# Assessing Airport Taxiway Systems on the Sustainable Safety Vision: the Case of Amsterdam Airport Schiphol

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## Abstract

In line with the global Air Transportation System, Amsterdam Airport Schiphol (AAS) has seen growth for the last decades and reached the current limit of 500,000 annual movements. Growth is only allowed if this is demonstrable safely possible. However, the Dutch Safety Board exposed several safety risks within surface operations at AAS. In this paper, for the first time, a taxiway system is assessed on the - in road transport proven - vision of Sustainable Safety to provide new insights on safety within taxiway systems. Based on the the case-study of AAS, assessing taxiway systems on Sustainable Safety showed to be valuable. The assessment denoted challenges and opportunities, before the taxiway system of AAS qualifies for meeting the principles of Sustainable Safety. Consequently, various topics for further research were found.

*Keywords:* Taxiway System, Airport Surface Safety, Sustainable Safety, Amsterdam Airport Schiphol

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## 1. Introduction

For the last decades, the Air Transportation System (ATS) has been growing almost ceaselessly. This growth can also be found at Amsterdam Airport Schiphol (AAS), where the number of passengers has grown from 37 million passengers in 1999 up to 71.7 million passengers in 2019 [1]. Accordingly, the number of aircraft movements increased from 393,606 (1999) to almost 500,000 in recent years, thereby reaching the current limit of allowable number of annual movements[1]. The Dutch Government underpinned the economic importance of AAS as major airport in The Netherlands, offering connectivity to the world. Yet, the Government stated that growth will only be allowed providing that a set of defined criteria is met [4]: (1) Growth shall be demonstrable safely possible; (2) the (noise) nuisance for AAS's neighbours shall be reduced, especially during night-hour operations; (3) the emission of $CO_2$ shall be reduced; and (4) growth shall be used as much as possible to support the network quality of AAS.

The first criterion might cause challenges. Both Hillestad et al. [5] in the 1990s and more recently the Dutch Safety Board [6] concluded that the past growth had an adverse effect on the safety of airside operations at AAS. Both investigations were performed in response to (a series of) incidents at the airport. The investigations exposed several safety risks and provided recommendations which should be tackled to ensure safe operations in the future. Frequent runway configuration changes result in a complex traffic handling process. Consequently, Air Traffic Controllers (ATCOs) operate under high workloads. In addition, the large number of taxiways, runway exits and entries (including Rapid Exit Taxiways (RETs)) and relative runway orientations rise the safety risk [6]. Moreover, it was concluded that runway incursions and confusion of flight crews might be caused by the large number of taxiways and the use of RETs for entering the runway. Since runway incursions are considered to be a separate topic of study, this research focuses on airport surface safety within taxiway systems, excluding runway incursions. Although airport surface safety has been researched (e.g. [7], [8]), the - in road transportation proven - vision of *Sustainable Safety* has not been used for assessing taxiway systems before. To provide new insights on safety within taxiway systems, the by the Institute for Road Safety Research (SWOV) [9] developed Sustainable Safety vision is used to assess the taxiway system of AAS in this research.

Taxiway systems are designed and developed following the Standards and Recommended Practices (SARPs) as developed in Annex 14 by the International Civil Aviation Organization (ICAO) [10]. Within Annex 14, safety can be seen as the thread. For European airports, including AAS, the European Union Aviation Safety Agency (EASA) [11] defined similar specifications. Since the specifications of EASA are based on the more globally applied ICAO's Annex 14, this research uses Annex 14 as reference. Besides, to limit the scope of the research, only commercial air traffic is taken into account for the case-study.

In the next section, the vision of Sustainable Safety is described and translated for taxiway systems. Next, supportive analyses are provided in section 3. Afterwards, section 4 assesses the taxiway system of AAS on Sustainable Safety. Lastly, conclusions and recommendations are provided in section 5.

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[1] Until 2021, the growth of AAS is limited to a number of 500,000 annual aircraft movements (one movement means one takeoff or one landing). This number includes commercial air traffic (referred to as 'handelsverkeer') and does not include General Aviation (GA) and technical air traffic [2, 3].

## 2. The vision of Sustainable Safety

In 1992, along with Sweden, a vision on sustainably safe road traffic was firstly conceptualized in The Netherlands. The goal of Sustainable Safety is to achieve safety by systematically reducing underlying risks of the traffic system. Hereby, the vision focuses on human factors [9], in line with the by ICAO [12] defined approaches to safety within the aviation industry. The awareness that human factors are important when it concerns road safety has been accepted for decades [13]. Already in 1979, Treat et al. [14] stated that people are not only physically vulnerable, but also fallible: they make errors. Therefore, human characteristics are of large importance when concerning safety. Amongst other industries, also in aviation it has been recognized that rather than adapting people to a system, the system should be adapted to people's abilities and desires, which is also known as 'safety by design' [9]. Sustainable Safety as described by SWOV [9] has not been applied to taxiway systems before, although taxiway systems show similarities to road systems. Below, the five road safety principles are described and a translation to the taxiway system is made.

