THE NEED FOR A COLLISION PREVENTION SYSTEM FOR THE PUSHBACK OF AIRCRAFT

TO MINIMIZE HAZARDS CAUSED BY NARROW SPACES, BAD VISUAL CONDITIONS AND OTHER FACTORS

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Abstract

Although the pushback of an aircraft holds several hazards, which results often in expensive aircraft damage and unfortunately also in injuries and fatalities of the ground personnel, the ground process is underrepresented in research and development up to now. Based on an elaborated, detailed empirical hazard-cause analysis the paper supplies evidence for the need of a system supported pushback process. A main finding of the analysis is the increasing incident/accident rate regarding collisions between the pushed aircraft and another aircraft or fixed objects. Taking into account the expected air traffic growth in the future this circumstance is alarming and provides a fundamental motivation for the development of a collision prevention system. A delineation of the argued pushback collision prevention system is given by the paper furthermore.

1 Introduction

In 2009 the Australian Transport Safety Bureau (ATSB) stated "Ground operations[1] are potentially one of the most dangerous areas of aircraft operation" [1]. In fact, in the year 2004 alone a survey of Airport Council International (ACI) counted 3.233 incidents and accidents (922 with aircraft involved) at aprons of 193 airports worldwide. From 1998 to 2004 the respondent airports reported even 32.295 incidents/accidents; aircraft were involved in 9.588 of these occurrences [2]. The extreme high numbers of incidents/accidents separately at aprons are alarming. The majority of the ground operation occurrences result almost in incidents with minor safety effects. But because of the enormous numbers of occurrences the financial strain of major airlines worldwide is staggering. In the context of a Ground Accident Prevention (GAP) program the Flight Safety Foundation estimated the costs of ramp accidents worldwide at least US$10billion a year [3]. Additionally, the risk of injury for ground personnel should not be undervalued. From 1998-2004 ACI counted 1.287 injured persons at aprons. Seven fatalities are to bewail. 76 persons sustained serious injuries [2].

A ground operation process, which holds a particularly high risk of injury, is the pushback of an aircraft. Pushing back an aircraft is necessary when an aircraft is unable to leave the aircraft stand itself with engine power because of the modality of stand ingress and basically egress. Due to capacity aspects, airports arrange the aircraft stands with a tug-assisted push-out to minimize the separation between adjacent aircraft on other stands, buildings or other objects. The tug (also tractor) driver must push the aircraft within a narrow passageway to a target position on the centerline of a taxilane/taxiway or to a safe area at the apron. According to Grabowski et al. 38.1% of the registered fatalities at U.S. airports from 1983-

[1] The ATSB defines ground operations as operations involving aircraft handling, and operations of aircraft and ground vehicle on aprons, taxiways and other airport areas, excluding the safety zone of active runways.

2004 are referred to activities for aircraft stand egress or ingress, including pushback [4]. According to a pushback-specific study of Dell 46 persons were injured during pushback operations worldwide from 1964-1992 [5]. The obvious risk of injury is based on the close proximity of the ground personnel to the nose gear, main gear and/or pushback tug in conjunction with the kinetic energy of the moving aircraft and the tug [5, 6]. Actually the mentioned circumstances hypothesize a selective attention regarding pushback operations. But still research and development disregard this issue, especially in the context of A-SMGCS. Up to now, no comprehensive incident/accident analysis of the pushback process is available. Only the studies of Dell and ATSB provide a pushback related, but context limited view of the problems.

2 Hazards of the Current Pushback Process

2.1 The pushback process

The basic pushback process, which is illustrated in Fig. 1, is similar at airports worldwide. In detail the pushback procedure depends on local conditions and effective regulations at airports. For example the necessary pushback clearance could be either requested by the flight crew, by the handling agent[2] or by the tug driver. Still the common practice is the pushback support by a handling agent. The handling agent performs the tasks of communication with the flight crew and safeguarding of an obstacle free maneuvering area. Physically the person walks besides the aircraft or is situated in the tug if possible and instructed. The extensions of the walk-out assistance by additional wing-walkers, who expand the four-eyes principle is still widely-used [6], but should be reduced as discussed later. Technically the pushback operation can be performed either with a towbar (a tug to aircraft link) or towbarless. For the latter, the nose gear is directly locked onto a platform and then lifted.

[2] Also ramp agent, lead agent or dispatcher.

