METHOD FOR FORMAL ANALYSIS OF THE TYPE AND CONTENT OF AIRLINE STANDARD OPERATING PROCEDURES

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***Abstract*:** Standard Operating Procedures (SOPs) are the "glue" that holds the airline cockpit together to ensure a safe and efficient mission. The SOPs define the sequence of navigation procedures and trajectory maneuvers required for normal, abnormal and emergency operations. SOP Steps define the specific perceptual, cognitive, and physical actions (e.g., button pushes) and communications for each procedure. Airline SOPs are derived from Original Equipment Manufacturer (OEM) SOPs and are adjusted to reflect the airline policies and the nature of airlines. The type of SOP step (e.g. action-only, decision-action, …), and the clarity and completeness of these written SOPs and their associated steps impacts the time crew proficiency in training, and the mission efficiency and safety. For example, a key component of accident investigations is the appropriateness of the SOP and whether the flight crew followed airline company procedures.

This paper describes a method for analyzing the type and content of SOPs. The SOP model used to define the type of SOP Step and the contents of the SOP Steps is based on a stimulus-response model of the cognition required to perform each SOP step.

An analysis of 224 SOP Steps for normal operations, equally split between wide-body and narrow-body aircraft, were annotated and analyzed. The SOP Steps classified by four distinct types: Action-only (63%), Decision-Action (22%), Action with Waiting-Verification (9%), and Action with Waiting-Verification (6%). The content of the SOP Steps, critical for training efficiency and operational reliability, showed the large degree to which the description of the SOP Steps require flight crew "aeronautical knowledge" and "system description" knowledge. For example, the triggering condition for the SOP step was explicitly included 40% of the time, the information that triggers the SOP step was explicitly included 21% of the time, and the location of the source of data to initiate an SOP Step was defined in 3% of the SOP Steps. Furthermore, the order of the trigger, decision, action information in the SOP Step description was not consistent. The implications of these results on training, flight operations and accident investigations are discussed.

1 Introduction

Standard Operating Procedures (SOPs) are the "glue" that holds the operator and automation on the flight deck of an airliner together. SOPs define detailed step-by-step instructions to maneuver and navigate the aircraft safely and efficiently. More importantly, they define the sequence of steps to be taken during abnormal and emergency events by standardizing the crew's mental model [1]. Therefore, it is crucial that procedures are unambiguous, and leave no room for misinterpretation to avoid delays in completing the procedure.

An SOP is a compilation of two or more procedural steps. Procedural steps define the particular action that must be taken under the specific conditions. If appropriate, the step also defines a decision that must be made. The procedural steps also specify who is responsible for executing the step. A procedural step could be physical actions such as an action on an input-device, or a call-out. The call-outs are important as they establish situational-awareness and a common-operating-picture between crew members (including air traffic control, ground crews, dispatch, etc.).

Airline SOPs are derived from Original Equipment Manufacturers (OEMs) SOPs and adjusted to reflect airline policies and the nature of the airline's operations. The clarity and completeness of these written SOPs and their associated steps is critical to reliable, efficient and safe missions. For example, accident investigations always evaluate the SOPs and whether the flight crew followed airline company SOP steps. An analysis of 12 aviation accident reports found that the crew were unable to complete the required procedure [2]. The analysis found that the SOPs in seven (7) accidents were attributed to absent or ambiguous SOP initiation conditions, while 4 were attributed to absent or ambiguous specific SOP step initiation conditions.

Whereas the aircraft and automation are certified for airworthiness, and operators are licensed and qualified by regulatory authorities, the SOPs are loosely regulated [3]–[5]. SOPs are generally approved following "inspection" and "vetting" by Subject Matter Experts [1]. In some cases, the SOPs are evaluated in a human-in-the-loop simulator [3]. However, these human-in-the-loop tests are time and cost prohibitive and cannot cover all the plausible scenarios.

This paper describes a method for quantifying the type of SOP Step and the contents of each SOP Step. The SOP step is annotated according to a stimulus-response model of the cognition required to perform the perception, decision, and physical motor skills in each step of a Trigger - Decide – Act cycle.

The SOP Step model is demonstrated in a case study analysis of 224 normal operations SOP Steps equally split between a wide-body and narrow-body aircraft OEM Flight Crew Operators Manual (FCOM). The min results are as follows:

- There are four types of SOP Steps: Action-only (63%), Decision-Action (22%), Action with Waiting-Verification (9%). and Action with Waiting-Verification (6%).
- The content of the SOP Step was ad-hoc with different order of the trigger-decide-act cycle.
- The content also exhibited missing information that is related to the location and operation of cockpit systems and aeronautical operations:
    - The triggering condition for the SOP step was explicitly included in 40% of the SOP Steps.
    - The information that triggers the SOP step was explicitly included in 21% of the SOP Steps.
    - The output device providing the source of information to trigger the SOP Step was explicitly identified in 7% of the SOP Steps.
    - The input device to be used was defined in 79% of the SOP Steps.
    - The physical motion required to manipulate the input device was defined in 54% of the SOP Steps.

Decision-Action with Waiting-Verification and Action with Waiting-Verification steps increase training time and are subject to poor reliability in operations, especially when the verification is not explicitly stated. For example, Action with Waiting for Verification is subject to errors due to disruptions during waiting. The ad-hoc structure of the SOP Steps and missing information requires the pilot to fill the gap with aeronautical knowledge and system description knowledge (e.g., location and operation of input/output devices in the cockpit.)

The paper is organized as follows: section 2 provides an overview of the cognitive theory involved in SOP steps, and explains a formal structure of procedures used for automated procedure execution. Section 3 provides a method to analyze the content of SOPs. Section 4 describes the case study using 224 SOP steps, and section 5 discusses the implications of the findings.