Three of the five principles are *design principles*. In accordance with the **functionality** design principle, a network ideally has a hierarchical and functional structure of traffic functions. In a road network, this structure is built up of three categories of roads:

- *through-roads* (flow function on road sections and across intersections)
- *distributor roads* (flow function on road sections and exchange function at intersections)
- *access roads*[2] (exchange function on road sections and at intersections)

In taxiway systems, this is split up in two major categories. For the flow function, ICAO defines *taxiways*, which are intended to provide links on the aerodrome. For the exchange function, ICAO defines *aircraft stand taxilanes*, which intended to exclusively provide access to aircraft stands.

For both categories, ICAO [10] defined different separation distance design criteria. The differences are based on the assumption that flight crews are more focused on aircraft stand taxilanes, as they will shortly access an aircraft stand, and therefore the aircraft's speed is lower as well. Additionally, SWOV [9] mentions that in cases where mono-functionality cannot be realized in the short term (referred to as 'grey roads'), efforts should be made to achieve (temporary) results that provide adequate safety by focusing on the most vulnerable user. In taxiway systems, 'grey roads' are referred to as *apron taxiways*.

The **(Bio)mechanics** principle implies limiting differences in speed, direction, mass and size, and giving road users appropriate protection. Accordingly, fast-flowing traffic should either physically, or timewise be separated from slow moving traffic, traffic travelling in opposite direction, traffic with a substantially different mass or width, and hazardous obstacles. Within taxiway systems, generally no speed limits are defined, as these are aircraft and/or airline specific. Whether opposite directional flows are separated depends on the airport layout: at larger airports, directional taxiways may be used to separate flows, where at smaller airports separation is solely done by Air Traffic Control (ATC)-guidance. Separation of vehicles with substantially different masses on airport surfaces are found in the separation of aircraft from service vehicles. Service vehicles are generally only allowed on service-roads and not on taxiways, unless otherwise instructed by ATC. Besides, several airports handle (small) GA flights in separate areas on the aerodrome. Separation of hazardous obstacles is achieved through clearances.

In accordance with the **psychology** design principle, the design of a traffic system environment is well-aligned with the competencies and expectation of its users. Hence, the information from the traffic system should be perceivable, understandable ("self-explaining"), credible, relevant and feasible. Accordingly, safe road behaviour is ideally as little as possible subject to individual users' choices. Transferring information to road users is done by the road layout, the road environment, traffic signs and regulations. Within taxiway systems, no differences in layout are present. The environment only differs for aircraft stand taxilanes, which are located along aircraft stands. Yet, no environmental distinction between apron taxiways and aircraft stand taxilanes can be seen. Traffic signs in taxiway systems are referred to as visual aids.

The other two principles are *organizational principles*. **Responsibilities** should be allocated and institutionally embedded in such a way that they optimally support maximum safety as a result for all users. Within road networks, national governments are generally responsible for the system in the first place, and as such carries the ultimate responsibility with the inherent task to protect its citizens while simultaneously providing transport opportunities. Since taxiway systems are not necessarily part of the public space and airports might be privatized, it is questionable whether national governments have the ultimate responsibility for taxiway systems too. Nonetheless, all involved stakeholders should take their responsibility in maximizing safety within taxiway systems.

The final principle supports continuously **learning** and **innovating**. Therefore, the principle refers to the Deming cycle [15], starting with the development of effective and preventive system innovations based on knowledge of causes of occurrences (*Plan*). By implementing these innovations (*Do*), by monitoring their effectiveness (*Check*) and by making the necessary adjustments (*Act*), system innovation ultimately results in fewer occurrences. To support learning from past events, occurrence reports are collected in a central database by the European Union [16] if it is related to: (1) the operation of the aircraft (e.g. collision-related); (2) technical conditions, main-

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[2] In Sustainable Safety, an access road is a road for local access. It is not the type of 'access road' that is used in some countries to provide access to a major destination such as a port or an airport, most often a through-road [9].

tenance and repair of the aircraft; (3) air navigation services and facilities (e.g. (near) collisions, specific occurrences or operational occurrences); or (4) aerodromes and ground services (e.g. related to ground equipment). Within The Netherlands, the Inspectie Leefomgeving & Transport (*Human Environment and Transport Inspectorate*) (ILT) is responsible for collecting occurrence reports.

## 3. Analysis of AAS

To support the assessment of AAS's taxiway system to the described vision, several other analyses are performed [17]. Major findings of these analyses are provided in this section.

