AVAILABLE OPERATIONAL TIME WINDOW (AOTW):

A METHOD FOR EVALUATING AND MONITORING AIRLINE PROCEDURES

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Abstract:

Airline Standard Operational Procedures (SOPs) define the sequence of flight crew actions to handle the set of mission situations that can emerge in the execution of a commercial airline flight. Failure to complete an SOP within an Allowable Operational Time Window (AOTW) can result in a hazardous outcome. For dynamic plants (e.g. airliner) the AOTW is a distribution that varies with the interaction between environment, plant, and operator actions. For complex systems, such as airliners, the AOTW is not always known a-priori and can change over time without notification.

This paper describes a method to characterize the AOTW distribution for procedures using data traditionally used for maintenance and aircraft performance analysis. A three step process is described: identify time-critical events with hazardous outcomes, map time-stamped data to the events, and generate AOTW time distributions. A case study analysis of a procedure for airline operations demonstrates how the AOTW can be used for procedure design and for monitoring procedure efficacy in a way that supplements existing anomaly detection analyses by capturing changes in the operational environment that affect the execution of the procedures. The implication of these results for monitoring safety margins and the limitations of this method are discussed.

SECTION 1 INTRODUCTION

Airline flight deck operations are governed by airline Standard Operating Procedures (SOPs). These SOPs identify the flight crew actions in response to all plausible situations that might emerge in the execution of a revenue-service airline flight. By standardizing procedures, the airline can ensure safe and efficient operations that are in adherence to its overall operational philosophy and policies (Barshi, Mauro, Degani, & Loukopoulou , 2016; Degani, & Wiener, 1997). The SOPs also enable crew members to be paired with other crew members with whom they may have never flown before, and to provide the basis for objective flight crew proficiency evaluation.

An SOP is a (conditional) sequence of operator actions designed to move the system from one safe state (e.g. intermediate approach segment) to another safe state (e.g. final approach segment). SOPs must ensure that there will be no known situations in which an event or a disturbance will unexpectedly drive the system to an unsafe state (Degani, Heyman, Shafto, 1999). For example reaching a phase a flight without configuring the aircraft control surfaces appropriately.

When executing a procedure that involves a dynamical system (e.g. airliner), the operators are in a race against the vehicle, and the vehicle systems, to complete the procedure before a hazardous state is reached. In this way each SOP must be performed within an Allowable Operational Time Window (AOTW) (Figure 1).

Due to the complex environment in which the procedure is performed, the AOTW is not a fixed time but a time distribution that can exhibit a large variance. The variance is a result of a large number of uncontrollable factors including: aircraft performance, atmospheric conditions (e.g. temperature, wind), air traffic navigation procedures and instructions, air traffic and other external factors that affect the flight trajectory and the flight operations.

One of the requirements for procedure design is to ensure that the sequence of conditional actions can be completed within the AOTW defined by the circumstances of each flight. Methods for this analysis of procedure include Time-line Analysis (Lauderman et.a l.19xx), Key-Stroke Level Mdoel (Card, Moran, Newlll, 1980), state-transition models (Degani & Heyman, 1999), and human-the-loop testing. Traditionally the time-on-task from these models is constrained by a discrete AOTW.

This paper describes an analytical method to use the recently available Flight Data Monitoring (FDM)/Flight Operations Quality Assurance (FOQA), typically used for aircraft performance and maintenance purposes, to characterize a stochastic AOTW. This data can be used in time-line analysis, state-machine and other models to verify procedures.

The method is demonstrated in a case study **of the airline** takeoff procedure. The case study highlighted the variance in the AOTW for four segments of an airline takeoff procedure. The 5^{th} %-tile for the four segments ranged from 28% of the mean to 60% of the mean. At worst case, this yielded 5.39 SOP actions per second. At best case, one SOP action every two seconds. The AOTW for one of the segments exhibited a bi-modal time distribution that was a result of a change in air traffic operations at one location. This change, managed by an adaptation to the procedure by the flight crews in the field that extended the AOTW to allow for the interruption, was not known by the SOP designers.

This paper is organized as follows: Section 2 provides an overview of SOPs and SOPP Design. Section 3 describes the method for characterization of the AOTW. Section 4 describes a case-study for the takeoff procedure for a jet aircraft. Section 5 provides a discussion of the implications of this method.

SECTION 2: PROCEDURES AND PROCEDURE DESIGN AND TESTING

An SOP is a (conditional) sequence of operator actions performed by the flight crew in response to emerging situations in the operation of an airline flight.

The SOPs, categorized into normal, non-normal procedures, specify: (1) what task to perform, (2) when to perform the task (timing and sequence), (3) what actions are required to perform the task, (4) who conducts the task (i.e. pilot-flying (PF) or pilot-monitoring (PM)), and (5) what feedback to provide (i.e., call-outs) (Barshi, Mauro, Degani, Loukopoulou , 2016; Degani & Wiener, 1997).

Each SOP is composed of a conditional sequence of operator actions. For example, during a segment of the takeoff procedure, between aircraft rotation (i.e. nose-up) and the first flap retraction airspeed, the flight crew must accomplish the following tasks in the exact sequence to establish the required aircraft state before the next task can be performed: (1) climb at the required pitch angle, (2) maintain the required airspeed, (3) raise the landing gear, (4) engage the autopilot, (5) select the NAV mode on the autopilot, (6) reduce thrust, and (7) set a new airspeed target on the autopilot Mode Control Panel (MCP).

By completing the action within the allowable operational time window the system is migrated from one safe state (e.g. intermediate approach segment) to another safe state (e.g. final approach segment). A well designed SOP ensures that there will be no known situations in which an event or a disturbance will unexpectedly drive the system to an unsafe state (Degani, Heyman, Shafto, 1999).