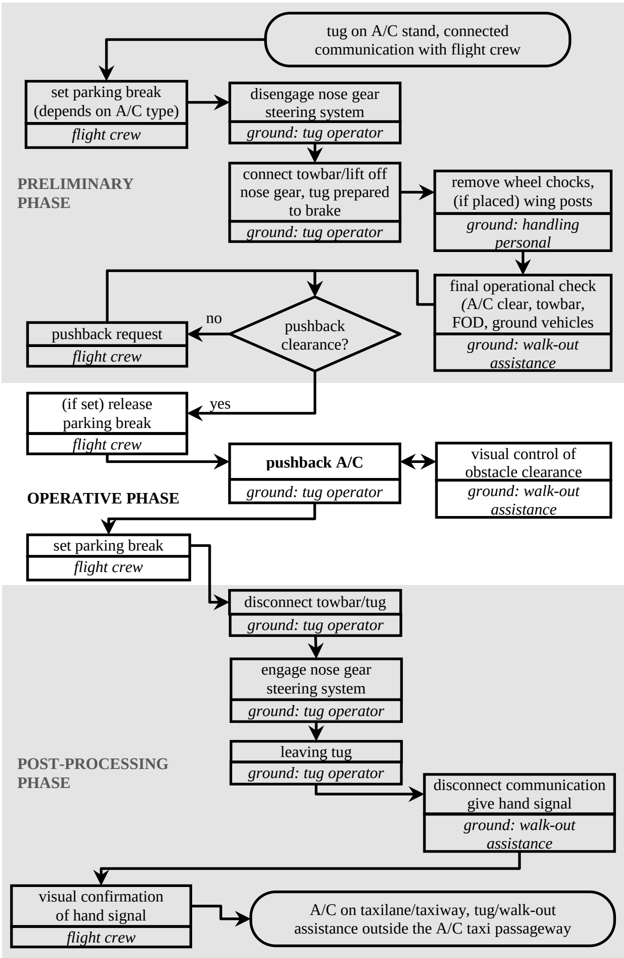

Fig. 1. The basic process of aircraft (A/C) pushback

2.2 The Incident/Accident Analysis

Pushback operations hold certain risks regarding the injury of personnel and the damage of an aircraft and/or equipment. An investigation of pushback accidents/incidents discloses 240 occurrences at U.S. airports from 1978-2010. The analysis is based on data from the National Transport Safety Board (NTSB), complemented by the Accident/Incident Data System (AIDS) of the FAA. Double data sets were eliminated. The used data involve commercial air carriers referred to Title 14, CFR Part 121|125|129 exclusively. Because of the poor informative value of the reports before the year 1990 only 179 occurrences could be analyzed in detail from 1991-2010. Furthermore to determine incident/accident rates the Air Traffic Activity Data System (ATADS), a database of FAA from 1991 till now, was used. The ATADS provides complete yearly traffic data, differentiated in air carrier, air taxi, general aviation and military.

Presenting a worldwide perspective is difficult. A comparison with the ICAO Accident/Incident Data Reporting (ADREP) system, which is recently embedded in the non-public ICAO Integrated Trend Analysis and Reporting System (iStars), shows a data gap. ADREP comprised approximately half of the NTSB registered events. AIDS registered events with mostly minor or none aircraft were not found in ADREP. Hence exclusively occurrences at U.S. airports were investigated to get a complete picture. A discussion regarding the transferability of the U.S. related results is carried out later.

The reported occurrences are distinguished regarding their safety effects in four categories:

- Category 1: Damage to/by pushed aircraft (A/C) to/by other moving/pushed, stationary aircraft (A/C) or fixed objects
- Category 2: Damage to/by pushed aircraft to/by tug or towbar
- Category 3: Damage to pushed aircraft by apron equipment or ground vehicle (except tug or towbar)
- Category 4: Ground/aircraft crew injuries and fatalities during pushback.

An overview of the basic investigation data is given in Tab. 1.

occurrences	1978-2010	1991-2010	1991-2010
	absolute	absolute	relative
category 1	82	57	31.8%
category 2	82	63	35.2%
category 3	54	40	22.4%
category 4	22	19	10.6%
sum	*240*	*179*	*100%*

Tab. 1. Basic investigation data of pushback incidents and accidents at U.S. airports, 1978-2010

2.3 Identification of Hazards

2.3.1 Category 1: Damage A/C – A/C or fixed object

Round about three times a year an aircraft collides with another aircraft or fixed object, like a blast or airport fence or a floodlight mast during pushback at U.S. airports. In the context of the incident/accident analysis five typical collision scenarios could be identified, which are illustrated in Fig. 2 to 6 exemplary.