### *3.1. Airport configuration*

The configuration of AAS can be seen as a legacy of Jan Dellaert. His 1950s master plan for AAS formed the basis for the airport as it is known nowadays. Dellaert's plan, with a tangential runway system and a central traffic area, enabled the airport to operate at maximum capacity regardless of the wind direction. The by Schiphol and Royal Dutch Airlines (KLM) further elaborated plan was based on 100,000 annual movements and 2 million passengers around the 1970s/1980s [18]. As a result of the tangential runway system, the main taxiways (A, B, Q) create a 'ring road' around the central terminal area. In Figure 6, to be found at the end of this paper, an overview of the runways and major taxiways of AAS is presented.

### *3.2. Stakeholder Interviews*

To gain insights from AAS stakeholders and to support findings from other analyses, nineteen interviews were conducted amongst pilots, airport authorities, ATCOs, ground handlers, and airport consultants. The experienced problems at AAS that were most referred to are: (1) the regularity of non-standard operations, (2) difficulties for rare visitors and (3) the difficulty of the area around the threshold of runway 24 [17].

### *3.3. Heat Map*

A heat map of traffic flows, with annual movements per node, is created to gain insights on traffic intensities in the taxiway system. Since historic data on traffic movements within the taxiway system of AAS was not available for this research, a stochastic model is developed to generate the heat map [17].

Based on the heat map of AAS (Figure 1), busy areas appear to be around the central area (taxiways A and B) and taxiway V - to and from the Polderbaan (18R/36L). The high number of taxi movements on taxiway V can be explained by the high preference of usage of the Polderbaan within the by regulations defined runway configurations [19].

Within the central area of AAS, on the 'ring road' of taxiways, the traffic demand is relatively high on taxiways A and B, parallel to the Aalsmeerbaan and Kaagbaan. The busiest area within the taxiway system at AAS is the intersection of RET S4, taxiway B and taxiway A4. The main traffic flows on this node are: (1) Traffic vacating the Kaagbaan (06) via S4 (primary RET) or earlier; (2) arriving traffic from taxiway Q, taxiing towards the B-, C- or D-pier; and (3) departing traffic from the A-apron and B-pier routing towards the Kaagbaan (24) or North.

Figure 1: Heat map of traffic demand in the taxiway system of AAS

Moreover, all nodes around the threshold of runway 24 (Kaagbaan) showed to be crowded. In this area, many conflicting traffic flows occur: (1) Traffic departing from the Kaagbaan (24), taxiing towards one of the entries from all directions; (2) traffic departing from the A-apron, B-pier or C-pier taxiing to the North over taxiway B; and (3) arriving traffic for the C/D-bay from all directions.

Amongst the busiest nodes are also the Eastern and Western end-nodes of taxiway Q, showing this taxiway's importance within the taxiway system. Yet, this high demand does not necessarily cause problems since traffic flows on taxiway Q are generally unidirectional. Nonetheless, conflicting traffic flows may occur on the end-nodes.

### *3.4. Occurrence Report Data*

For this research, occurrence report data related to the taxiway system of AAS of the past decade is provided by the ILT from the European central database. To enable more detailed analysis within taxiway systems, nine specific categories are defined based on the occurrence categories [16] as mentioned in section 2:

- ***ATC***: Deviation from standard procedures by ATC;
- ***Lacking ATC***: Guidance of ATC is lacking;
- ***Flight Crew***: The flight crew deviates from the instruction of ATC or a standard procedure;
- ***Other vehicle***: An occurrence of an aircraft with another vehicle (no aircraft), e.g. tow movements on taxiways or service vehicle or ambulances on intersections of taxiways with service roads;
- ***Failure***: A failure within the taxiway system, such as Foreign Object Debris (FOD);

- ***Taxi speed***: The flight crew exceeds the maximum allowed taxi speed;
- ***Technical issue***: A technical issue with the aircraft;
- ***Pushback/docking***: An occurrence during pushback or docking at the stand.
- ***Other***: All other occurrences.

Each report is categorized in accordance with the above defined categories. Occurrences categorized as *technical issue, pushback/docking* and *other* are outside the scope of this research and are therefore not considered. In the end, the used data set contains 1,766 occurrence reports. Based on the number of movements in the time period of the data set [1], on average 3.7 occurrences per 10,000 movements within the taxiway system at AAS were encountered in the past decade. Figure 2 shows an increasing trend in the number of annual occurrences per 10,000 movements. A stabilization is seen after 2016, potentially suggesting positive results of the initiated Integral Safety Management System (ISMS). However, the occurrence report data does not permit any definite conclusions to be drawn regarding the number of occurrences, since legislation on reporting and reporting behaviour has changed over the years [20]: The reporting regulations by the European Union [16] are implemented by the National organizations between 2014 and 2017.