Definition of Terms

The time to complete the SOP actions is known as Time on Procedure (ToP). The Allowable Operational Time Window (AOTW) is the time in which the SOP must be completed before a hazardous state is achieved. The Procedure Buffer Time (PBT) is the difference between the AOTW and the ToP (Figure 1). A positive PBT indicates that the SOP was completed in a timely manner. A negative PBT indicates that the completion of the SOP took too long and may have resulted in a hazardous condition.

Neither the AOTW or the ToP is a fixed number and can exhibit significant variance. The variance for the AOTW is a result of a large number of uncontrollable factors including: aircraft performance, atmospheric conditions (e.g. temperature, wind), air traffic navigation procedures and instructions, air traffic and other external factors that affect the flight trajectory and the flight operations. Likewise the ToP can vary due to factors such as the availability of information to perform the next action, aircraft performance, individual technique, variability in attention and reaction times, and fatigue. The scatter-plot in Figure 1 illustrates the variance in AOTW and ToP resulting in a distribution for PBT.

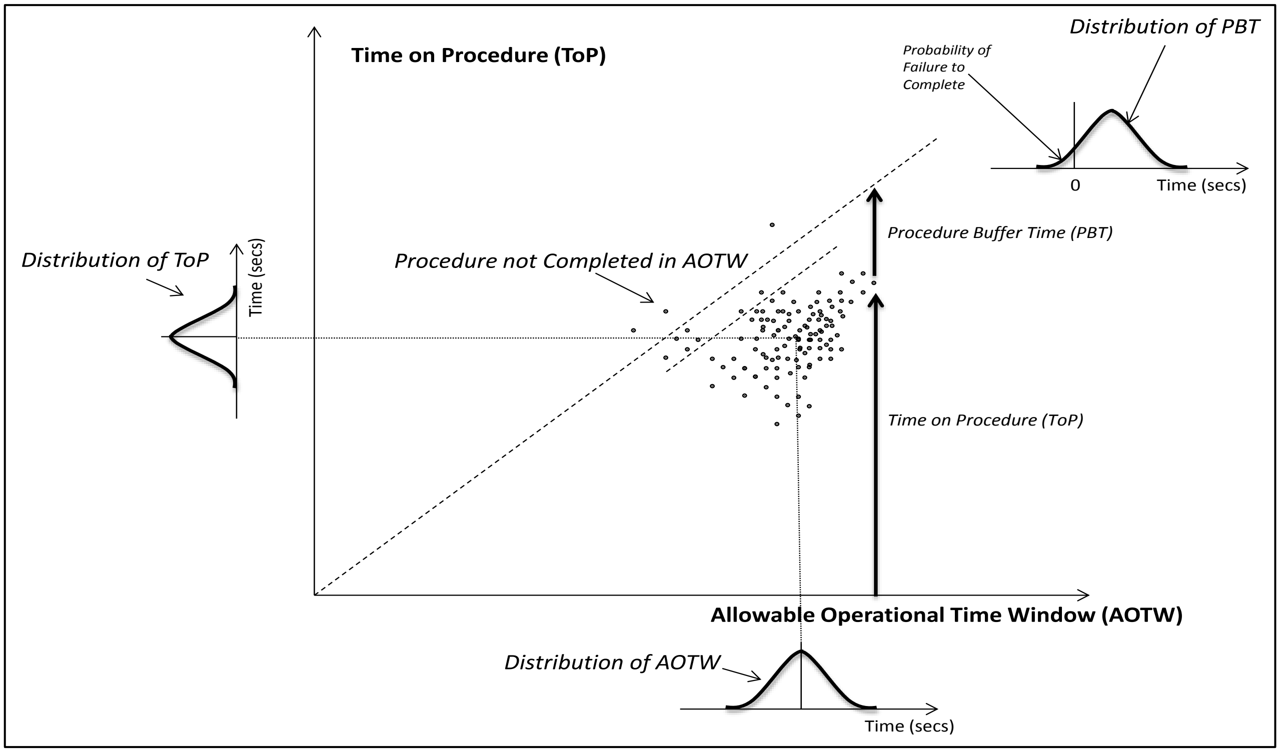

FIGURE. 1: Scatter-plot of ToP and AOTW for a set of flights yield distributions for ToP relative to the AOTW. The difference between the AOTW and the ToP for a given flight is the Procedure Buffer Time (PBT).

When the ToP is in excess of the AOTW it may be of no consequence, or it may place the aircraft in a potentially hazardous situation (e.g. flap over-speed, altitude deviation), or result in an inefficiency (e.g. extra leg in a Holding Pattern, extended along-track distance, go-around). The percentage of the PBT distribution that is less than zero determines the Probability of Failure to Complete (PFtoC) the procedure on time (Figure 1). A PFtoC for a procedure less than a design threshold (e.g. 0.05) could serve as a quantitative indication that the procedure is verified.

Procedure Design and Testing

The Federal Aviation Administration (FAA) Advisory Circular AC 120-71A “Standard Operating Procedures for Flight Deck Crewmembers” provides guidelines on the background, basic concepts, and philosophy of SOPs (FAA, 2003; FAA, 2016). To meet these guidelines, SOPs must be carefully designed to maintain appropriate workload by ensuring the sequential execution of actions and by ensuring the correct information is available before it is required in the procedure (Degani & Wiener, 1997).

Most often, procedures are designed by the aircraft manufacturer with primary, if not exclusive, attention to intended use of aircraft systems and the engineering requirements. The procedures are then adapted by the airlines to reflect company philosophy, policy, and the type and location of operations. The modified procedures are vetted by a team of experts with human factors, aircraft systems, and operations knowledge.