The frequent collision scenario 1 (20 occurrences) is characterized by a collision of a pushed aircraft with another aircraft on an adjacent aircraft stand or with a fixed object in the vicinity of the pushed aircraft. Narrow spaces and their undervaluing are the causes for this type of collision.

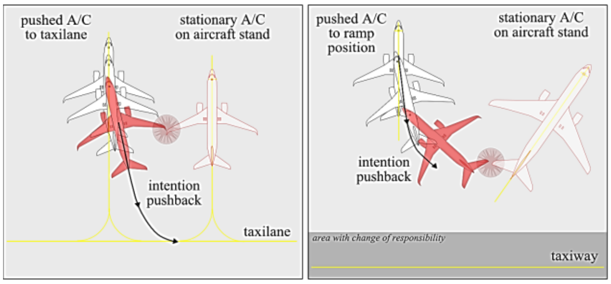

Fig. 2. Collision scenario 1

As result of pushback operations the wrong positioning of the aircraft at the apron within the safety zone of a taxiway (collision scenario 2) led to 11 collisions with taxiing aircraft. After the completed pushback the flight crew intents the beginning of taxi; with a procedure turn if necessary. Because of the limited view the flight crew of the pushback completed, waiting aircraft as well as the flight crew of the taxiing aircraft are not always aware of the hazardous situation. So it must be the task of the tug driver to position the aircraft in a safe distance to the taxiing aircraft. The causes for category 2 occurrences are missing markings for pushback, especially of a target aircraft positioning point/line or the neglecting of these markings or given procedures. It has to be noted that this problem is specific for small ramp areas in responsibility of an airline or an aerodrome management service. A taxiing guidance and control within the apron is not envisaged. For taxiing a change to the ATC controlled maneuvering area is necessary. But without a clearance the aircraft has to wait at the apron. In Europe an aircraft is pushed to a taxilane, which is in legitimate responsibility by apron control. A positioning of the pushed aircraft at the taxilane centerline assures a sufficient separation to parallel taxilanes or taxiways.

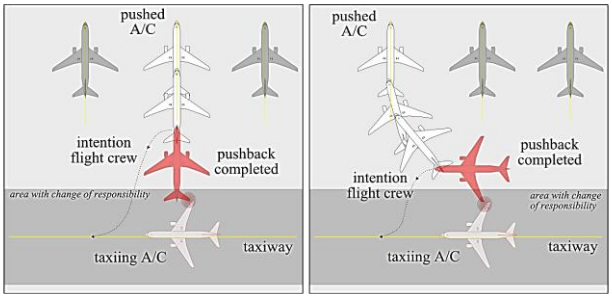

Fig. 3. Collision scenario 2

The collision scenarios 3 and 4 are similar to scenario 1. But now the affected aircraft is situated at an opposite aircraft stand or stationary at the taxilane.

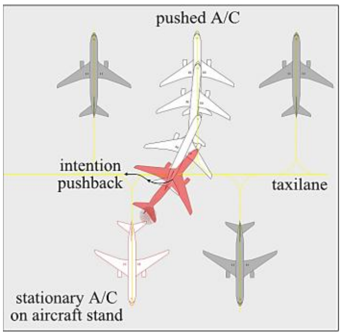

Fig. 4. Collision scenario 3

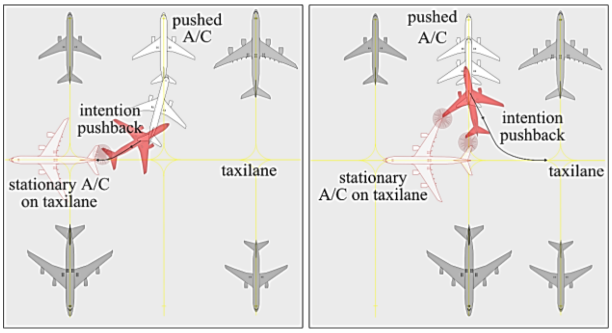

Fig. 5. Collision scenario 4

Collisions during simultaneous pushback operations (scenario 5) caused by mistaken or without pushback clearances are very infrequent currently.