The majority of reports regards deviations by *flight crews* from instructions of ATC or from standard procedures (on average > 50%). Thereafter, the major contributing occurrence category (on average 27%) regards occurrences of aircraft with *other vehicles*, such as towing movements or service vehicles. Besides, a large increase in number of occurrence reports on *taxi speed* exceeding of the airline-specific maximum taxi speed is seen, which might (partly) be caused by increasingly monitoring taxi speeds by airlines. Notwithstanding, several causes for over-speeding can be found in the report data. Partly, over-speeds were performed by the flight crew on request of ATC. Three reported reasons for this request are: (1) to let the aircraft overtake a preceding aircraft to adjust the planned departure sequence, (2) to cross runway 18C/36C at intersection W5 before the runway is opened, or (3) to expedite vacating a runway after landing because of another runway on short final, which is also recognized by interviewed pilots. Moreover, a number of over-speeds were on request of the flight crew, primarily based on the pressure of arriving on time and meeting the schedule. In the end, the majority of over-speeds were unconsciously caused by the flight crews and were only momentary.

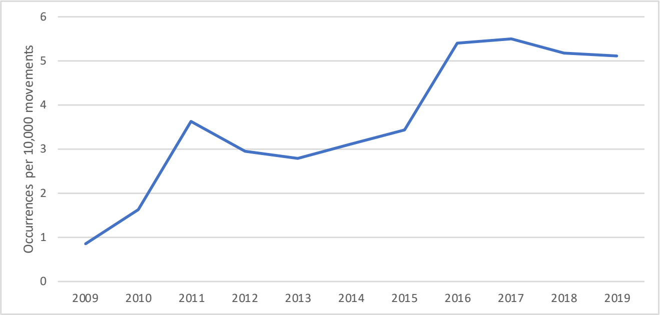

Figure 2: Number of occurrences per 10,000 movements

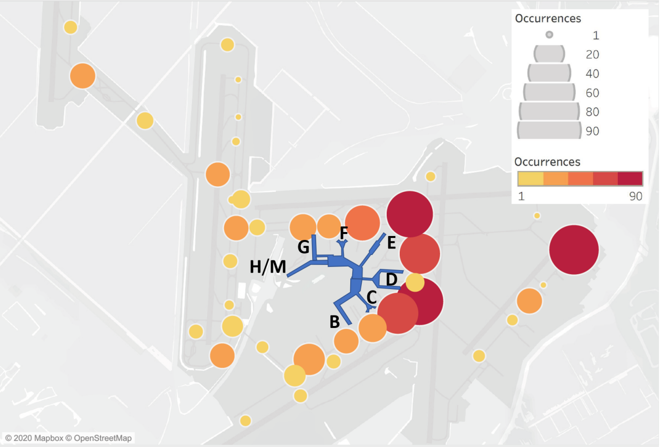

Figure 3: Black spots and zones of the taxiway system at AAS

The large share of occurrences related to deviations by *flight crews* seems a superficial observation. Flight crews are given the majority of the blame. Yet, to improve the system, a shift in focus is needed from individual blame to the system and related processes [21].

### 3.5. *Black Spot Analysis*

Although 846 of the 1,766 occurrence reports did not contain a location indication, a black spot analysis is performed. Black zones [22] were used since in a large part of the taxiway system (especially along taxiways A and B) intersections are located close to each other. Figure 3 shows the black spots and black zones of the taxiway system of AAS, from which several things can be concluded. Firstly, the largest black zones appear to be the area close to the threshold of runway 24, which also was identified as one of the busiest areas. Secondly, a high number of occurrences are reported in the North-East area of the ‘ring road’. A large number of runway exits/entries of two different runways are situated close to each other in this ‘corner’ of AAS’s central area. Besides, the major remote holding apron is located in the middle of the area, as well as three bays.

## 4. Sustainable Safety of AAS

As mentioned before, Dellaert’s master plan formed the basis of AAS’s tangential runway system. The ‘ring road’ of taxiways, parallel to the runways around the central traffic area, creates a boundary for expansion of piers. As a result, piers and adjacent aircraft stands are located very close to - and even along - through taxi routes on taxiways A and B, which users experience as undesirable and which is not in line with the design principles of sustainable safety. Furthermore, during taxi-in after landing, aircraft regularly have to hold due to unavailability of gates and stands.

