transfer relations with short connection times for passengers and bags, more traffic on the tarmac, manpower shortage, etc. Therefore, the processes on the ramp are becoming more complex and, thus, the risk of incidents arises.

This paper tries to highlight some general results that came out of a master thesis at ETH Zurich, which evaluated and classified ground operation occurrences at Zurich Airport [Ref. 1]. As a theoretical background, the Heinrich Triangle is assumed. Based on this model, the following main question is addressed: *Is the Heinrich Triangle applicable for ground operations at airports?*

## Scope

This paper will focus on various processes on the apron, which includes all stands, taxiways, runways, service streets, de-icing pads and the infrastructure on the airside zone of the airport perimeter (e.g., finger docks, jet bridges, equipment, etc.). Most of the relevant processes being treated in this paper happen on the aircraft stands. The contextual scope of the study will focus on the so-called *ground operations.*

*"Ground Operations involve all aspects of aircraft handling at the airport as well as aircraft movement around the aerodrome except when on active runways. The safety challenges of ground operations are partly to do directly with those operations, for example ensuring that aircraft are not involved in collisions and that the jet efflux from large aircraft does not hazard small ones. Even more important, ground operations are about preparing aircraft for departure in such a way that the subsequent flight will be safe, too; for example, correct loading of cargo and baggage, sufficient and verified fuel of adequate quantity and quality and the correct use of ground de/anti icing facilities where appropriate"* [Ref. 2].

Figure 1 illustrates the thematic scope. Ground Operations include pre-flight (load planning, loading, cleaning, etc.), taxiing (including push-back and de-icing) and post-flight (unloading). The exact border between ground and airborne operations is defined by the take-off clearance.

At Zurich Airport, a large number of companies are involved in ground operation processes. In total, 270 firms work on the airport perimeter [Ref. 4], but only a few are directly involved in ground operations. One decade ago, all these tasks were handled by one single company (Swissair). Currently, the airlines do not perform their ground handling with their own divisions, but the processes have been outsourced to different companies.

The fact that more suppliers are involved in the processes leads to the conclusion that the complexity of ground handling — and, therefore, the probability of an incident — has increased. All the companies are strongly encouraged to maintain the short turnaround times constituted by the airlines. This time pressure, associated with the limited space on the tarmac, aggravates the challenges for safety in a more sensitive way. Figure 2 gives an idea of the critical spatial situation on the apron. More actors need more space, each person has to concentrate on his own duties (to follow the given turnaround time) and mutual consideration is not possible, which increases the risk of unsafe acts.

## The Heinrich Triangle

*Accident prevention is both science AND art [Ref. 6].*

This quotation gives an idea of Heinrich's motivation for the topic. Especially within the avia-