Following the review process, the procedures can be validated empirically by testing them against the behavior of regular pilots (Barshi, et. al., 2016, page 51]. The test takes place in a flight simulator using a sample of the target population of pilots to serve as subjects for the test. Due to the complexity of the operating environment, even a well-funded test with 20 flight crews, may not be able to cover all the plausible scenarios that can occur that constrain the design of a procedure.

Using Time to Evaluate Procedures

Time is a widely accepted means for evaluation of procedures under naturalistic and experimental conditions as it offers a common unit of measurement of measurement of operator performance in the context of the task. Time is correlated with errors (De Keyser, 1995), performance (Raby & Wickens, 1994), and task loading (Gawron, 2000). Alternative methods for evaluating procedures include using design methods such as Time-line Analysis (Lauderman et.a l.19xx), state-transition models (Degani & Heyman, 1999), and simulations using models such as the Key Stroke Level Model (Card, Moran & Newell, 1980). For all the above methods, the designer/analyst must have knowledge of the stochastic properties of the AOTW. Not just the mean, but also, critically, the 5^{th} percentile which serves as the shortest time to complete the procedure. Information on the AOTW is not readily available.

This paper describes the use of the recently available Flight Data Monitoring (FDM)/Flight Operations Quality Assurance (FOQA), typically used for aircraft performance and maintenance purposes, to characterize the AOTW.

SECTION 3: CALCULATING THE AOTW DISTRIBUTION

This section describes the FDM/FOQA data and the method used to derive the AOTW distribution.

Data

FDM or FOQA data can provide time-stamp for each event. The time stamp is the time when the event occurred. For example, the time that the aircraft achieve the V_1 speed. Example FDM/FOQA data and time stamps are shown in Appendix B.

Determining Segments of a Procedure

An airline SOP can be defined as a sequence of actions. These actions include: (1) physical/motor actions (e.g. select NAV1 button, place hand on throttles, set autopilot speed to 146 knots), (2) call-outs (e.g. “GEAR UP”), and (3) perceptual actions (e.g. visually check FMA “AP” is green). Many of these actions must be completed before a specific operational event to avoid a hazardous outcome such as an over speed (e.g. flap overspeed on takeoff), violating airspace restrictions (e.g. altitude deviation, turn radius deviation), and separation restrictions or unstable approach resulting in a go-around.

One class of these events are generally associated with the position of the aircraft in three-dimensional space. For example, failure to raise the Clearance Altitude prior to reaching the altitude capture point can result in an altitude deviation (Learmount, 1994), or failure to perform actions can result in separation or airspace violations. Another class of these events is associated with aircraft trajectory. For example, failure to retract the flaps prior to reaching the maximum safe operating airspeed for the current flap setting can result in a flap over speed hazard.

Events associated with hazardous or inefficient outcomes are considered time-critical hazard events and define the segments of a procedure. For example, the events associated with the Takeoff procedure for a jet (see Appendix A) and their potential hazardous outcomes are illustrated in Figure 2.

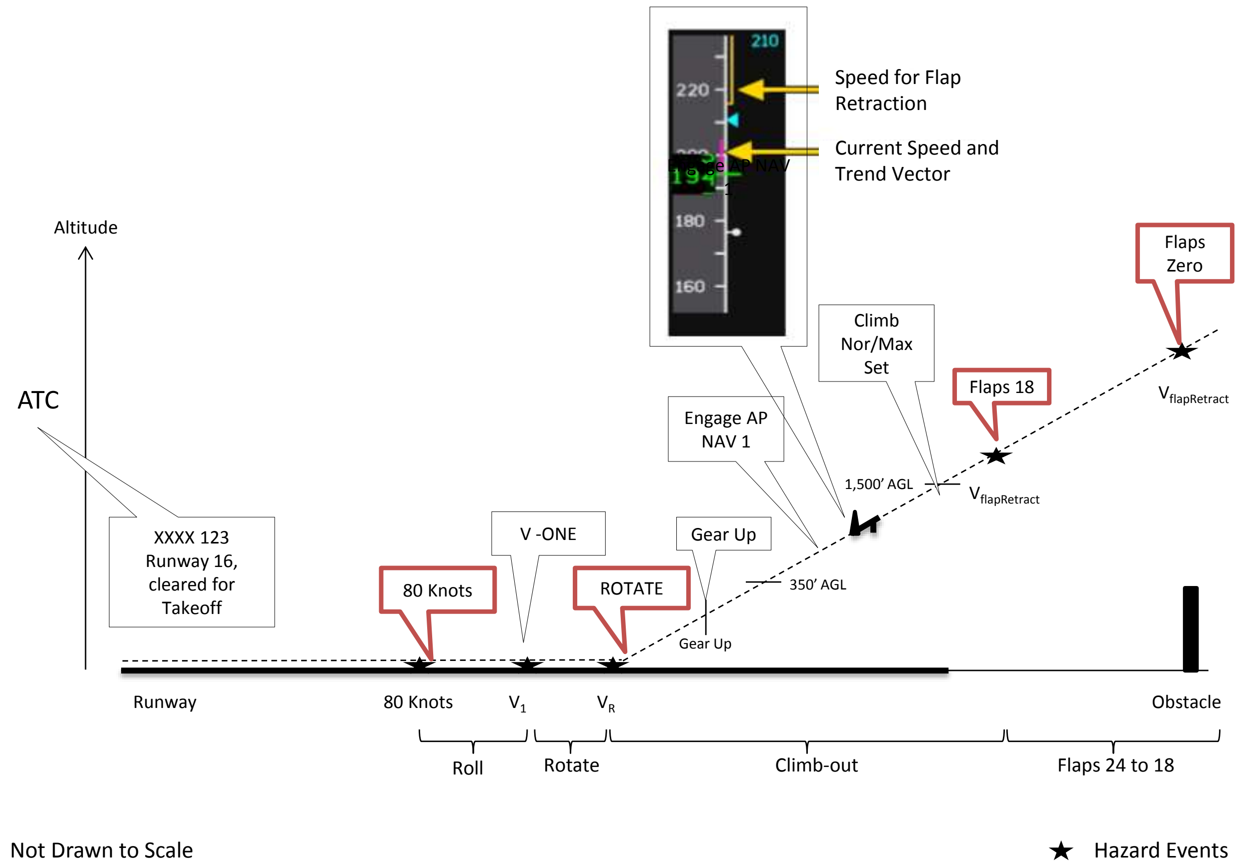

FIGURE 2: Summary of takeoff SOP for jet airliner. SOP includes 79 actions that can be divided into 4 segments determined by time-critical events