In accordance with the **functionality** design principle, a network should have a hierarchical and functional structure. All bays around piers at AAS are designed by using *aircraft stand taxilane separation distances* and all other taxiways using *taxiway separation distances*. However, as mentioned before, also 'grey roads' [9] can be identified, namely apron taxiways. It was found that the definition and distinction of apron taxiways and aircraft stand taxilanes is debatable. The only difference in definition is that aircraft stand taxilanes exclusively provide access to aircraft stands, whereas apron taxiways (next to providing access to aircraft stands) also provide through taxi-routes. Since no strict definition of through taxi-routes is provided, airports could use the 'greyness' of the definition for the sake of handling increasing traffic demand, possibly undervaluing the impact on safety, by easier defining a taxiway as aircraft stand taxilane (requiring less horizontal spacing). Hence, the usage of the 'greyness' of the definition tends to be the result of 'practical drift' [23]: the system, procedures and regulations are designed in a theoretical environment with implicit assumptions (slower taxiing aircraft at aircraft stand taxilanes), which might differ in practice. Nonetheless, Figure 4 shows the clearly identified apron taxiways at AAS. These are designed with taxiway clearances, but also provide access to stands.

Two debatable aircraft stand taxilanes are shown in Figure 5. Within the left red circle in Figure 5, the currently as aircraft stand taxilane designed taxiways A19E and A19W are shown as apron taxiway. These taxiways are primarily used by Narrow Body aircraft (NaBo) aircraft to and from the H/M-pier, where taxiway A19C is used by Wide Body aircraft (WiBo) aircraft for access to G-stands. Hence, along the G-pier, taxiways A19E and A19W provide a through-route to the H/M-pier and taxi speeds might be expected to be relatively high for taxilanes.

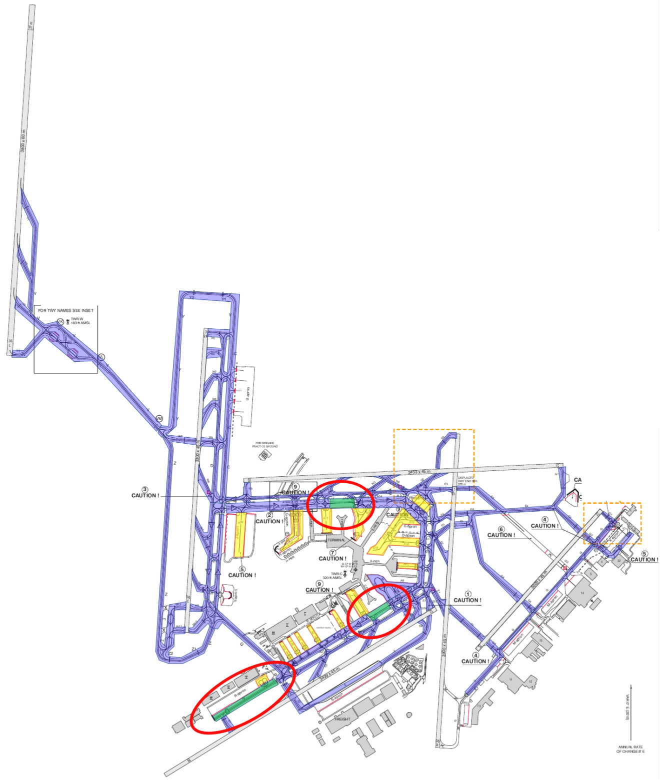

Figure 4: Taxiways (blue), Apron taxiways (green, red circled) and Aircraft Stand Taxilanes (yellow) at AAS

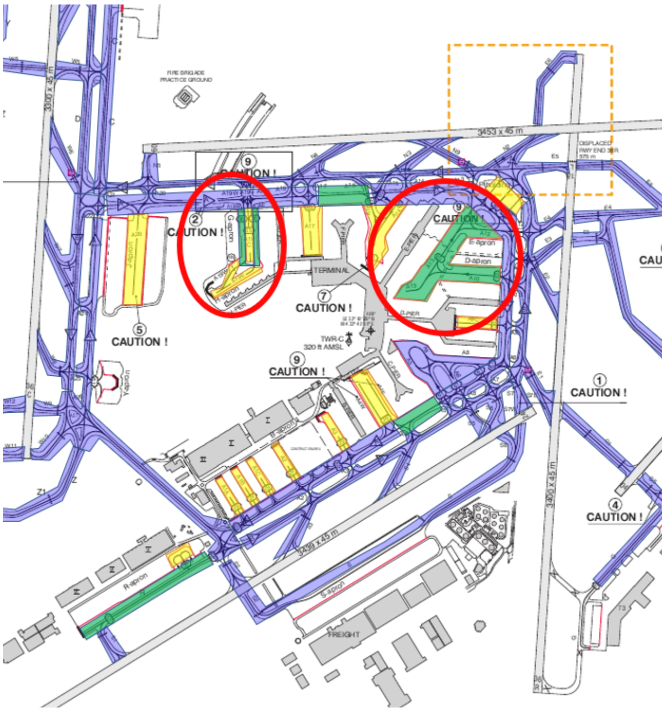

Figure 5: Debatable apron taxiways (green, red circled)

Within the right red circle in Figure 5, taxiways A10 and A13 are shown as apron taxiway. Although the taxiways are primarily used for accessing stands, pilots stated that they are seduced to taxi at relatively high speeds due to the extensive length of the bay. Therefore, it is suggested to conduct further research on introducing a maximum length of aircraft stand taxilanes.