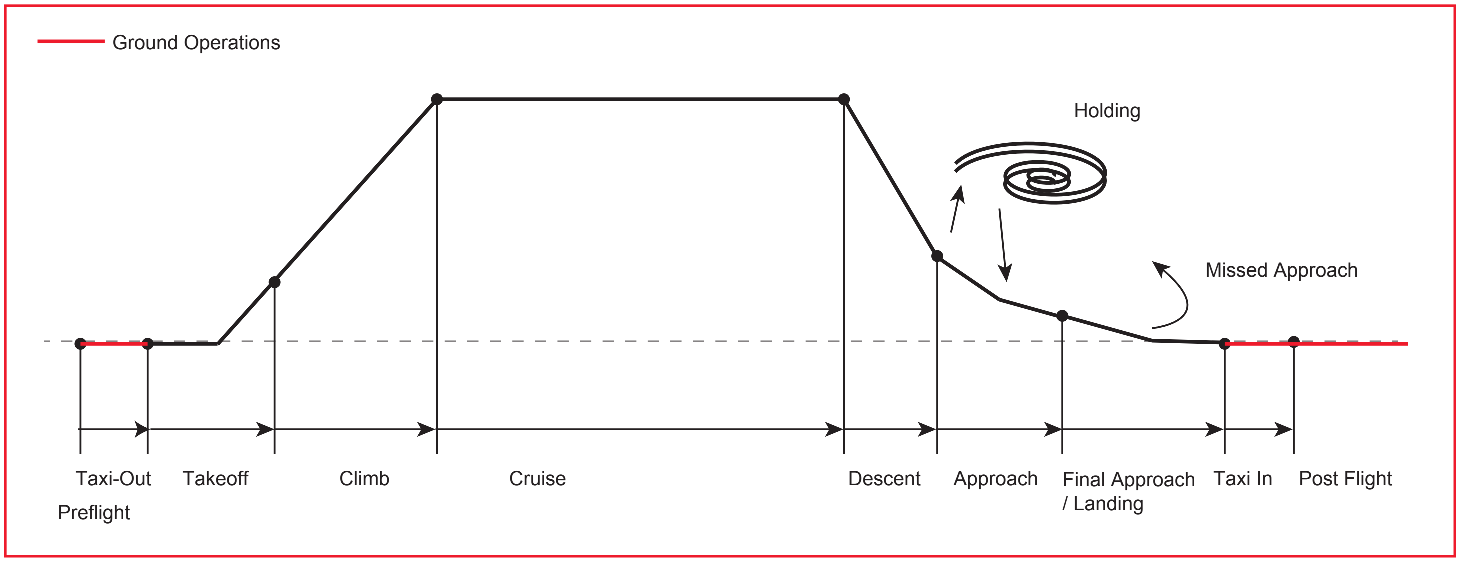


*Figure 1 — Ground Operations [Ref. 3].*

tion science, strict concentration on mathematical formulas and models do not create a safe environment. Beyond doubt, accurate guidelines and concrete rules are needed to help people work safely, but on a higher level (supervision, management), an elaborated and mature organization of all involved stakeholders is needed to establish a safety culture and to promote safety itself as a mandatory function within the daily business, which can be declared as art, not as (natural) science. In this context, Heinrich describes two approaches in accident prevention, which are both required:

- Immediate approach: The control of personal performance and the environment
- Long-term approach: Training and education [Ref. 6].

As a result of empirical studies, Heinrich published his model of incidents and accidents within various industries. He found that occurrences approximate a 1:300 ratio between near-misses without serious impact (e.g., injured personnel or damaged infrastructure) and major accidents with fatal consequences. The intermediate range between the two impact sectors is described as "minor injuries" with a ratio of 1:29 on the major injuries. Figure 3 shows the Heinrich Triangle with its ratios.

As the conclusions of Heinrich are generally well known and accepted in different domains, the Safety Office at Zurich Airport also uses the triangle, although in an adopted form with four classes. Figure 4 shows the application of the Heinrich Triangle for aviation safety. The classes have been modified and named with adequate terminologies;