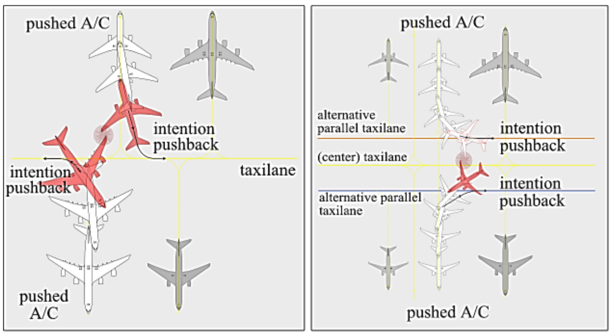

Fig. 6. Collision scenario 5

The right picture of Fig. 6 shows the interesting aspect of a simultaneous opposite pushback to an alternative parallel taxilane (APT), as permitted at the airport Munich (Germany). The procedure holds the hazard of a confusion by the tug driver regarding the cleared taxilane, which could result in a collision with another pushed aircraft or a taxiing aircraft at the second APT. Because of this hazard and possible jet blast effects on ground personnel simultaneous opposite pushbacks are not permitted in the majority of the airports [7]. An overview of the absolute and relative numbers of the classified occurrences is given in Tab. 2.

occurrences	absolute	relative
collision scenario 1	20	35.1%
collision scenario 2	11	19.3%
collision scenario 3	11	19.3%
collision scenario 4	8	14.0%
collision scenario 5	3	5.3%
collision scenario 1 or 3*	4	7.0%
* (imprecise report regarding the course of events)		

Tab. 2. Numbers of occurrences at U.S. airports, classified in collision scenarios, 1991-2010

The occurrences of category 1 underline clearly the challenge for the tug driver to push the aircraft within a narrow passageway. Additionally the driver sees the taxilane centerline as important guidance not before its immediate reaching because of the long distances at pushback beginning and the resulting very small visual angle from the floor-mounted tug-cockpit. Figure 7 illustrates the visual relations schematically.

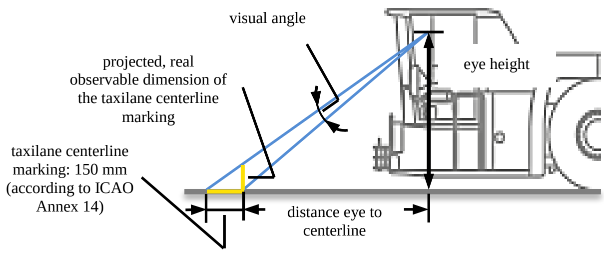

Fig. 7. Schematic diagram of the taxilane visibility

Assuming a seat height of 1.0 m to 1.5 m and a resulting eye height of 1.85 m to 2.35 m (seating size for 95% of male according to DIN 33 402, the German standards of human body sizes) the real observable dimension (width) of the taxilane centerline marking is determined. Fig. 8 shows these dimensions of the noticed taxilane in millimeters depending on the distance to the taxilane. It is evident, that the tug driver (and also the assistants) is not able to notice a line of 2 mm in a distance of 130.5 m (80 m aircraft stand length + 50.5 m half taxilane width for ICAO code F) at pushback beginning. The smallest visual angle is 20'', which is seen by the human eye [8]. So a close distance to the taxilane of around 10 m is necessary to identify the centerline certainly.

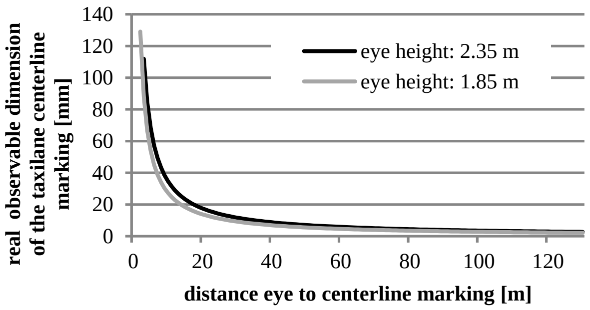

Fig. 8. Real visual observed width of the taxilane centerline marking in dependency on the distance between eye to taxilane

Hence the driver has to look for distinctive points like grooves, scratches or edges of ground plates at the apron surface to start the turn. Only few airports provide special markings for pushback. Furthermore neuralgic parts of the aircraft, like the tail cone or the horizontal stabilizer are often not visible to the tug driver. This aspect is also significant for the attending ground personnel and could be a reason for the high number of collisions between pushed aircraft and obstacles occurred in spite of pushback attendance, like Fig. 9 shows. Another reason is the long distance between the pushback participants, especially between wing walker and tug driver. The coordination is often characterized by a face-to-face interaction without wireless communication support. In case of an identified conflict by a wing walker the remaining time could not be sufficient to achieve the tug driver's attention for stopping the pushback immediately. In spite of innovative approaches to solve this problem [6] the analysis results suggest the provocative question: do the advantages of the pushback assistance legitimate the high risks of injury for the ground personnel?