The **(bio)mechanical** design principle advises separation of road users with differences in speed, direction, mass and size. No airport-specific maximum taxi speed is defined. Speed limits are airline-specific. Nonetheless, most commercial airlines use 30 *kts* as maximum taxi speed on straight taxiways. Pilots also stated that they generally taxi with lower speeds within the bays - which is in line with the design criteria for taxilanes. However, they also mentioned that on long taxilanes, speeds are still relatively high. Putting the aforementioned into perspective of other transportation systems, it can be considered as exceptional that there is no maximum speed for given infrastructure on airports. Within road and rail transport, the infrastructure-operator defines maximum speeds for specific parts of infrastructure in order to ensure safe operations. Therefore, it is suggested to explore possibilities of introducing a maximum speed by the airport operator. Additionally, introducing airport-specific maximum taxi speeds enables defining differences in maximum taxi speeds between taxiways and taxilanes, increasing the effectiveness of used decreased clearances at taxilanes, since it increases certainty on lower taxi speeds.

Separation in direction at AAS is primarily present on taxiways A and B with defined directions. Yet, pilots stated that ATC regularly deviates from these directions. Moreover, currently taxiway Q might be used in both directions alternately at the same time, increasing the chance of traffic standing opposite each other in case of inattention of either ATC or flight crews. Known crashes in the rail transportation (e.g. Westerpark Amsterdam with almost 200 injuries and 1 fatality) underpin the importance of mitigating the risk of opposite traffic [24]. Therefore, a parallel taxiway South of taxiway Q is currently being planned and constructed, to complete the double 'ringroad' of taxiways around the central area of AAS with separated directions [25].

Aircraft of different masses and sizes are partly separated in the taxiway system at AAS. The (smaller and lighter) GA-aircraft are handled at Schiphol East, separated from all commercial traffic (generally medium and heavy). Within the central commercial traffic area of AAS, also a separation of NaBo and WiBo can be seen: On the B-, C-, and H/M- pier, only NaBo aircraft are handled, on the D-pier a mixture of NaBo and WiBo aircraft is handled, where on the E-, F- and G-pier primarily WiBo aircraft are handled. Looking at the black spot analysis in Figure 3, keeping this separation in mind, it can be seen that the largest black spots and black zones are found in the area where NaBo and WiBo merge and mix. Therefore, it is suggested to conduct further research on the impact of mixing NaBo and WiBo aircraft in the taxiway system.

In accordance with the **psychology** principle, the system shall be "self-explaining". Hence, transferring information to users shall be done through the layout, the environment, visual aids and procedures. At several intersections in the taxiway system at AAS, information signs are used to indicate directions, as well as markings showing directions. However, no visual differences are seen by pilots on the distinction between apron taxiways and aircraft stand taxilanes. Both have aircraft stands along-side, and differences in clearances are too small to be perceived optically. Therefore, in order to increase awareness amongst pilots, it is suggested to investigate distinctions in visual aids for taxiways/apron taxiways and aircraft stand taxilanes; e.g. different colors of center line markings, dashed center line markings and different types or colors of center line lights.

Besides, the level of "self-explaining" is questionable within the taxiway system at AAS given the noticeable, and amongst pilots and airport representatives recognized, large number of deviations from standard procedures by both flight crews and ATC. It is also acknowledged that this might cause safety risks. By repeatedly deviating from procedures and standards without hazards, users are inclined to make the deviation a habit and taking the risk of deviating is accepted, also known as *normalization of deviance* [26]. Besides, once deviation is ingrained, rooting it out is challenging [21]. It is recommended to further investigate and reconsider the standards and procedures at AAS.

Moreover, interviewed pilots felt that for flight crews who visit AAS for the first time (or rarely), taxiing within the taxiway system might be very challenging due to the special conditions and usage of standard taxi routings. The airport's Operations department indicated to receive similar feedback on non-AAS based carriers having more difficulties resulting them in stopping more often and requiring more communication with ATC. It is acknowledged that investigating differences amongst (reported) occurrences of regular and irregular AAS visitors can be difficult in an international perspective[5]. Nonetheless, it is recommended to do so and treat rare visitors as vulnerable users, providing them special attention during operations.