*Figure 2 — Ground Operations [Ref. 3].*

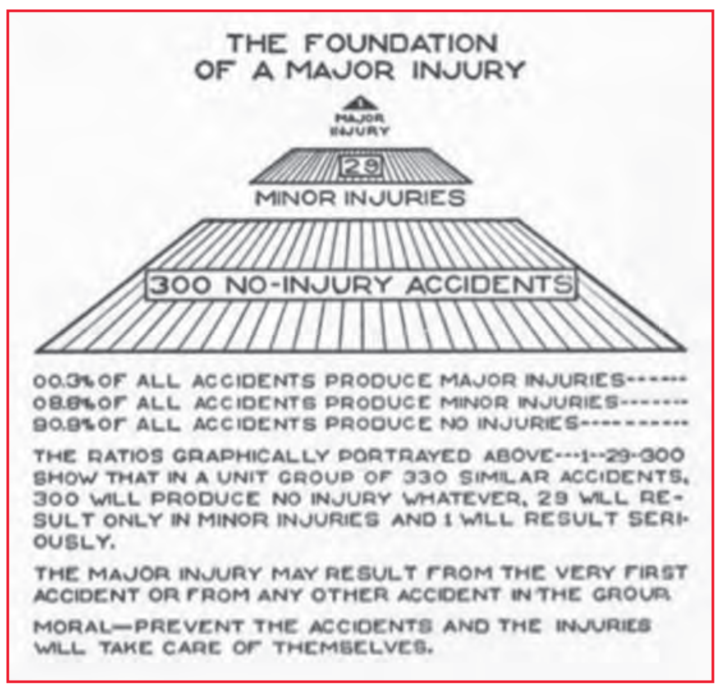


*Figure 3 — Heinrich Triangle [Ref. 6].*

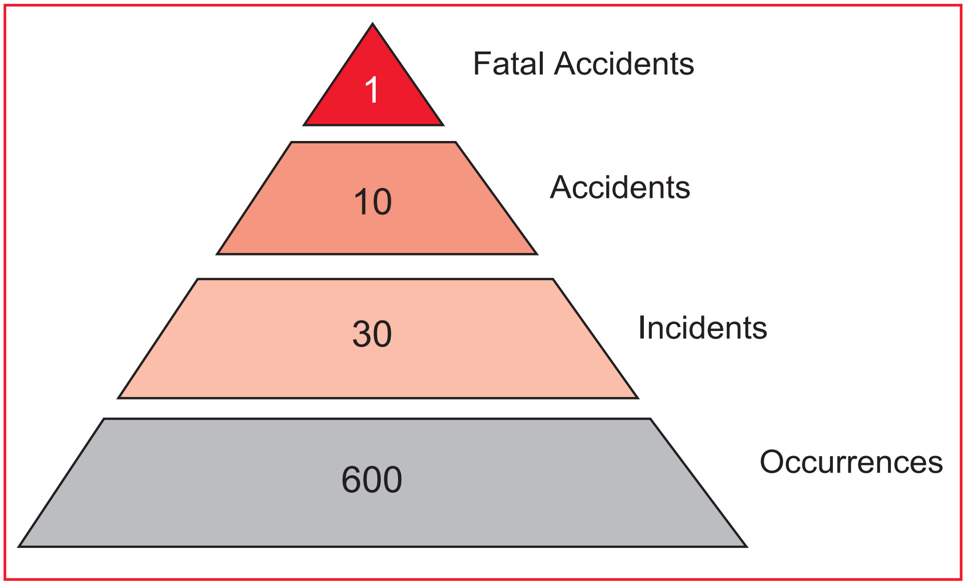


*Figure 4 — Occurrences as Indicator for Accidents – the 1:600 Rule [Ref. 7].*

the data is expected to show up in a 1:600 rule.

Heinrich associates his model with the illustration of an iceberg, where only the top part can be seen from a distance. But the actual root of the problem (the generation of the ice) remains hidden.

This association is also useful from an air transport-related point of view. We will see later that the analysis of accidents does not cover the whole occurrence reporting. It is required to disclose near-misses, organizational problems and preconditions for unsafe acts, as well. Preconditions for unsafe acts can be classified roughly into environmental factors, condition of operators and personnel factors [Ref. 8 & 9].

## Critical Acclaim

Based on the fact that Heinrich compared industrial accidents without a further discussion of the causes of events, the theory cannot be adapted to any industrial domains. According to Wright et al. [Ref. 10], the triangle has to be calibrated under the assumption that near-misses and accidents have the same relative causal patterns (the so-called "common cause hypothesis"). Wright questions the validity of the common cause hypothesis, and whether the different levels really do have completely different patterns of causes, by concentrating on the level of severity.

Additionally, Wright records that data on injuries and damage will not be meaningful enough to derive a Heinrich Triangle, and effort is required to collect appropriate data on voluntary near-miss reporting schemes.

## Analysis of Occurrences

*"At Zurich Airport, an open-minded and transparent safety-culture shall be conveyance and hosted; We shall learn from former events and near-misses"* [Ref. 11].

This goal in the safety policy is covered by the occurrence reporting procedure, steered and

*Table 1 — New Severity Classes [Ref. 12].*

| Classification | | Definition | Examples (ZRH Data) |
|---|---|---|---|
| A | Catastrophic | Loss of aircraft, several casualties, no remaining safety barriers | Collision Taxiway-/Runway-Intersection, Fueling Incident |
| B | Hazardous | Significant damage on aircraft, few casualties, no remaining safety barriers | Collision of aircraft with airport infrastructure (e.g., jet bridge), de-icing incidents |
| C | Major | Few damages on aircraft, seriously injured persons, few safety barriers left | Collision ground service equipment with aircraft, jet blast incidents |
| D | Minor | No significant aircraft damage, several slightly injured persons, several safety barriers left | Collision between two vehicles on apron, accidents during loading/unloading |
| E | Negligible | No significant aircraft or equipment damage, no injured persons, existing barriers take effect | Snow truck damages airport fence, spills (fuel, de-icing fluid, cargo items) |

supervised by the Safety Office (strategic part) and the Airport Authority (operational part). Every single occurrence (e.g., near-misses, incidents, accidents, hazardous situations) shall be reported to the Airport Authority and collected by the airport manager on duty. This data is transmitted regularly to the Safety Office and serves as the raw data for this analysis.

## Classification of Occurrences According to Safety Assessment Guidelines

The initial part of this paper essentially follows the new methodology of safety assessment, published by Zurich Airport Ltd. and Ernst Basler + Partner AG [Ref. 12]. This risk management approach defines "risk" as a function of probability and impact, while the modified safety assessment guide classifies the incidents according to their severity and probability. A clear classification of the dimension "severity" is necessary to establish a proper risk characterization. Hence, the Safety Office and Ernst Basler + Partner established a new classification scheme with five severity classes. Examples of incidents have been added to all the classes, with the focus on ground handling processes and operations (Table 1).