2. Model of the Structure and Content of SOPs

Operator-Machine interaction is governed by trigger-decide-act cycles [6]–[10], and reflects human cognition steps to (a) Observe, (b) Orient, (c) Decide, and (d) Act. The SOP Step Model is summarized in Figure 1.

2.1 Perceptual, Cognitive, Motor Model of Human Machine Interaction

The cognitive steps of (a) Observe, (b) Orient, and (c) Decide are captured in the See/Hear/Remember & Decide (2) of the SOP Step model. The operator first uses senses (see, hear, feel) to receive any triggering information (Observe). This information is coupled with pre-existing knowledge and mental models (Orient) to formulate and decide on an appropriate response (Decide). The (d) Act step of the OODA loop is captured in the Act (3) phase of the SOP step model, where a physical action, based on the formulated decision, is made.

Information can be collected from changes in the environment (1.1), or from the automation displays (1.3) as a result of changes in the plant (1.2). Information can also be present as a long-term memory item (1.5) or working memory item (1.4). After a decision has been made, a physical act or manipulation of an input device is captured in the Act (3). An action on an input device (4) will typically result in a change to the plant (5), and eventually, a change to the automation's display, which in turn triggers the next decision-making loop.

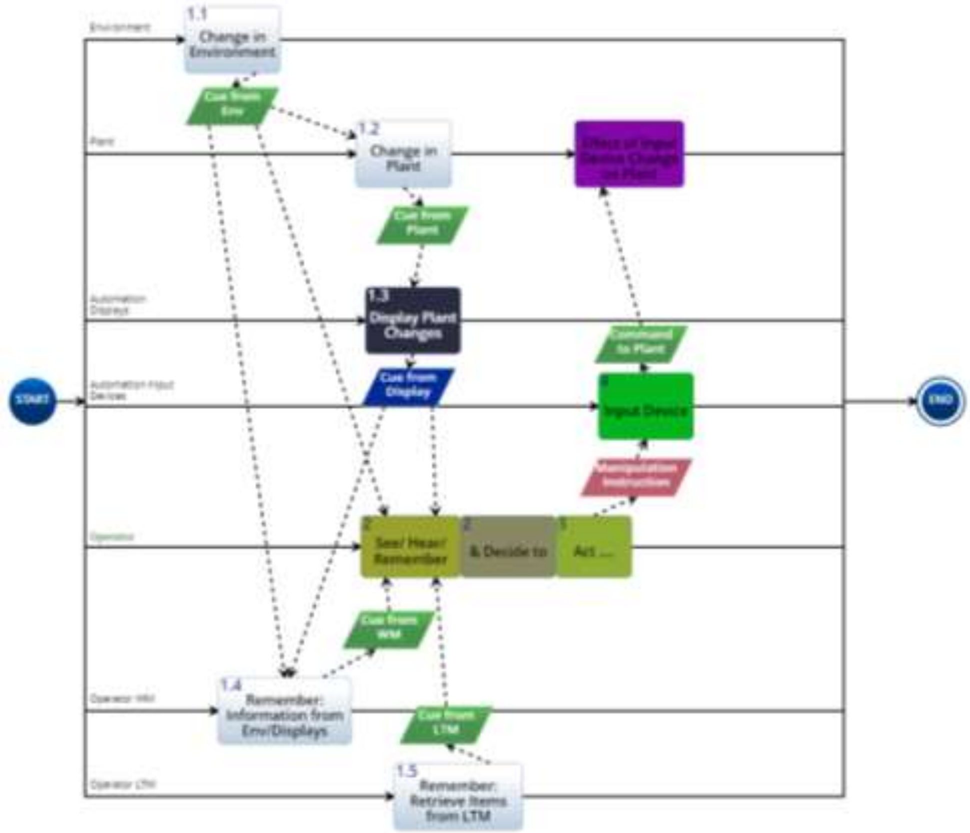

Figure 1 SOP Step Model. Defines the cognitive and physical entities of an SOP.

As seen in figure 1, each See/Hear/Remember & Decide (2) can have one or more cues to trigger that See/Hear/Remember & Decide (see parallelograms). The cue to "trigger" each See/Hear/Remember & Decide (3) step, can be an external cue such as visual, aural, haptic or smell cues. Visual cues that are in the Field-of-View, salient (i.e., not lost in clutter or noise), and match the semantics of the task result in the most reliable human operator performance (Figure 2). When the cues are not in the Field-of-View, not salient, or have ambiguous semantics, the human operator must rely on Long-term Memory (LTM) and/or Working Memory (WM). It is well known that SOP steps that do not occur with high frequency and are not supported by external cues, result in poor reliability (see Figure 2).

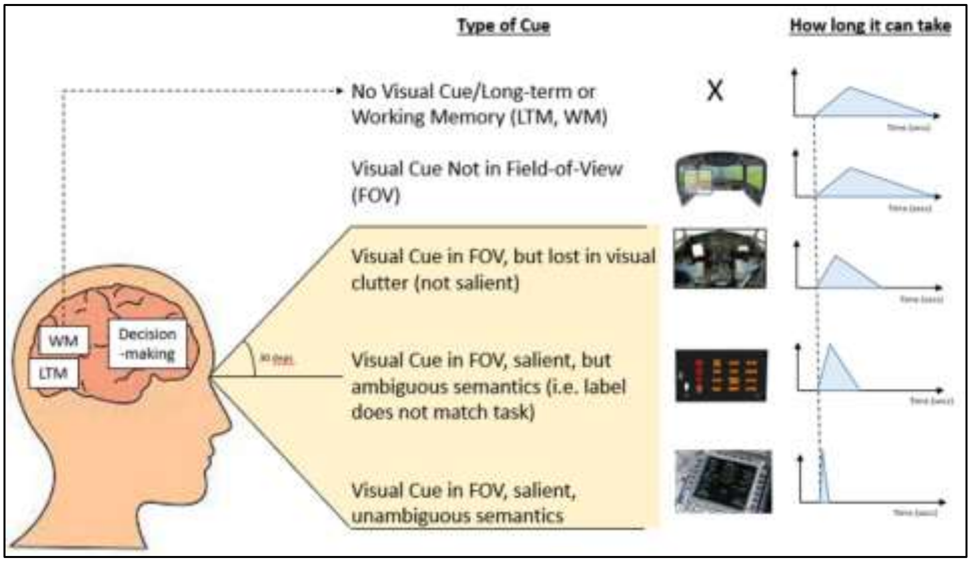

Figure 2 SOP Step Performance by Cue Type

2.2. SOP Canonical Structure

Based on the SOP step model, the basic form of the SOP step structure was defined. Each SOP step has the components (1) trigger (*perceptual*), (2) decision (*cognitive*), (3) action (*motor*), (4) waiting/timing and (5) verification after waiting following the SOP step model in figure 1. The basic structure of SOP steps is shown in figure 3.