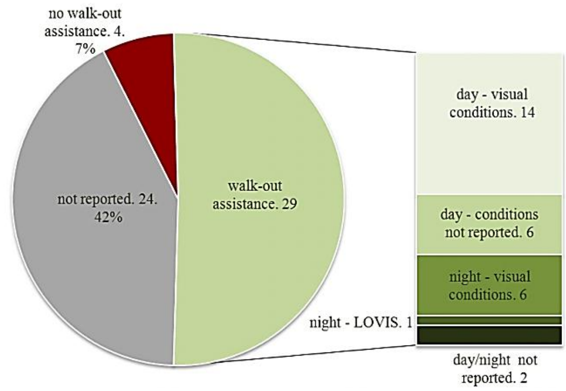

Fig. 9. Collisions categorized regarding the conditions of assistance and weather

A dependency on weather conditions could not be verified with the investigated data.

2.3.2 Category 2: Damage A/C – tug/towbar

With 63 incidents category 2 occurrences are the greatest part of the analyzed data. This category includes the technical hazards of pushback, as the detailed list of causes in Tab. 3 presents. A frequent hazard is the jackknife of the tug. Caused by poor surface conditions or inadequate driver operations the tug deflects the nose gear over a maximum allowable deflection angle. In the worst case the nose gear has to be replaced because of unduly torques. According to airline information the costs could amount to a half million U.S. $ for a new B747 nose gear.

Another hazard of the pushback operation is the missed hand signal "free for taxi" given by the ground crew. Flight crews begin taxiing assuming that the disconnection of the tug is completed and the ground crew left the aircraft vicinity. This mistake could result in a collision with the tug and leads to a very dangerous situation for the ground crew. One occurrence of the category 4 (see 2.3.4) resulted in a serious injury of a ground crew member because the aircraft rolled over his leg. The aircraft sustained no damage [9]. In the case of events listed below in Tab. 3 no serious or fatal injuries occurred fortunately. But aircraft sustained minor or substantial damages. The reason for mistakes is the poor situational awareness of the flight crew regarding the ground operations because of the limited aircraft cockpit view and the given concentration to fulfill the standard operation procedures (SOPs). This can result in communicational misinterpretation or lack of clarity regarding a given or not given hand signal. In the past many airlines sensitized their pilots to this hazard.

collision by	caused by	occ.
tug/ towbar	jackknife of the tug because of	
	poor surface conditions	10
	high speed, abrupt stop o. a.	5
	defect of the tug	3
	icy surface – no braking action	1
	loss of connection tug to aircraft (causation not specified)	8
	broken towbar	5
	broken shear pin	5
aircraft	aircraft defect	4
	unintentional moving aircraft	7
	mistakes/lack of hand signal "free"	8
	parallel engine start (e.g. wrong power setting)	3
	released/not released parking break	2
	collapsed nose gear	4
	sum	*65* ‡

‡ Comparing to Tab. 1 two pushback occurrences are listed in category 4 but caused also substantial aircraft damage.

Tab. 3. Occurrences of damage to/by pushed aircraft to/by tug or towbar at U.S. airports from 1991-2010

Providing technical solutions to reduce category 2 hazards is difficult. In addition to the maintenance (e.g. of the towbar), an adequate use of equipment and accordant training aspects are important efforts.

2.3.3 Category 3: Damage A/C – ground vehicle

Surprisingly aircraft damages caused by collisions with ground vehicles or equipment (others than tug or towbar) are not the biggest part of the analyzed data. From 1991 to 2010 the number of 40 occurrences was reported. A significant correlation with weather conditions is not verifiable with the present data. Only few events are caused by pushback maneuvering mistakes or by neglecting of the final operational check regarding a clear ramp area. In the majority of the occurrences the vehicle driver/equipment operator is responsible for the collision. Referring to ground operation related studies [1, 2] it can be assumed, that the dark figure of category 3 incidents is higher in reality, whether with minor or none damage for aircraft. A specific reason for the underrepresented category 3 could be a poor reporting caused by a fear of retribution or damage to the reputation of staff, airport or the handling company.

Effective improvements to reduce category 3 events are anticipated with the implementation of the A-SMGCS functionalities at airports. The A-SMGCS implementation Level 3 envisages the providing of a moving map with displayed active aircrafts for ground vehicles [10]. Then the vehicle drivers are able to minimize their risk of injury because of a better situational awareness, especially in case of bad weather or obstacle caused limited visual conditions.