An analysis of the actions in a Flaps 24 takeoff procedure, listed in Appendix A, identified time critical hazard events: 80 knots, V_1, V_R, V_{F18} and V_{F0}. Four segments of the procedure between these events are summarized in Table 1.

TABLE 1: Example SOP Events and Segments

Time-critical Hazard Events	Segment of Procedure	Outcome
80 knots to V_1	Roll	Hazard: runway excursion

		Hazard: Insufficient thrust
V_1 to V_R	Rotate	Hazard: stall from early rotate, extended takeoff roll for early rotate Hazard: obstacle clearance from late rotate Hazard: tail strike
V_R to V_{F18} (schedule speed for flap retraction from 24^o to 18^o)	Climb-out	Hazard: flap over speed from late retraction Hazard: stall from early retraction of flap
V_{F18} to V_{F0} (schedule speed for flap retraction from 18^o to 0^o)	Flap Retraction	Hazard: flap over speed from late retraction Hazard: stall from early retraction of flap

Calculating the AOTW Distribution between Critical Events (i.e. Segments)

The AOTW for Segment x, flight i, or $AOTW\ (x_i)$ is the difference between the time stamps for sequential critical events in a flight.

$$AOTW\ (x_i) = t@Critical\ Point_{(i,2)} - t@Critical\ Point_{(i,1)}$$

Where: $i\ is\ the\ flight\ index$

The distribution for AOTW for each Segment, across all flights is the aggregation of these flights. The statistical parameters of this distribution can be calculated as follows:

To characterize the AOTW, measures and metrics were defined:

(1) Number of SOP actions done by the flight crew between two critical events

(2) 5th percentile of the AOTW distribution as a measure to how fact the segment can get

$$5th\ percentile\ \ AOTW\ (x) = \mu_{AOTW} + Z_{0.05} * \sigma_{AOTW}$$

(3) 95th percentile to have a sense of the right tail of the distributions, or the slower cases

$$95th\ \% - tile\ \ AOTW\ (x) = \mu_{AOTW} + Z_{0.95} * \sigma_{AOTW}$$

(4) Median

$$Median\ AOTW\ (x) = \left\{\frac{(n+1)}{2}\right\}^{th} Value$$

(5) Mean

$$Mean\ AOTW\ (x) = \frac{\sum_i^n AOTW(x)}{n}$$

Where:

i is the flight index

n is the number of total recorded flights

x is the procedure segment

(6) Standard Deviation

(7) Skew are the parameters that enable the visualization of the distribution, and the metrics

(8) Signal-to-Noise Ratio to measure the variability relative to the mean

(9) Action Tempo is the fraction of the number of actions to the 5th percentile as an estimation the workload.

Action Temp = $\left({}^{Actions}/_{5th\ Percentile\ Time}\right)$.

SECTION 4: CASE STUDY – TAKEOFF PROCEDURE

The Takeoff Procedure for a jet aircraft is one of the most complex procedures in the airline revenue service mission. The aircraft must generate sufficient lift to become airborne within the constraints of the runway length and aircraft performance, and then climbout with sufficient lift to generate a climb rate that will avoid obstacles (Figure 2). During this procedure the aircraft is physically reconfigured from “ground operations” to “airborne operations” by retracting the landing gear and by retracting the high lift (but high drag) flaps on the wings to for low drag flight. The procedure includes several time-critical events with potential for hazardous outcomes summarized in Figure 2 and Table 1 above.

The SOP for the takeoff procedure for a jet aircraft, listed in Appendix A, is described by 79 actions. These actions include physical/motor actions (e.g. select Flaps 18^{o}), verbal communication (e.g. call outs) and perceptual actions (e.g. visual check of parameter). Although not shown as part of the procedure, all of the actions are associated with various types of cognitive demands (e.g. decision-making).

FDM data for 5,312 departures for a jet aircraft were analyzed. Among these, 1,042 flights were performed with 24^{o} flap configuration for takeoff and departed from multiple airports. The flights occurred between January 2014 and June 2014.

The analysis of the Takeoff Procedure identified 5 time-critical events associated with hazardous outcomes (Table 1 above).

Results

The AOTW for the 4 segments of the Takeoff procedure are summarized in Table 2. The Takeoff Roll segment from 80 knots the V1 decision airspeed has 7 SOP actions. The AOTW for the actions ranges between 0 seconds and 18 seconds depending on the acceleration of the aircraft based on aircraft performance, runway conditions and weather. The distribution skewed with a right tail. To meet the 5^{th} percentile AOTW, the flight crew would need to perform 2.8 SOP actions per second. This is an estimation of the tempo at which the flight crew should perform their actions in the fastest operations.

The Rotate segment of the procedure has 3 SOP actions. The AOTW ranges between 0 and 8.5 seconds. The distribution is symmetrical with a median of 3.3 seconds and a mean of 3.4 seconds. To meet the 5th percentile AOTW tempo, the flight crew would need to perform 2.4 SOP actions per second.