[**Actor**]: [**1. Trigger**] [**2. decide**] then [**3. Action**] <<Then wait for [**4. Waiting/Timing**], and [**5. Verification after Waiting**]>>

Figure 3 Basic Structure of SOP Steps

Each of the 5 components is further defined by its perceptual, cognitive, and motor element (figure 4).

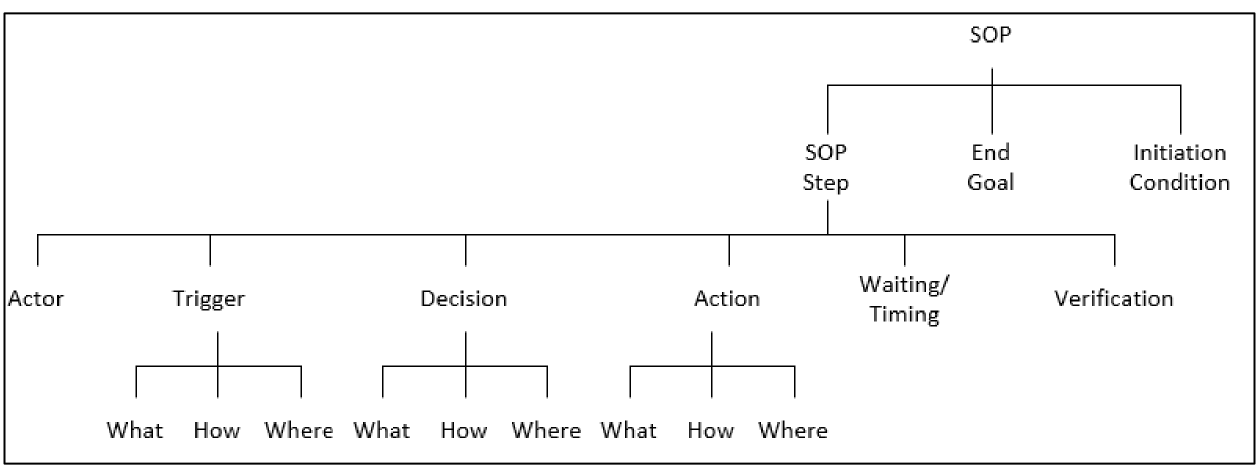

Figure 4 Canonical Structure of SOP Steps

2.3. Procedure Representation Language (PRL)

Advances in simulation have enabled model-based/digital-twin technology that could be used to evaluate SOPs [11]–[13]. A critical element of these model-based/digital-twin simulation models is the underlying model of the SOP steps.

A formal representation of procedures to support the increased attention to automated procedure execution was developed [14]. This formal representation, called Procedure Representation Language (PRL), is an executable language understood by both the machine and the human [14].

The PRL data-structure is described in Figure 4. Procedures in PRL consist of steps. Steps are made up of Blocks, which are wrappers that contain instructions. Instructions are the most detailed components of PRL, and they hold the detailed information to accomplish the step, i.e., what action to perform. Each instruction performs a different action. Instructions grouped together, based on a specific end goal or purpose, make up the procedural step. A set of procedural steps are grouped together to compose the procedure itself. The hierarchical structure of PRL is shown in Figure 5 [14].