2.3.4 Category 4: Injuries and fatalities

Three fatalities and 16 serious injuries of ground and flight personnel occurred during pushback operations from 1991-2010 at U.S. airports (see Tab. 4). 18 additional persons suffered minor injuries while being involved in incidents of category 2 and 3.

accident/incidents		fatalities	serious injuries
walk out assistance	contact with nose gear	1	4
	contact with tug	1	1
	other causes (towbar …)	0	3
tug operator	contact with aircraft	1	5
aircraft cabin crew	(abrupt) pushback stop or begin	0	3
	sum	*3*	*16*

Tab. 4. Ground/aircraft crew injuries and fatalities during pushback at U.S. airports from 1991-2010

The pushback holds risks of injury for the tug driver especially in case of a breakaway of the connection from tug to aircraft and a resulting uncontrolled aircraft movement in the direction of tug. In addition the pushback involves the risk of injury of the attending walking personnel. The operation with a walk-out assistance requires a good awareness and consequently a high workload of the tug driver. A survey pointed out that tug driver advocate to move the handling agent on the pushback tug [5]. Also the NTSB criticized the unnecessary and unsafe procedure of required ground personnel close to the nose gear and recommended that the Air Transport Association (ATA) „Urge member air carriers to conduct pushback operations in a manner that eliminates the need for ground service personnel to be close to the airplane landing gear while the airplane is in motion" [11]. In the meantime procedure changes referring to this are implemented at some airports and by major airlines [6,12], but are not standardized worldwide.

2.4 Target Level of Safety

Fortunately the imaginable worst case: a hull loss accident with multiple fatalities caused by a fracture of an aircraft tank and following combustion as result of a pushback collision has not happened up to now, but it is possible. Considering the increasing rate of category 1 incidents/accidents (see Fig. 10) an urgent need for actions exists. The determinations of the incident/accident rates are based on traffic data of ATADS: The data comprehend traffic data of commercial air carriers (excluding air taxi, general aviation and military). The rates are modeled with the very conservative approach: 100% of outbound traffic needs pushback. This approach covers pushback/towing events for maintenance and flight preparation, which additionally take place to scheduled flight operations and are not counted in the ATADS.
The incident/accident rate of category 4 decreases since 1991 and reflects the efforts regarding the risk minimization of injury, as described below. The decreasing trends of category 2 and 3 occurrences need further verification in the next years to come to make a significant statement.

According to the NTSB definition of accidents, which complies with ICAO Annex 13, 81 occurrences with substantial aircraft damage (62) or fatalities (3) or serious injuries (16) were recorded. With reference to the ATADS traffic data from 1991-2010 and assuming a 100% pushback quota for outbound traffic

- an accident rate of 6.0E-07 (8.0E-07 assuming a 75% pushback quota)
- a fatal accident rate of 2.2E-08 (2.9E-07 assuming a 75% pushback quota)

are determined. Comparing these figures to the formal A-SMGCS Target Level of Safety (TLS) equaling 1.0E-08 [13], obviously a violation of the TLS is given!