The concentration of damage (aircraft, equipment, buildings, etc.) and the appearance of casualties was also used to develop a severity classification catalogue specifically for ground handling, where casualties may only appear in classes A and B. To simplify the allocation of "damage," the determination has been done according to a defined cost level (*CHF 1'000*) and the accident type (aircraft damage *Yes* or *No*).

Class A does not show up in many examples because ground handling is not involved in processes that may end up in catastrophic impact. Class E is actually inconsiderable for this analysis because normally, "negligible" incidents are not subject to reporting and have no significant impact on operations. For example, a damaged airport fence does not have any impact on safety, but it does on security. In any event, some near-misses have been observed lately, where an occurrence of a Class A event has been avoided only by chance. Aircraft movements on the aerodrome (taxiing) run an especially high risk of catastrophic incidents.

A high level of danger also exists at taxiway/runway intersections. In June, 2011, an Egypt Air Jet almost crashed into a starting Lufthansa Airbus at JFK International Airport in New York because it rolled onto the runway against the instructions given by the Apron Controller. Another incident is known tragically as one of the most serious air traffic disasters in history, where two wide-body aircrafts (Boeing 747; Pan Am and KLM) crashed at Tenerife Airport (TFS). The accident caused 583 casualties.

Nevertheless, severity Class A may be factored out for the data analysis, but the possibility of occurrence must be kept in mind for an adequate hazard identification and risk perception. Considerations on Class-E incidents will be re-launched for a qualitative assessment of safety measures because many organizational problems and unsafe acts are included in this class and sometimes have the capability to transform into a grave incident.

Severity is not classified by the type of incident; it is defined by fixed attributes such as the gravity of

*Table 2 — Heinrich Calibration with new Severity Classes (from 2004 – 2010).*

| Class | Classification | Occurrences acc. Data Analysis |
|---|---|---|
| A | Catastrophic | 0 Occurrences<br>→ Can be neglected (occurrences seem to be extremely improbable within ground handling) |
| B | Hazardous | 4 Occurrences |
| C | Major | 195 Occurrences |
| D | Minor | 519 Occurrences |
| E | Negligible | 26 Occurrences<br>→ Can be neglected (no impact on safety and on the dispatch of aircrafts) |