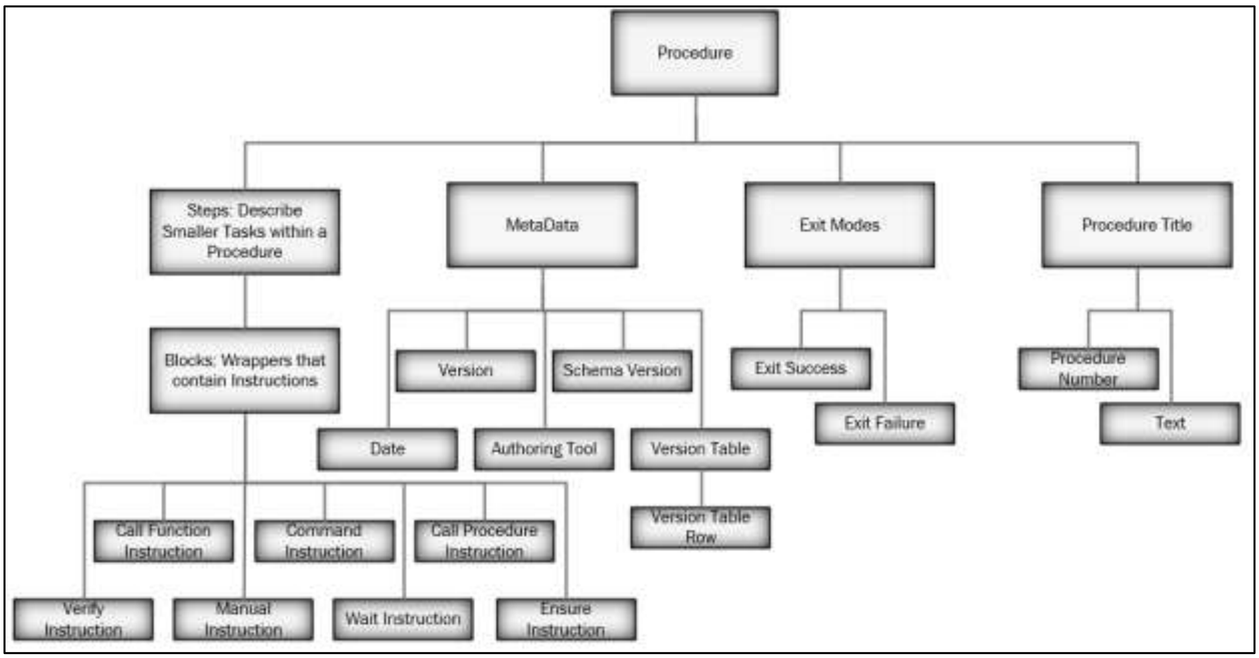

Figure 5 Hierarchical Structure of PRL [14]

2.3.1 Types of Instruction

Instructions are the lowest level of PRL definition. They include Command, Verify, Ensure, Wait, Call Procedure, Call Function and Manual. A computer command is issued to the automation via a command instruction. To compare a recorded value with a target value, the Verify instruction is used. The result of the comparison, if TRUE, is what triggers the instruction to be accomplished. If the result of the comparison is FALSE, the Ensure instructions commands the automation (similar to command instruction, but only occurs after a Verify instruction is FALSE). A Wait instruction is used when an instruction depends on a predetermined amount of time or until a Boolean expression becomes TRUE. The Call Procedure instruction calls another procedure and can sometime wait until the called procedure is completed. A user-defined function can be called using the Call Function instruction.

2.3.2 Manual Instruction

All instruction types are used for commanding the automation to perform an action, except for the Manual Instruction. This instruction is used to when an action must be performed by the human operator. There is no clear structure for this manual instruction that follows the cognitive behavior of the human operator.

Following the SOP Step model, the Manual Instruction could be further decomposed into the SOP Step Structure to achieve a higher level of granularity that follows the way human operators perceive information and act upon received information.

2.4 Extended PRL (e-PRL)

Using the SOP step canonical structure in figure 4, the PRL manual instruction was further defined by the SOP canonical structure to define Extended PRL (e-PRL). e-PRL contains the following entities:

(1) an operator responsible for the SOP step (Actor). E.g., *"Pilot Monitoring"*.
(2) Condition for initiating the SOP step (Trigger (What)). E.g., *"When aircraft reaches V1"*.
(3) Data required for initiating the SOP step (Trigger (How)). E.g., *"… V1 speed"*
(4) Source of data for initiating the SOP step (Trigger (Where)). E.g., "*on the PFD airspeed tape"*
(5) Decision to be made (Decide (What)). E.g., *"… if there are no alerts and the aircraft is configured appropriately for takeoff, then"*
(6) Data required to make a decision (Decide (How)). E.g., "*… flaps set to FLAPS 20…"*
(7) Source of data required to make a decision (Decide (Where)). E.g., "*… on the EICAS…"*
(8) Action for the SOP step (Action (What)). E.g., *"Activate TO/GA Mode"*
(9) Physical motion required for the action (Action (How)). E.g., *"by pressing…"*
(10) Input device used to complete the action (Action (Where)). E.g., *"… TO/GA Button on Throttle Lever…"*

Some steps require the operator to wait, and verify a condition has been met. In that case, the following entities are also required:

(11) Waiting requirement, if any, that must be met (Waiting (What)). E.g., *"… and wait for engines to stabilize…"*
(12) Data needed for fulfilling waiting requirement (Waiting (How)). E.g., *"… 50% N1…"*
(13) Source of data needed to fulfill waiting requirement (Waiting (Where)). E.g., *"… on the EICAS…"*
(14) Verification action after a waiting requirement has been met (Verification (What)). E.g.," *… verify engines have been stabilized…"*
(15) Data required for verification (Verification (How)). E.g., *"… 50% N1… "*
(16) Source of data required for verification (Verification (Where)). E.g., *"… on the EICAS…"*

Figure 6 shows how the PRL Manual Instruction could be further decomposed into the SOP Step Structure.