The Climbout segment from rotation speed to the speed to retract flaps from 24^{o} to 18^{o}, is the highest workload segment with 27 SOP actions. These SOP actions include: gear-up, engage autopilot, engage NAV, thrust reduction, and setting the speed on the MCP. The AOTW ranges between 3.5 and 97 seconds. The distribution is skewed to the right with a median of 8.5 seconds and a mean of 20.9 seconds. To meet the 5th percentile AOTW tempo, the flight crew would need to perform 5.39 SOP actions per second.

The Flaps Retraction segment from the speed to retract flaps from 18^{o} to 0^{o} has 13 SOP actions. The AOTW ranges between 23.8 and 288.8 seconds. The distribution is skewed to the right with a median of 109.6 seconds and a mean of 6.5 seconds. To meet the 5th percentile AOTW tempo, the flight crew would need to perform 0.2 SOP actions per second.

TABLE 2: Summary of AOTW Statistics

			AOTW Distributions (sec.)							
Segments	**Critical Events**	**SOP actions in this Segment**	**5th % tile**	**Median**	**Mean**	**95% tile**	**Std.**	**Skew**	**Signal-to-Noise**	**5th%tile Action Tempo (sec^{-1})**
Roll (80 kts. to V_1)	Hazard: V1 is final decision event to abort takeoff and stop the aircraft before the end of the runway	7	2.5	6.3	6.5	12.5	2.6	1.1	2.5	2.80
Rotate (V_1 to	Efficiency: VR is the airspeed to pitch the aircraft up	3	1.3	3.3	3.4	6.0	1.4	0.4	2.4	2.40

V_R)	to climb (i.e. rotate)									
Climbout (V_R to V_{F18})	Hazard: VF18 is the airspeed at which the Flaps must be retracted (from 24^0) to 18^0 to avoid an over speed	27	5.0	8.5	20.9	73.2	22.4	1.5	0.9	5.39
Flap 18 to 0 (V_{F18} to V_{F0})	Hazard: VF0 is the airspeed at which the Flaps must be fully retracted (i.e. Zero degrees) to avoid an over speed	13	66.1	109.6	118.5	189.0	42.0	0.6	0.2	0.20

The AOTW time distributions for each of the 4 segments of the procedure are shown in Figure 3.

The distribution for V1 to VR segment is symmetric. However, the other 3 segments are asymmetric with long right-tailed distributions.

The distribution for the Flap Retraction segments (i.e.: from V_{F18} to V_{F0}), in particular exhibits a bimodal form. Analysis of aircraft dynamics for this segment showed that service operating out a specific airport required an immediate turn during the takeoff procedure. Although not specified explicitly in the procedure, company procedure is to add 10 knots to the Flap Retract target speed and delay the retraction of the flaps until the aircraft is wings level. In this data set 44% of the flights performed a turn and retracted flaps later than the standard schedule speed, resulting in a longer AOTW and a change of workload. Although the flight crews routinely perform this procedure without issues using guidance in other parts of the operator procedure manual, the deviation from the procedure is not explicitly documented in the takeoff procedure. In this case the additional 10 knots is sufficient delay to complete the turn.

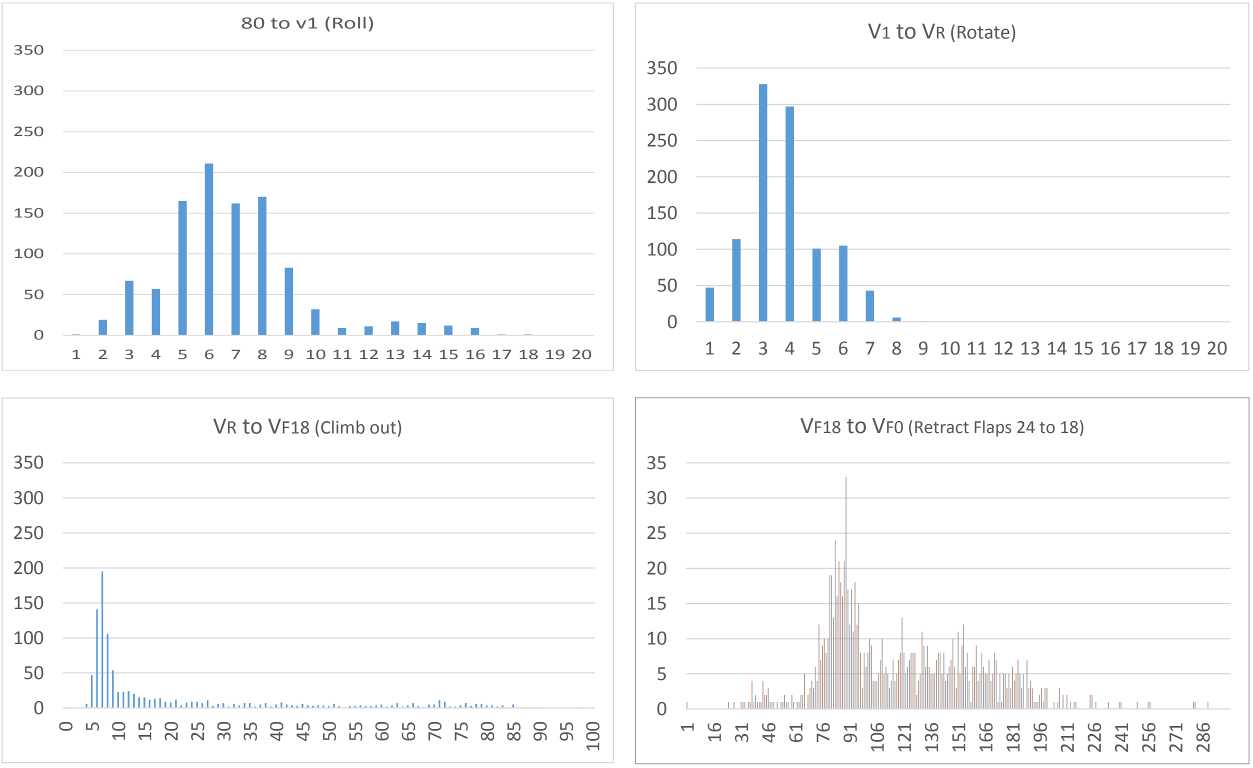

FIGURE 3: Distributions for the 4 segments of the Takeoff Procedure: (a) Takeoff Roll, (b) Rotate, (c) Climbout, and (d) Retract Flaps 24 to 18.