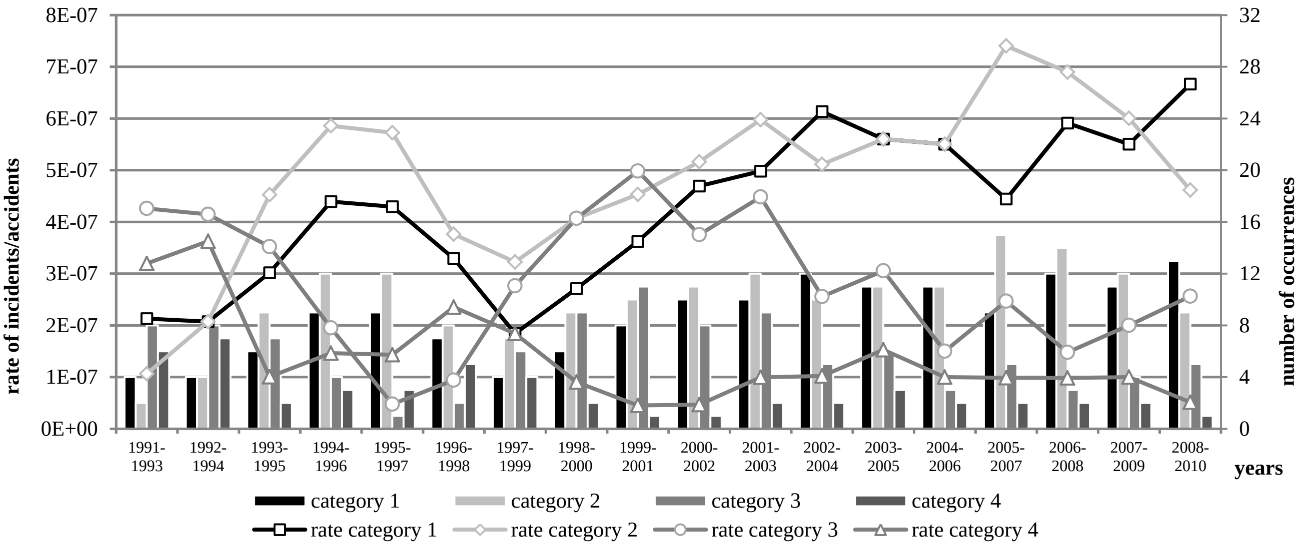

Fig. 10. Categorized pushback occurrences and their corresponding incidents/accident rates, U.S. aiports, 1991-2010

2.5 Conclusion

Current pushback operations are characterized by:

- interactions close to the aircraft with ground personal (tug driver, handling agent, wing walkers)
- minimum distances between an aircraft on stand and adjacent buildings, aircraft on other stands and/or other objects
- minimum distances between pushed aircraft in direction of/on taxilane-centerline and other aircraft and objects
- a limited view of the tug driver and the walk-out assistance.

All these facts combined with time pressure and stress of the ground crew and high traffic [5,14,15] frame the current operational environment of the pushback at many airports worldwide. The empirical analysis shows a worrying hazard situation at U.S. airports. It can be assumed that the outlined hazard situation and problems are similar in other regions of the world with comparable standards, like Europe. An indication for that is given in the mentioned study of ATSB. From 1998 to 2008 the ATSB identified 74 diverse pushback occurrences at Australian airport [1], in average seven events per year. According to the aircraft movement (outbound) at Australian airports in the given time period an overall incident/ accident rate of 2.77E-06 is determined. Compared to the presented U.S. related analysis with 179 occurrences from 1991-2010 and an overall incident/accident rate of 1.32E-06 the assumed transferability of the results seem to be coherent.

The determined violation of the A-SMGCS TLS clearly underlines the urgent necessity of actions and the correctness of the ATSB criticism: „There has been less industry-wide attention on risk controls to improve safety in ground operations” [1]. The attention of ground operations hazard control (inclusive pushback) is almost limited to proposed human related measures, such as improved education and training, establishing safety committees, control of procedure compliance [2,16,17]. Of course the measures wisely meet with the discussed hazards but seem to be exhausted. So the question arises: why pushback operations are not supported by an engineering solution which prevents collisions and eliminates the requirement of attending ground personnel. The motivation to develop such a collision prevention system is also justified by monetary aspects. The impact of pushback occurrences are not only direct damage of an aircraft but also economic consequences due to flight cancelations, financial equivalents for passengers and others. Taking into account, that an apron incident costs $250.000 in average [18], the costs for system development and tooling and user training should be amortized in a passable time. Furthermore the reduction of risks for ground personnel and saving of life are invaluable.

2.6 Trends and affected developments

Well founded in economic pressures primarily the interesting trend of single pushback (also one-man pushback) is noticed at smaller airports with low or medium traffic and with an uncritical obstacle environment. The unattended pushback is operated only by the tug driver, who also is responsible for the communication with the flight crew and the engine start procedure during or after pushback. At concerned German airports no negative safety effects are observable up to now. But to implement this procedure at airports with high traffic and/or difficult obstacle environment a system support should be provided.

Still, the pushback of an aircraft - like other ground maneuvering processes at airports - is based on the principle “see and avoid”. Operations under low weather caused visibility conditions (LOVIS) result in a decrease of capacities and inefficient use of resources. The main intention of the Advanced Surface Movement Guidance and Control System (A-SMGCS) is to overcome these dependencies at airports worldwide. But efforts in the context of A-SMGCS concentrate on implementations of adapted equipment for surveillance of aircraft and ground moving vehicles and developments of support tools and displays to provide routing and guidance functionalities for taxiing aircraft. Surprisingly, pushback is out of scope of current research and development as well as conceptual definitions. A system supported aircraft pushback is the evident and essential measure to comply with the envisaged seamless, weather independent "gate-to-gate" business trajectory concept as set out in SESAR or NextGen [19].