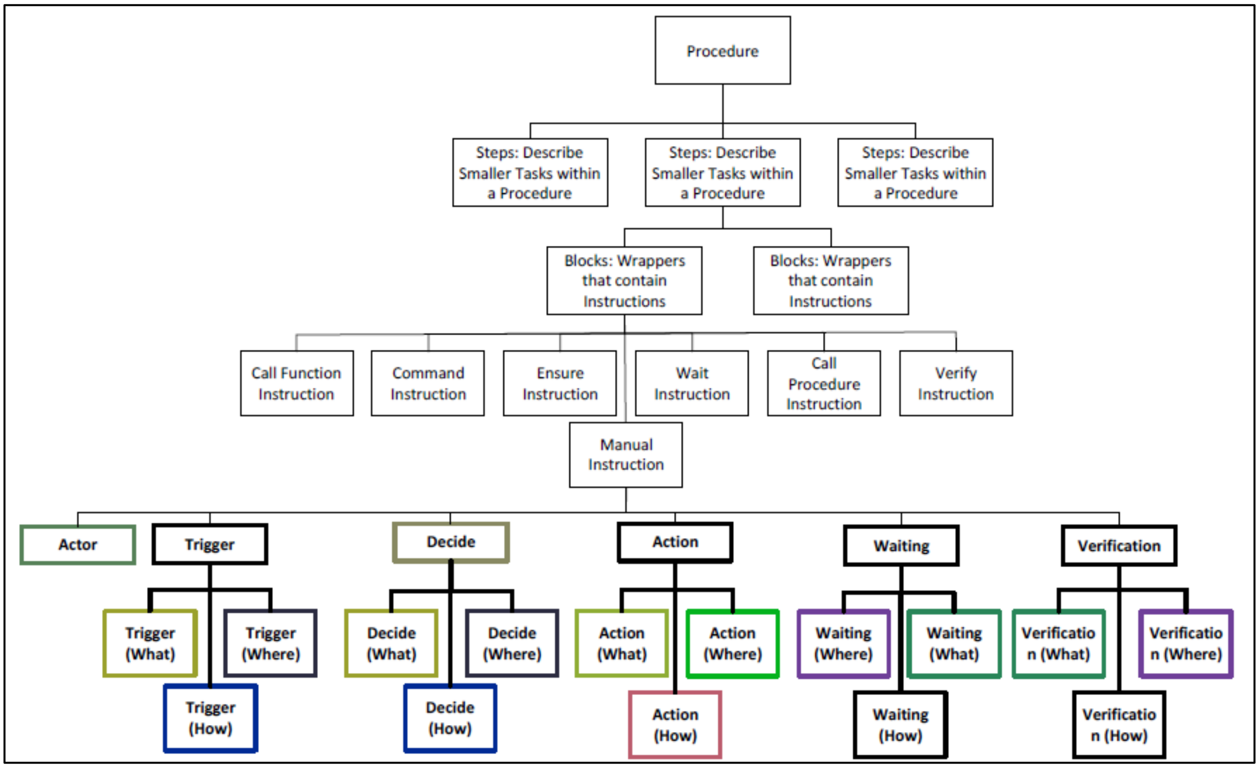

Figure 6 Granular Decomposition of the Manual Instruction to Include SOP Step Structure

3. Method of Analysis

This section describes the process for analyzing SOP steps using e-PRL.

To analyze the completeness and underlying knowledge assumed in the SOPs, the process in Figure 7 can be used. The input to the process is the SOP Steps in Text Form. The output of the process is the SOP/SOP Step metrics. Annotation Coding Rules are used for annotation.

1. Convert text to Optical Character Recognition (OCR)
2. (Manually) Code the SOPs using an Annotation Tool
3. Covert the Coded SOP in a JSON file to an Excel Spreadsheet
4. (Manually) Cross-check the Spreadsheet for correct conversion and completeness
5. Calculate the SOP/SOP Step Metrics

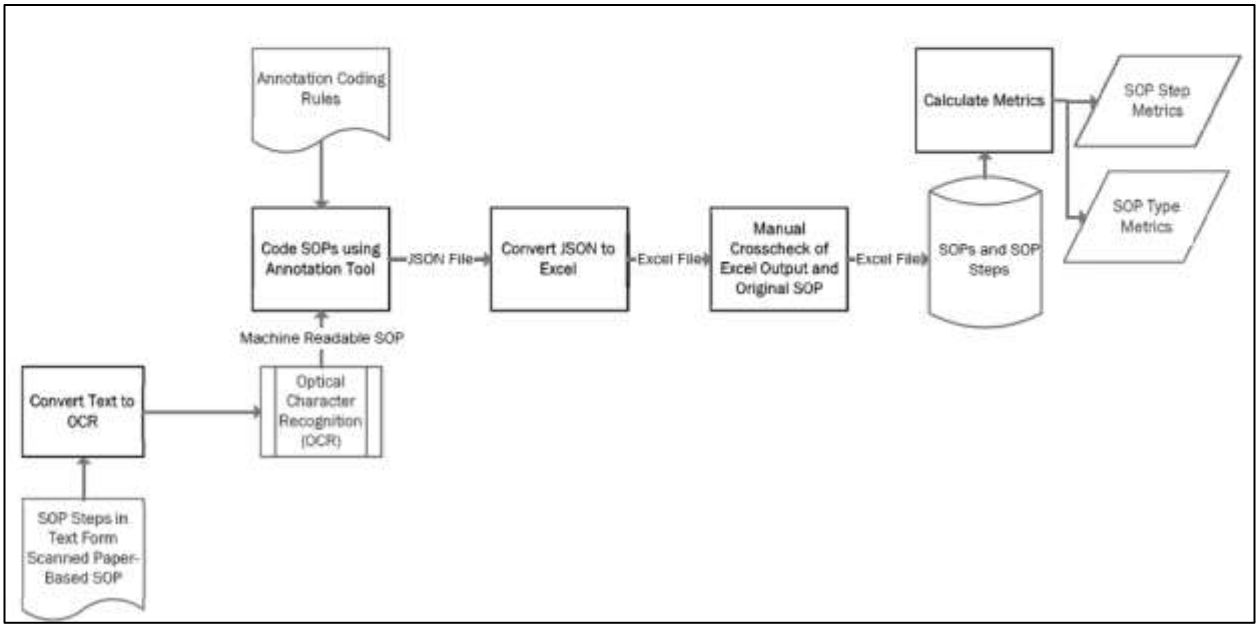

Figure 7 Process for Analyzing SOP Content

Step 1: Code SOPs Using Annotation Tool

The first step of the process for analyzing SOP content was to annotate the SOP steps. To do so, a cloud-based annotation tool called UBIAI [15] was used. To use the tool, the entities must first be defined. The entities for this analysis were defined in section 2.4. After defining the entities, the SOPs were uploaded into UBIAI, and the text was annotated using the process defined in figure 8. For each decision node, a path is taken based on the answer to the questions in Table 1. Figure 9 shows a screenshot of an annotated SOP, where each color represents a different entity.