Table 3 summarizes the fit for each AOTW distribution for each segment. The Rotate segment has a Beta distribution for AOTW with parameters of shape α=4.49 and β = 7.84. The Rotate segment data fits best a Weibull distribution with parameters of scale of λ = 3.76, and shape *k* = 2.43. The Climbout segment fit a lognormal distribution with mean μ = 17.5 and σ = 30.5. The Flaps Retraction segment as explained above exhibits a bimodal distribution composed of gamma distribution with scale α = 17.2 and shape r = 6.88 and a beta distribution with shape α = 1.77 and β = 4.59 sec. These distributions can be used for the design and testing of new or modified procedures. They can also be used as the reference for monitoring trends in the field.

TABLE 3: Summary of AOTW Distribution Fit for each Segment

Segment	Distribution	Square Error
Roll	18 * *Beta* (4.49, 7.84)	0.009127
Rotate	*Wei* (3.76, 2.43)	0.010956

Climbout	3 + Ln*N* (17.5, 30.5)	0.038238
Flaps Retraction	Bimodal (Gamma + Beta) *Gamma* (17.2, 6.88); 90 + 199 * *Beta* (1.77, 4.59)	0.015141; 0.001706

SECTION 5 CONCLUSIONS

The Available Operational Time Window (AOTW) distribution provides a means to establish the time constraints for the design and evaluation of procedures. The AOTW also provides a powerful tool for monitoring operations in the field to understand how the changes in the environment impact procedure efficacy.

Design and Evaluation of Procedures

Traditional airline industry practices convert aircraft manufacturer's procedures into airline specific procedures. The airline procedures reflect company philosophies and policies as well as operational constraints of airline network and locations. These procedures are generally vetted by subject matter experts such as pilots, training specialists, human factors, aircraft systems and flight operations staff. In some cases, procedures are tested in simulators by a sample of representative flight crews. For complex procedures, the new procedures are tested in simulators with a larger sample size (e.g. 20 crews). However, even under these circumstances, the full range of plausible scenarios in which the procedure may be used cannot be covered.

The availability of FDM/FOQA data provides a powerful mechanism to provide the time distribution of the Allowable Operational Time Window (AOTW) for the purpose of designing the procedure. It can provide important information on the tempo and timing of the SOP actions in particular for the short AOTW (i.e. 5^{th} percentile AOTW).

Further, the AOTW explicitly provides data on the variability in time to complete the procedure that is affected by weather conditions, aircraft performance, air traffic, etc. form a real-world environment. This information is not always known by the SME and cannot be easily duplicated in simulator tests. This information provides a critical constraint for the design of the procedure.

Monitoring Procedures Efficacy

Use of FDM/FOQA data for monitoring operations is a widespread practice. This analysis generally takes the form of anomaly detection such as unusual attitudes, speed deviations, mode changes are identified. The AOTW can supplement this type of monitoring. It is different in four ways. First, the AOTW reflects changes in environment such as air traffic control procedures that are not part of the anomaly detection analysis. Second, the AOTW provides a measure of efficacy of the procedures that may result in unusual attitudes and speed deviations. Third the AOTW accounts for stochastic nature of the operations that can exhibit long tails that are not necessarily anomalies. Fourth, it provides a means to monitor the trends over time. A hypothetical example, illustrated in Figure 4, shows the Statistical Process Control (SPC) chart for AOTW for the Flap Retract segment of the takeoff procedure. A change in the distribution reflects service to a new destination with air traffic control procedures that interrupt the procedures and require a procedural adaptation by the flight crews. This change may be worthy of review by the airline procedure designers.

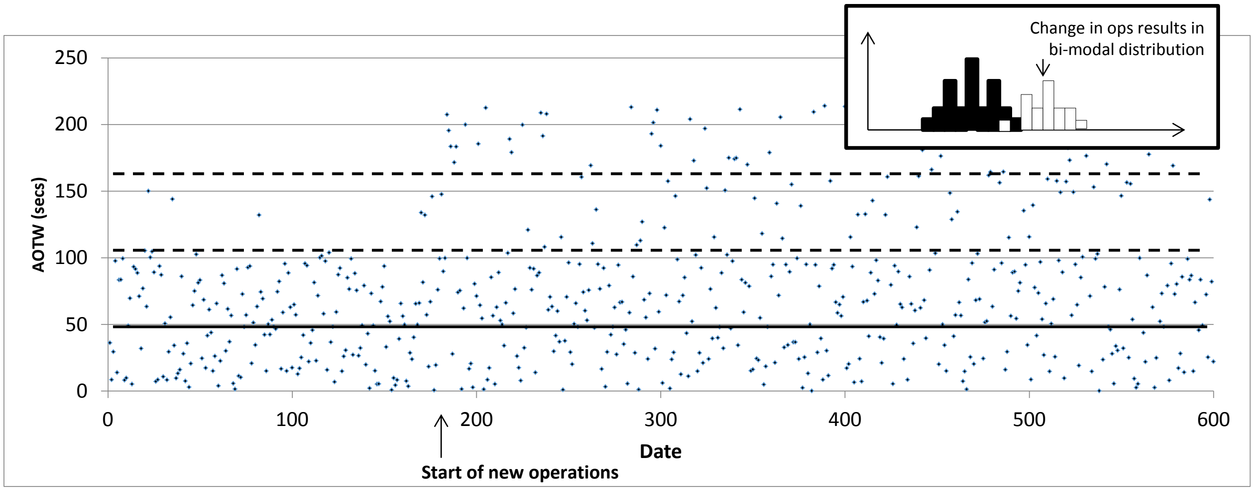

FIGURE 4: Statistical Process Control Chart of AOTW identifies the operational change in the field that should be addressed by changes to the standard operating procedures.