Lastly, a paradigm shift becomes apparent. Motived by environmental and fuel saving considerations, aircraft taxiing without engine power is current in development and already partly in testing phases. One of the general approaches of aircraft taxiing without engine power is the use of electrical motors in the main gear or nose gear of the aircraft, powered by the auxiliary power unit (APU) or fuel cell aircraft (the other approach: taxiing with a modified tug). In December 2011 an A320 of Lufthansa, equipped with electrical motors, imposingly demonstrated forward as well as backward maneuvers at Frankfurt airport. Using this technology for "rollback" operations necessarily results in fundamental changes for the pushback and its participants, but provides the advantages of reduction of handling resources and equipment, saving of taxi-out time and offering significant reduction of aircraft damage risk through elimination of tug-aircraft-connection related hazards (see category 2 occurrences) [19]. Because of the limited cockpit view a "rollback" under steering control of the legitimate responsible flight crew needs also an adequate system support to operate without vulnerable ground personnel. A system development should take into account this (redundancy) aspect.

3 Delineation of a Pushback Collision Prevention System

Fig. 11 illustrates a system architecture approach of the aimed collision prevention system for aircraft pushback. Corresponding to the presented conclusion a pushback support system has to provide primarily:

- the actual aircraft position at the apron and the obstacle (fixed and aircraft) environment to obtain an adequate situation awareness
- the ideal pushback trajectory as reference
- a look-ahead assessment of possible dangerous approaches in consideration of actual aircraft parameters (e.g. nose wheel angle, speed)
- a warning notice in the case of a conflict
- a stop instruction in the case of an imminent collision.

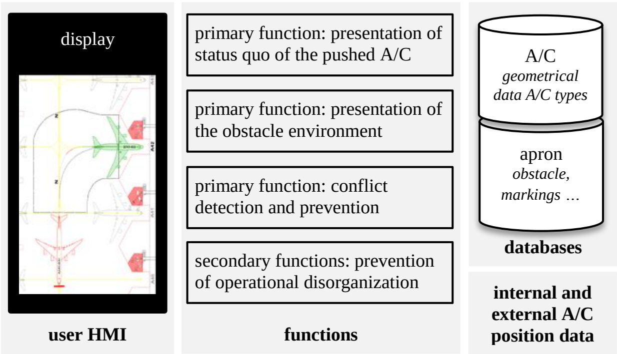

Fig. 11. System architecture approach of a pushback collision prevention system

A fulfill of these requirements is a challenge undoubtedly, especially regarding the providing of adequate aircraft position data. The current achieved ground-based surveillance system performance [20] does not conform to requirements of pushback operations. Furthermore the current, in the context of A-SMGCS used elliptical contour and defined expansion of a protection zone (e.g. in [21]) is unsuitable for a pushback safety assessment function. As the left picture of Fig. 12 shows such a zone would trigger an alert also in case of uncritical situations. The right picture of Fig. 12 provides an approach for a more suitable pushback protection zone.

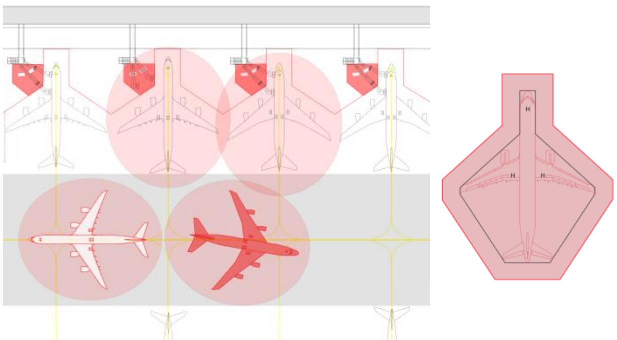

Fig. 12. Unsuitable and practical protection zone for a system support

4 Outlook

Safety improvements of the current pushback process require sophisticated engineering solutions. The delineated pushback support system is a probate application to reduce pushback hazards significantly but needs further research and development. The next steps are the modeling and validating of pushback trajectories (with/without tug) and the identification of the optimal pushback trajectory within a safe maneuvering corridor. The trajectory has to be a function of costs for tire load and pushback process time. To provide a conflict and collision warning an efficient conflict detection algorithm and safety assessment method have to be developed furthermore. All this functions must comply with the requirement of the on-time-performance.

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