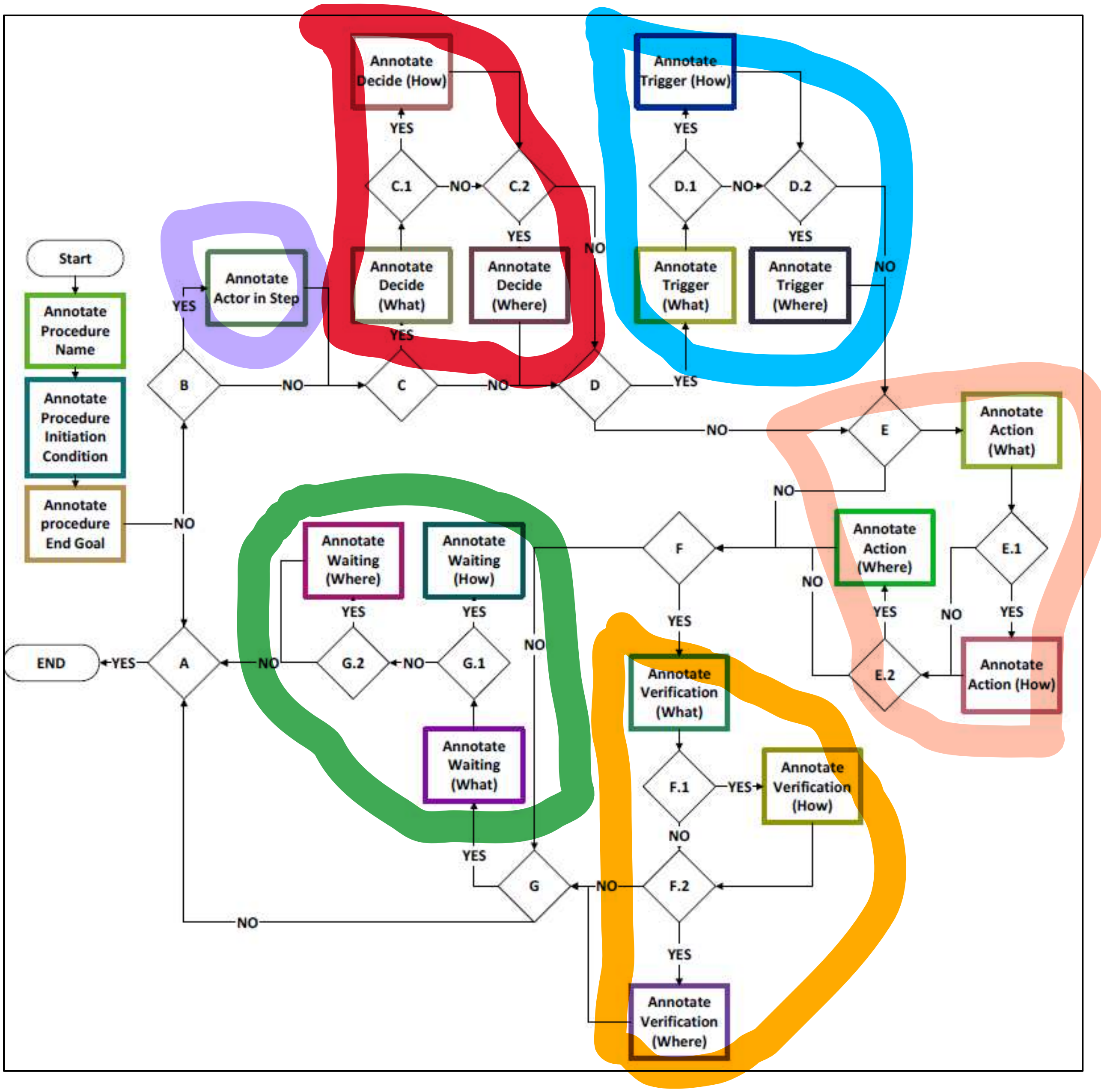

Figure 8 Process of Annotating SOPs

Table 1 Questions for Decision Nodes

Decision Node	Decision	Path
A	Are All SOP Steps Annotated?	Yes: End annotation process.
		No: Go to decision node B.
B	Is there an actor? i.e., PM, PF, Pilot Monitoring, Pilot Flying	Yes: Annotate the actor, then go to decision node C.
		No: Go to decision node C.
C	Is there an explicit decision? i.e., "IF"	Yes: Annotate the decision, then go to node C.1.

		No: go to decision node D.
C.1	Is the data required for the decision explicit?	Yes: Annotate the data required for the decision, then go to decision node C.2.
		No: Go to decision node C.2
C.2	Is the source of the data explicit?	Yes: Annotate the source of the data, then go to decision node D.
		No: Go to decision node D.
D	Is there an explicit initiation condition i.e., “WHEN”, “DURING”, “AFTER”, “BEFORE”	Yes: Annotate the trigger, then go to decision node D.1.
		No: Go to decision node E.
D.1	Is the data required for initiating the SOP explicit? i.e., speed, altitude.	Yes: Annotate the data required for initiating the SOP, then go to decision node D.2.
		No: Go to decision node D.2.
D.2	Is the source of the data (output display) explicit? i.e., “PFD”, “ALTIMETER”, “AIRSPEED INDICATOR”.	Yes: Annotate the source of the data, then go to decision node E.
		No: Go to decision node E.
E	Is the action explicitly stated?	Yes: Annotate the action, then go to decision node E.1.
		No: Go to decision node F.
E.1	Is the required physical motion explicitly stated? i.e., “PUSH”, “SELECT”, “ROTATE”, “FLIP”, “TURN”, “PUSH AND HOLD”, call-out	Yes: Annotate the physical motion, then go to decision node E.2.
		No: Go to decision node E.2.
E.2	Is the input device required for the action explicitly stated? i.e., “THRUST LEVERS”, “BAROMETRIC PRESSURE KNOB”, “MCP”, “EICAS”	Yes: Annotate the input device, then go to decision node F.
		No: Go to decision node F.
F	Is there an explicit verification? i.e., “VERIFY”	Yes: Annotate the verification action, then go to decision node F.1.
		No: Go to decision node G.
F.1	Is the data required for the verification explicitly stated?	Yes: Annotate the data required for verification, then go to decision node F.2.
		No: Go to decision node F.2.
F.2	Is the source of the data required for the verification explicitly stated?	Yes: Annotate the source of the data required for verification, then go to decision node G.
		No: Go to decision node G.
G	Is there an explicit waiting requirement? i.e., “UNTILL”	Yes: Annotate the waiting requirement, then go to decision node G.1.
		No: Go to decision node A.