Limitations and Future Work

The quality of the FDM/FOQA data is critical for accurate results. Data preprocessing must be conducted to prune the data set of unreasonable values. The time and cost of this task should not be under estimated. Further several critical parameters may not be available in the data and can be estimated using kinematic models of aircraft performance.

Future work involves using the FDM/FOQA data and similar analytical techniques to quantify the Time-on-Procedure (ToP) and make assessments of the Probability of Failure to Complete the procedure (PFtoC). These statistics form the basis for a quantitative measure of flight deck the workload in each segment of the procedure. In addition, Monte Carlo simulation of the SOPs using empirically derived distributions for each of the actions could be used to test procedures without extensive, expensive human-in-the-loop testing (Kourdali & Sherry, 2016; Stimpson, Ryan, & Cummings, 2016)

A data-mining algorithm can also be developed to monitor the AOTW at each operation (e.g. i.e. departure runway) to create SPC charts that can be used to identify changes in operations.

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APPENDIX A:

Note: Assume AC lined up on the runway ready for departure

1. ATC gives clearance to Takeoff: "XXX123, RNW16, cleared for takeoff"
2. PF reads back clearance "Cleared for takeoff, XXX123"
3. PM announces "TAKE-OFF"
4. PM announces "YOUR CONTROLS" simultaneously holds ailerons into wind
5. PF puts right hand on the nose wheel steering control and simultaneously keeps left hand on lap, and simultaneously confirms "MY CONTROLS"
6. PM advances throttle levers
7. PM checks that all 4 engines accelerate symmetrically beyond 50% N1
8. PM activates auto throttles by means of TOGA buttons
9. PM checks FMA auto-throttle engagement: A/T green arc and FADEC trim arrow extinguished (if applicable)
10. PF simultaneously checks FMA auto-throttle engagement: A/T green arc and FADEC trim arrow extinguished (if applicable)
11. PM: <u>before reaching 80 kts</u>. Checks that take-off thrust is set
12. Needs time/aircraft dynamics awareness
13. PM: reports "TAKE-OFF THRUST SET"
14. PF verifies that takeoff thrust is set
15. PF confirms "CHECKED"
16. PM checks engine parameters throughout the take-off toll to be within limits
17. **Aircraft Reaches 80 kts**
18. PM sees 80 kts (or past)
19. PM calls "80 KTS"
20. PF compares speed indication on his/her side of the PFD
21. PF releases NWS
22. PF takes over control column with both hands
23. PF simultaneously confirms "MY COLUMN"
24. PM simultaneously keeps his right hand on the thrust levers throughout the take-off roll until V1
25. **AC reaches V1=115kts (average) speed**

26. PM sees V1 (e.g. 115 kts) on the PFD
27. PF calls “V1”
28. PM takes his/her hand away from the thrust lever after passing V1 = 115kts.
29. **AC reaches V_R**
30. PM sees V_R
31. PM calls “ROTATE”
32. PF starts a smooth rotation with about 3 º/sec. to simultaneously follow the FD pitch command. If FD is not usable, pilot needs to know climb with max V2+10 (initially 12º-15º ANU)
33. PF sees clear of ground
34. PF sees positive rate of climb (simultaneously since previous step is in the field of vision)
35. PF orders “GEAR UP”
36. PM silently checks positive rate of climb
37. PM selects gear up
38. PM monitors gear retraction
39. PF checks above 350 ft. RA (Do not engage the autopilot in the TO mode below 350 ft AGL. Do not deselect the TO mode until obstacle clearance is assured.)
40. PF orders “ENGAGE AUTOPILOT NAV1” (or NAV2)
41. PM pushes AP engage button on the MCP
42. PM pushes NAV1 button on the MCP
43. PM checks annunciation on FMA (…)
44. PM confirms “AP NAV1”
45. PF checks FMA AP green
46. PF confirms “CHECKED”
47. PF sees thrust reduction altitude (1,500ft AAL.)
48. PF sets (retards) thrust to climb thrust
49. PF calls “CLIMB NORM/MAX SET”
50. PM checks thrust on PFD
51. PM reports “CHECKED”
52. PF after thrust reduction and passing acceleration altitude accelerates (Acceleration altitude 1500 ft. AAL of 3000 ft. AAL if not otherwise stated in OM-C)

53. PF sees acceleration altitude 1,500 ft. AAL (check previous step) sets speed (VF18+20. E.g. 146kts)
54. PF calls “SPEED 146 SET”
55. PM sees 146 kts on the MCP
56. PM reports “CHECKED”
57. **SPEED ACHIEVES VF18 (e.g. 126 knots)**
58. PF sees VF18 (e.g. 126kts) on PFD
59. *PF orders “FLAPS 18”*
60. PM silently checks VF18 (e.g. 126 kts) on the PFD
61. PM selects flaps lever to 18^{o}
62. PM monitors flaps transition on flaps position indicator
63. PM confirms “FLAPS 18”
64. PF checks flaps position 18^{o} on flaps position indicator
65. PF confirms “CHECKED”
66. PF checks altitude on the PFD
67. PF sets appropriate speed VFT0+20 (e.g. 155kts)
68. PF states “SPEED 155”
69. PM sees 155 kts on the MCP
70. PM report “CHECKED”
71. **SPEED ACHIEVES VF0 (e.g. 135 knots)**
72. PF sees VF0 (e.g. 135 kts) on the PFD ~ flap retraction from 18 to 0
73. *PF orders “FLAPS 0”*
74. PM silently checks VF0 on the PFD
75. PM selects flaps lever t 0^{o}
76. PM monitors flap retraction on flap position indicator ~ end
77. PM confirms after clean-up “FLAPS AT 0”
78. PF checks flaps position 0^{o}
79. PF confirms “CHECKED”

APPENDIX B:

The FDM data included weight, speed, and timestamps information for critical events on the procedure in Table below.