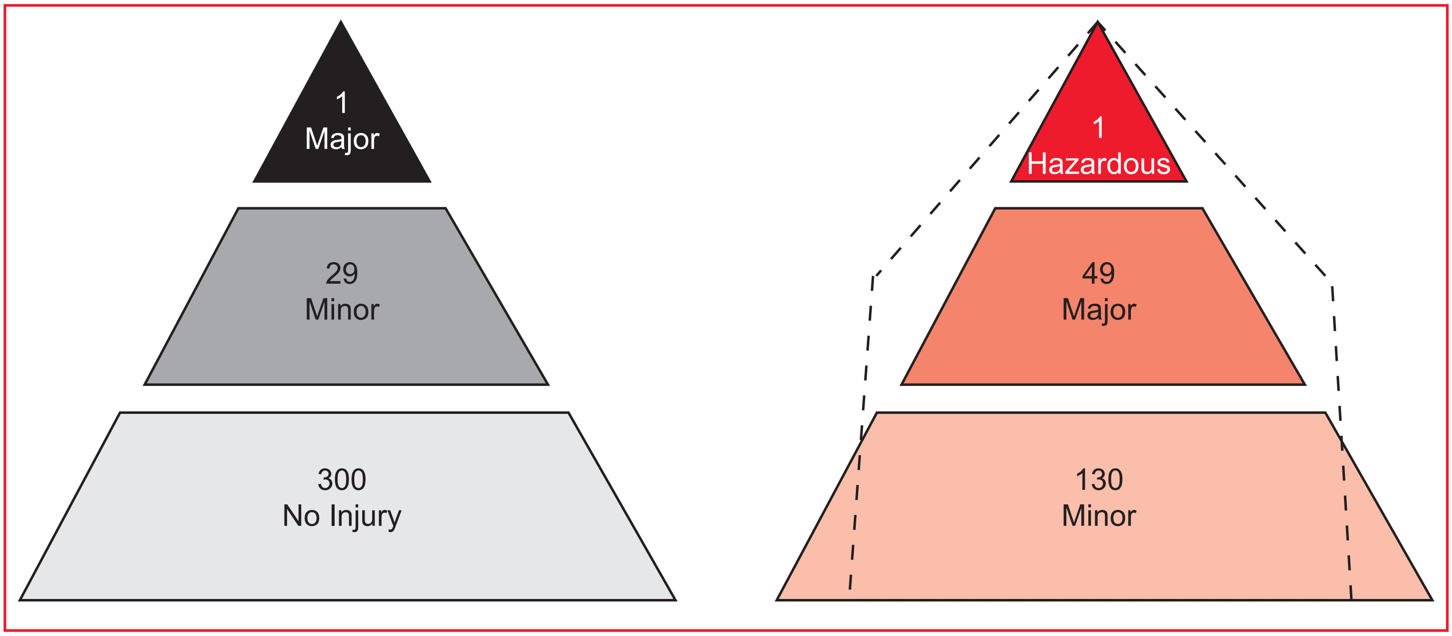


*Figure 5 — Comparison Heinrich Triangle to Ground Operation Triangle (Classes B – D).*

physical injuries and/or infrastructure damage. The aim of this new approach is a more detailed and more objective classification.

## Calibration of Heinrich's Triangle

To perform an adequate classification of defined severity levels, the raw data (occurrences at Zurich Airport, 2004-2010) has been reviewed carefully, and each event has been classified according to its severity. The occurrence database is maintained by the Safety Office and the Airport Authority of Zurich Airport Ltd. and was provided by the safety officer.

Accidents classified as "catastrophic" are expected to happen with an extremely low probability; hence, no events were found in the observation period.

The summary from Table 2 ends up in a 1:49:130-relation. Compared to the idealized 1:29:300-rule [Ref. 6], the triangle — referring to ground handling — shows the shape of an urn (Figure 4).

Even though the evidence that Heinrich's ideas are directly applicable for the occurrences caused by ground handling is not fully provided, a relatively adequate correlation has been found in the data analysis. Heinrich also included near-misses, preconditions for unsafe acts and organizational problems in the base of his triangle, where the occurrence reporting only exhibits data from former accidents. Near-misses are not included.

> "Ground operation is a domain with high complexity and partially high danger. The treatment and monitoring of these processes remains a challenge, particularly the detection of undetected hazards ("hidden" part of the iceberg below the water surface). This may be seen as a challenge for future research."

## Conclusions

This paper presented some general results from a master thesis at ETH Zurich, Switzerland about target level of safety for ground operations at Zurich Airport. The paper focused on the question of whether the famous Heinrich Triangle is applicable to ground operation in general.

As a result, it can be stated that the well-established approach from Heinrich's Triangle may be applied for ground operation, provided that the data is treated carefully and that all aspects (from unsafe acts to violations) are evaluated and incorporated. The general effective applicability of the Heinrich Triangle could not be evidenced in this examination; more detailed studies and an international acclaim with other hubs would be needed to eliminate the constrictive factors (common cause hypothesis, etc.).

Nevertheless, the study showed that an accurate analysis of incidents in the (partial) high-risk duties of staff involved within ground operations and aircraft dispatch, and the allocation into reasonable severity classes, may illustrate where prevention measures may be implemented and where risks may be minimized.

Ground operation is a domain with high complexity and partially high danger. The treatment and monitoring of these processes remains a challenge, particularly the detection of undetected hazards ("hidden" part of the iceberg below the water surface). This may be seen as a challenge for future research.


## Acknowledgments

We would like to express our gratitude to Marc Keusch, safety officer at Zurich Airport Ltd., for the disposal of the raw data and his valuable input and advice in aviation safety-related issues.


## About the Authors


**Reto Rieder** studied geography and spatial planning at the University of Zurich and specialized in his master studies in spatial development and Infrastructure Systems at the Swiss Federal Institute of Technology in Zurich (MSc ETH SD & IS). During his studies, Rieder worked at Zurich Airport as a load controller and de-icing coordinator for Swissport International Ltd., the world's leading ground service provider. This part-time job and a lecture in safety management and accident cause analysis methods by Sonja-Lara Bepperling gave him the motivation to perform a master thesis about safety targets within the air transport industry. As of September 1, 2011, Rieder began work at the Swiss Federal Office of Civil Aviation as a project manager in the Safety Infrastructure Division, Section Aerodromes and Air Navigation Obstacles.

**Sonja-Lara Bepperling** studied civil engineering at the Technical University of Braunschweig, Germany. She specialized in transportation engineering and received her master of science from the University of Rhode Island. Her Ph.D. focused on validating a semi-quantitative approach for railway risk assessments, which she has done at Siemens Transportation Rail Automation Academy as a graduate student in Germany. From 2009 until 2011, she was a post-doctoral student at the Institute of Traffic Planning and Systems at the Swiss Federal Institute of Technology in Switzerland. Recently, she has started working at Ernst Basler + Partner, which is a Swiss engineering and consulting company, working in the field of railway safety.


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