G.1	Is the data needed to fulfil the waiting requirement explicitly stated?	Yes: Annotate the data needed to fulfil waiting requirement, then go to decision node G.2.
		No: Go to decision node G.2.
G.2	Is the source of the data needed to fulfil the waiting requirement explicitly stated?	Yes: Annotate the source of the data needed to fulfil waiting requirement, then go to decision node A.
		No: Go to decision node A.

Following the process in figure 8 produces the annotated SOP in figure 9-bottom right.

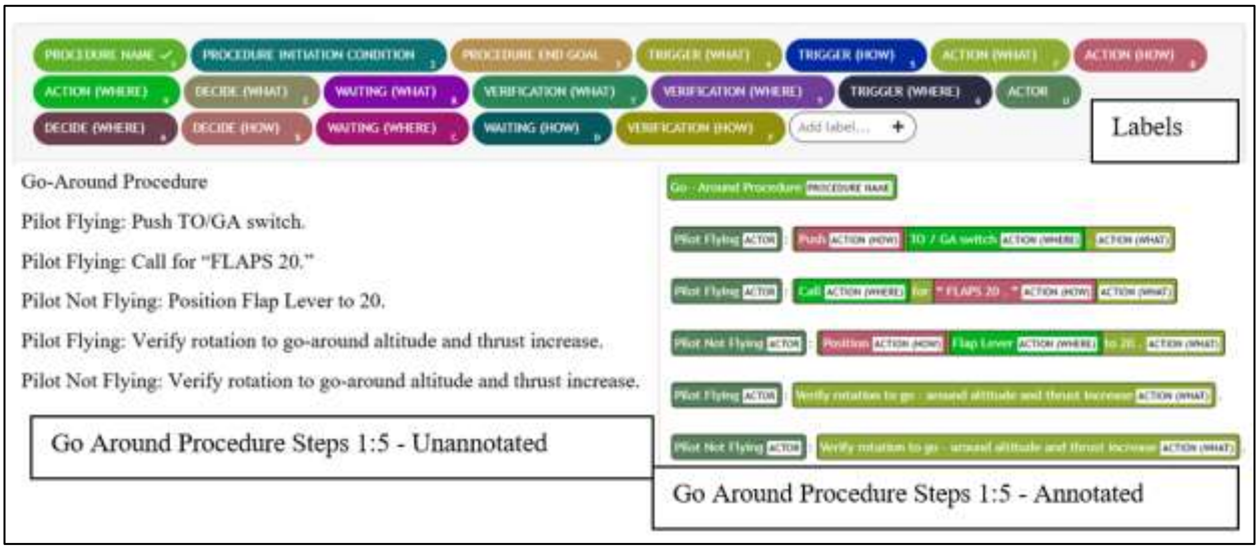

Figure 9 Example SOP Annotated in UBIAI [15]

Step 2: Convert JSON Annotations to Excel

After successfully annotating the SOP in UBIAI, the annotations were exported from the tool as a JSON file. To extract the annotations from the JSON file to the database, a python script that parses the JSON dictionary, and exports the parsed dictionary entries into the database was used. An example of the resulting excel file is shown in figure 20. This file is not complete and requires the additional step to manually check the SOP and excel file, and modify the file as necessary.

Figure 10 Resulting Excel file

Step 3: Cross-check Excel Output and Original SOP

The excel file is then crosschecked with the SOP to check for completeness and structure. When completing the check, the user must make sure each record has only one entry. If multiple entries are present for an entity in one row, the entries must be split into different records. For example, Row 3 in figure 10 shows a list under column K "Action (What)", indicating multiple actions in one row. The two actions must be separated into different rows, and the remaining entities should be completed from the SOP as necessary. Additionally, any missing entries must be completed in this phase. For example, in figure 10, the "ACTOR" in C4-C5 was missing. Looking back at the SOP, it can be seen that the actor for those steps was the "Pilot Flying". Therefore, "Pilot Flying" was copied over for those cells. Moreover, any missing cell was colored in a shade of green to aid in the process of calculating metrics. Figure 11 shows an example of a complete excel file after successfully completing the check.

PROCEDURE NAME	PROCEDURE INITIATION CONDITION	PROCEDURE END GOAL	ACTOR	TRIGGER (WHAT)	TRIGGER (HOW)	TRIGGER (WHERE)	DECIDE (WHAT)	DECIDE (HOW)	DECIDE (WHERE)	ACTION (WHAT)	ACTION (HOW)	ACTION (WHERE)	WAITING (WHAT)	WAITING (HOW)	WAITING (WHERE)	VERIFICATION (WHAT)	VERIFICATION (HOW)	VERIFICATION (WHERE)
			Pilot Not Flying							Obtain taxi clearance	Obtain							
			Pilot Flying	When PNF obtains taxi clearance						Brief taxi clearance	Brief							
			Pilot Flying							Release parking brake.	Release	parking brake						
			Pilot Flying							Call for "FLAPS as required for takeoff.	"FLAPS	Call						
Before Takeoff Procedu			Pilot Not Flying							Position Flap lever to takeoff setting.	position	Flap lever						

Figure 11 Complete Excel File

Step 4: SOPs and SOP Steps Database

The completed procedure was then exported into the SOP database. Currently, the SOP database is an Excel file that contains all annotated SOPs and SOP steps. In the future, a relational database could be built to store the data. The database can also be used to calculate the metrics described in step 5.

Step 5: Calculate metrics

Using the process, the quality of the description of each SOP step is calculated by counting the number of elements present in an SOP step. Table 2 describes the metrics for the SOP step.