TABLE: FDM and Calculated Data

Parameter Name	Description	Units
Flight ID	unique number to reference the flight	None
Takeoff Weight	Takeoff Weight	Tons
Takeoff-Flap	Flap setting at takeoff. Typical take off is performed with 18°, but a short field would require a higher flap setting	° of flaps
t@80	Timestamp when passing 80 kts	Secs
V_1	V_1 (the decision speed at which the flightcrew need to decide whether to continue take-off or to abort it)	Knots
t@V_1	Timestamp at which the aircraft reached the V_1 speed	Secs
V_R	Rotation speed at which the pilot initiates action to raise the nose gear off the ground	Knots
t@V_R	Timestamp when passing rotation speed V_R	Secs
t@pitch-up	Timestamp when initial pitch-up is detected	Secs
t@gear-sel	Timestamp when gear is selected up	Secs
t@gear-sel&up	Timestamp when gear is up and locked	Secs
V_{F24}	Schedule speed for flap retraction to 24°	Knots
t@V_{F24}	Timestamp when passing schedule speed for flap retraction to 24°	Secs
$V_{F\_Sel\_24}$	Speed when flap is selected from 33° or 30° to 24°	Knots
t@ $V_{F\_Sel\_24}$	Timestamp when flap is selected from 33° or 30° to 24°	Secs
t@$V_{F\_Set\_24}$	Speed when flap reaches 24°	Secs
V_{F18}	Schedule speed for flap retraction to 18°	Knots
t@V_{F18}	Timestamp when passing schedule speed for flap retraction to 18°	Secs
$V_{F\_Sel\_18}$	Speed when flap is selected from 24° to 18°	Knots
t@$V_{F\_Sel\_18}$	Timestamp when flap is selected from 24° to 18°	Secs
V_{F18_Set}	Speed when flap is 18°	Knots
V_{F0}	Schedule speed for flap retraction to 0°	Knots
t@V_{F0}	Timestamp when passing schedule speed for flap retraction to 0°	Secs

$V_{F\_\mathrm{Sel}\_0}$	speed when flap is selected from 18° to 0°.	Knots
t@$V_{F\_\mathrm{Sel}\_0}$	timestamp when flap is selected from 18° to 0°	Secs
V_{F0_Set}	speed when flap is 0°.	Knots

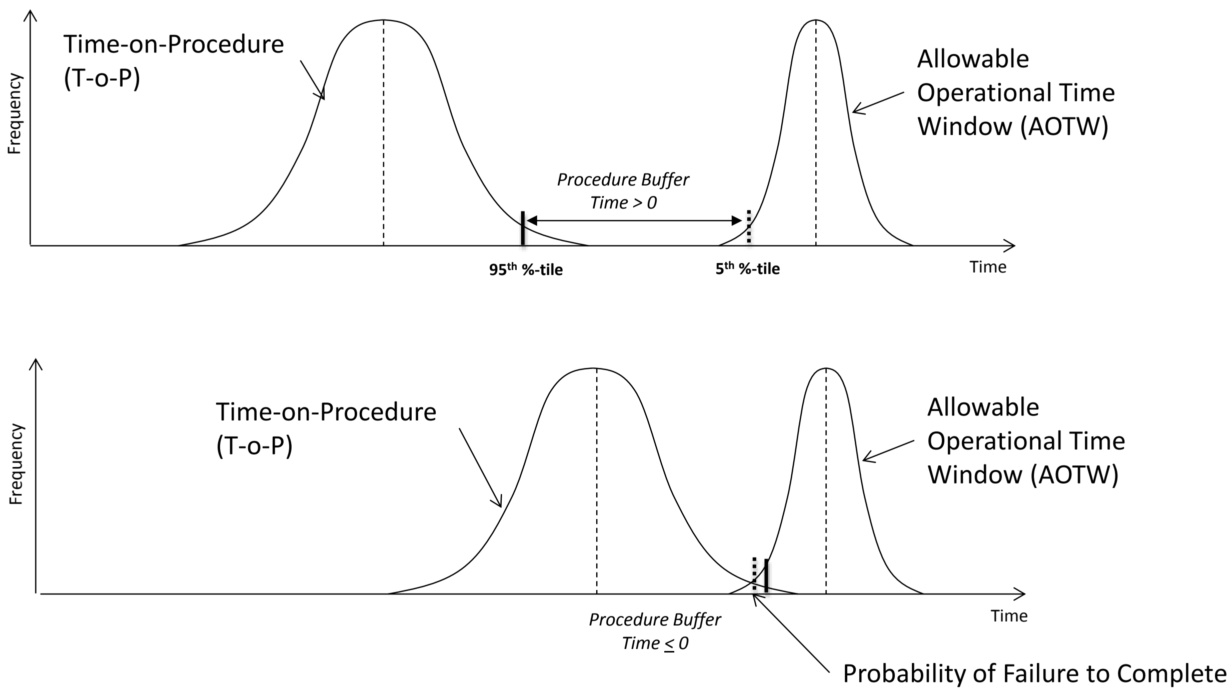

Figure. 1. Distributions for Time-on-Procedure (ToP) relative to the Allowable Operational Time Window (AOTW). The difference between the 95th %-tile for ToP and the 5th %-tile of the AOTW is the Procedure Buffer Time (PBT).