Both Hillestad et al. [5] and the Dutch Safety Board [6] recommended to establish an organization in which stakeholders cooperate to improve safety management at AAS. Successively, the ISMS was founded, wherein Royal Schiphol Group joined forces with airlines, ATC, ground handlers and refueling services to take an integral approach to the management of safety at AAS [27]. Besides, the Dutch Government was recommended to take ultimate **responsibility** for the safety of air traffic at and around AAS.

Despite the tangential runway system, the number of runway configuration changes at AAS is extremely high in an international context. Due to the tangential system, most changes are not weather based. Instead, 90% of the on average 18 daily configuration changes are related to noise regulations, resulting in a contradiction. The Dutch government requires AAS to follow up recommendations of the Dutch Safety Board [6] to reduce the daily number of runway configuration changes on the one hand, where on the other hand the Dutch government set the regulations on noise restrictions causing the high number of changes. The current situation tends to be an over-optimization for a single aspect, namely noise complaints from local residents. Moreover, where the Dutch Safety Board focuses on safety implications of this large number of daily configuration changes for the runway system, it should be recognized that a runway configuration change also impacts the taxiway system: each runway configuration results in a certain traffic flow of taxiing aircraft. Hence, each runway configuration change causes a different traffic flow within the taxiway system too, eventually leading to conflicting traffic flows. Besides, the large number of changes decreases the predictability for flight crews on taxi routings, making operations more complex. Consequently, the Dutch government should take responsibility for the extensive number of runway configuration changes at AAS related to noise.

The continuously **learning** and **innovating** loop is described by the Deming cycle [9, 15]. Gaining knowledge on causes of occurrences within the taxiway system of AAS is done by the ILT and Dutch Safety Board. However, room for improvement was found on the occurrence report data. In order to increase and improve opportunities of analyzing the occurrence data report, all reports should be written in English. Additionally, in order to increase accuracy of the black spot analysis, each report for occurrences within airports should contain a specific location indicator (e.g. intersection name or coordinate). Nonetheless, based on gained knowledge, Straube et al. [28] concluded that radio communication for guidance of aircraft during taxiing is near the capacity limit at many airports. Therefore, through the

Single European Sky ATM Research (SESAR) program, a surface traffic management concept was developed (*Plan*), which provides individual guidance to taxiing aircraft by automatically and progressively activating taxiway centerline lights along the route cleared by the ATCO: ‘Follow the Greens’ [29]. It has been validated that ‘Follow the Greens’ is a safer, quicker and greener surface traffic management concept [28]. At AAS, a project on Advanced Surface Movement Guidance and Control System (ASMGCS) has started. In this project, ‘Follow the Greens’ is presented as one of the alternatives. However, since fully implementing the technique requires extensive time and investments, first and early version of ‘Follow the Greens’ was installed at the intersection of taxiways W5, V, Y and Z as a proof of concept for AAS (*Do* and *Check*).

For the long term, the European Commission [30] defined topics for research in order increase safety and to reduce fuel consumption and emissions in surface operations at airports, which may also be valuable for AAS. Therefore, AAS shall keep abreast of the latest developments of this research and anticipate on eventual required adjustments on the taxiway system.

## 5. Conclusions and recommendations

In this paper, for the first time a taxiway system is assessed on the Sustainable Safety vision. Based on the case-study of AAS, assessing taxiway systems on Sustainable Safety showed to be valuable, by denoting challenges and opportunities towards improvements. Besides, it is expected that Sustainable Safety might be of added value in (re)designing taxiway systems. Human factors are the thread in the vision, with special attention for vulnerable users. In taxiway systems, rare visitors can be considered as vulnerable users, since they appear to have difficulties in operating within rather complex taxiway systems such as AAS.

On the operational safety of the taxiway system at AAS, the following can be concluded. The present taxiway system seems to be safe, yet shows challenges and opportunities for improvements. Looking at the legacy of AAS, Dellaert’s 1950s master plan showed to deliver a solid airport system. The design, based on 2 million passengers and 100,000 movements in the 1970s/1980s, appeared to be able to handle 71.7 million passengers and almost 500,000 movements last year with extended terminal areas and piers in the by Dellaert designated central traffic area and one additional runway. Nonetheless, pressure from ATC on flight crews seems to increase and the present taxiway system tends to reach its safe operational limits, suggesting the system reached the ‘wear-out’ phase of the bathtub curve [31]. This might partly be caused by the ‘practical drift’ throughout the years. Hence, the assessment exposed various specific topics for further research. Below, recommendations are provided.

Due to a lacking strict definition of through taxi-routes in ICAO’s Annex 14, it appears that the ‘greyness’ of the definition of apron taxiways is utilized by the airport in order to handle the peak traffic demands within the set systems boundaries. Therefore, it is suggested to conduct further research on introducing a maximum length of aircraft stand taxilanes. To increase the effectiveness of decreased separation distances at taxilanes, it is suggested to explore possibilities of introducing a maximum speed by the airport operator. Introducing airport specific maximum taxi speeds enables the implementation of a difference in speed limits for taxiways and taxilanes. Additionally, in order to increase awareness amongst pilots, it is suggested to investigate distinctions in visual aids for taxiways/apron taxiways and aircraft stand taxilanes; for example different colors of center line markings, dashed center line markings and different types or colors of center line lights.

Within the taxiway system of AAS, *normalization of deviance* [26] seems ingrained: both flight crews and ATC regularly deviate from standards and procedures. Past incidents in both aviation and rail underpinned the consequent safety risks of the deviance. To improve the system, a shift in focus is needed from individual blame to the system and related processes [21]. Therefore, it is recommended to investigate and reconsider the applicable standards and procedures at AAS. Moreover, it is recommended to investigate differences amongst (reported) occurrences of regular and irregular AAS visitors and investigate how to ensure safe operations for both, despite the acknowledged difficulties in international perspective [5].

From the black spot analysis it can be seen that the largest black spots and black zones are found in the area where NaBo and WiBo merge and mix. Therefore, it is suggested to conduct further research on the impact of mixing NaBo and WiBo aircraft in the taxiway system.

The 16 daily runway configuration changes at AAS related to noise regulations tend to be an over-optimization for a single aspect. Consequently, the Dutch government should take responsibility for the extensive number of runway configuration changes at AAS related to noise. A trade-off is recommended on the benefits of current noise regulations for local residents on the one hand, and side effects which include a consequently high number of runway configuration changes implying safety risks, on the other hand. In this trade-off, it should be acknowledged that runway configuration changes not only impact the safety around runways, but also within the taxiway system due to changes in traffic flows.

Despite the steps the aviation industry in The Netherlands has made towards an integral approach on safety, care must be taken to ensure that the taxiway system is not underexposed and that safety continuously remains a first considerations and is not unnecessarily or unconsciously subordinated.

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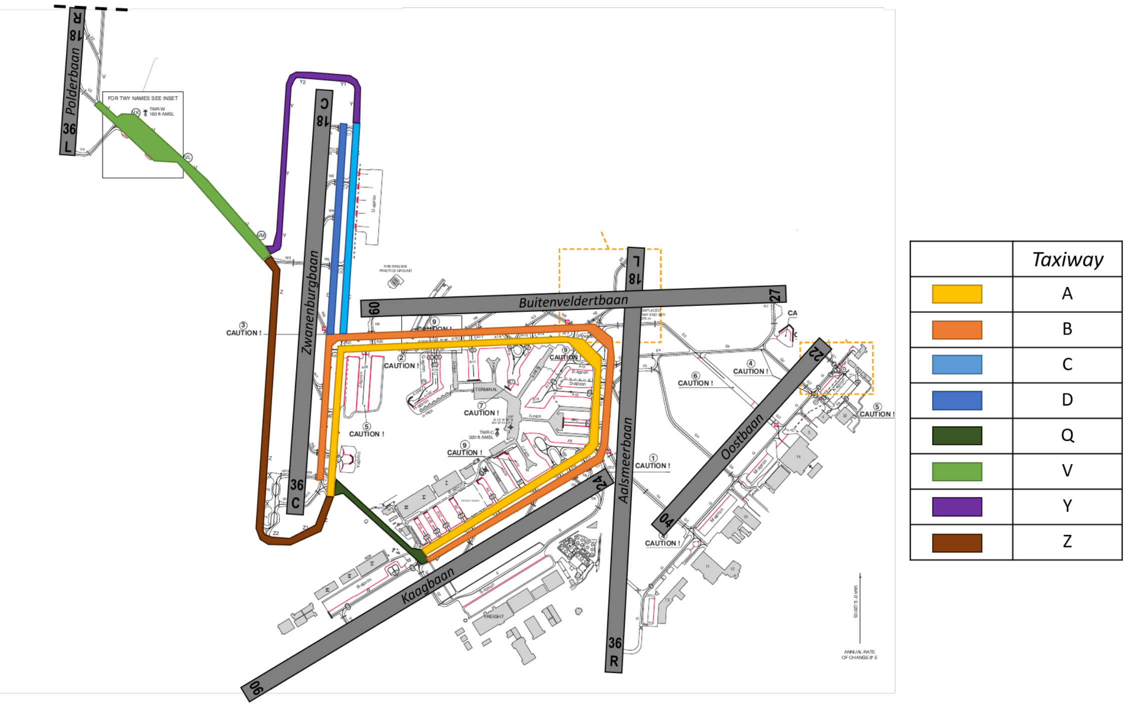

Figure 6: Runways and major taxiways at AAS

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