Alongside the metrics for an SOP step, the value distribution (minimum, max, mean, median) is calculated for each SOP step type to understand the “quality” of the description of the SOP step.

Table 2 Metrics for the SOP Step

Metric Name	Metric Description	Metric Algorithm/Equation
Explicit Actor for SOP Step	Captures the number of steps that explicitly state the actor.	Count number of SOP Steps with Actors explicitly identified
Explicit Timing Requirement for SOP Step (when)	Captures the number of steps that explicitly state *when* the step should be taken.	Count number of SOP Steps with explicit timing identified
Explicit Cue for Start of SOP Step (what)	Captures the number of steps that explicitly state *what* the actor sees/hears/ or feels to start an SOP step.	Count number of SOP steps with explicit cue identified
Explicit Output Display for Cue for Start of SOP Step (where)	Captures the number of steps that explicitly state *where* the actor should look/hear to start a step.	Count number of SOP steps with explicit output display identified
Explicit Decision in SOP Step	Captures the number of steps that explicitly state the decision to be made. i.e., decision was not implied.	Count number of SOP steps with explicit decision identified
If Then Decision in SOP Step	Captures the number of steps that were a part of an “IF/THEN” block.	Count number of SOP steps with if/then conditions
If Then Else in SOP Step	Captures the number of steps that were a part of an “IF/THEN/ELSE” block.	Count number of SOP steps with if/then/else cue identified
Nested Decisions in SOP Step	Captures the number of steps that were part of an “IF/THEN” block embedded within “IF/THEN” blocks	Count number of SOP steps with nested if decisions
Explicit Action in SOP Step (What)	Captures the number of steps that explicitly state *what* the action is.	Count number of SOP steps with explicit action identified
Explicit Physical Motion in SOP Step (How)	Captures the number of steps that explicitly state *how* the step is performed. I.e., physical motion e.g., push.	Count number of SOP steps with explicit motion identified
Explicit Input Device for Action in SOP Step (Where)	Captures the number of steps that explicitly state *where* the action is performed. i.e., on what input device	Count number of SOP steps with explicit input device identified

Waiting for Machine Response following Action in SOP Step	Captures the number of steps that included a waiting condition as a result of a machine response.	Count number of SOP steps with explicit waiting requirement identified
Explicit Verification after Waiting for Machine Response following Action in SOP Step	Captures the number of steps that included a delay due to machine response and explicitly stated how to verify the response has occurred.	Count number of SOP steps with explicit verification requirement identified
Multiple Cues for an SOP Step	Captures the number of steps that included two (2) or more cues for a single SOP step. i.e., required more than one cue	Count number of SOP steps where number of See/Remember (What) was greater than or equal to two (2)

4. Case Study

A case study of 20 SOPs was completed using the method described in section 3. The SOPs were obtained from the A318/A319/A320/A321 FCOM and the Boeing 747-441 Operations Manual. All SOPs were normal SOPs i.e., done on a regular basis and non-emergency use. The 20 SOPs had a total of 224 SOP steps. Table 3 summarizes the categorization of SOP steps, and table 4 summarizes the content present in the SOP steps by SOP step type.

Table 3 SOP Step Types

SOP Step Type	Percent of SOP Steps
Action-only	63%
Decision-Action	22%
Action with Waiting and Verification	9%
Decision- Action with Waiting and Verification	6%

Table 4 Content Present in SOP Steps

SOP Step Element	Action-only (63%) 142 out of 224	Decision-Action (22%) 50 out of 224	Action with Waiting and Verification (9%) 19 out of 224	Decision - Action with Waiting and Verification (6%) 13 out of 224	TOTAL (100%) Out of 224 steps
Trigger	37% (52 out of 142)	68% (34 out of 50)	5% (1 out of 19)	23% (3 out of 13)	40% (90 out of 224)
What (Cue)	37% (52 out of 142)	68% (34 out of 50)	5% (1 out of 19)	23% (3 out of 13)	40% (90 out of 224)
Where (Output Device)	4% (5 out of 142)	0% (0 out of 50)	5% (1 out of 19)	0% (0 out of 13)	3% (6 out of 224)
How (Data)	16% (23 out of 142)	46% (23 out of 50)	5% (1 out of 19)	0% (0 out of 13)	21% (47 out of 224)

Decide		100% (50 out of 50)		100% (13 out of 13)	28% (63 out of 224)
What (Cue)		100% (50 out of 50)		100% (13 out of 13)	28% (63 out of 224)
Where (Output Device)		0% (0 out of 50)		0% (0 out of 13)	0% 0 out of 224)
How (Data)		26% (13 out of 50)		0% (0 out of 13)	6% (13 out of 224)
Action	100% (142 out of 142)	100% (50 out of 50)	100% (19 out of 19)	100% (13 out of 13)	100% (224 out of 224)
What (Cue)	100% (142 out of 142)	100% (50 out of 50)	100% (19 out of 19)	100% (13 out of 13)	100% (224 out of 224)
Where (Input Device)	74% (105 out of 142)	82% 41 out of 50)	95% (18 out of 19)	100% (13 out of 13)	79% (177 out of 224)
How (Motor Skill)	51% (73 out of 142)	52% (26 out of 50)	58% (11 out of 19)	92% (12 out of 13)	54% (122 out of 224)
Waiting			11% (2 out of 19)	0% (0 out of 13)	1% (2 out of 224)
What (Cue)			11% (2 out of 19)	0% (0 out of 13)	1% (2 out of 224)
Where (Output Device)			0% (0 out of 19)	0% (0 out of 13)	0% (0 out of 224)
How (Data)			0% (0 out of 19)	0% (0 out of 13)	0% (0 out of 224)
Verification			95% (18 out of 19)	100% (13 out of 13)	14% (31 out of 224)
What (Cue)			95% (18 out of 19)	100% (13 out of 13)	14% (31 out of 224)
Where (Output Device)			68% (13 out of 19)	77% (10 out of 13)	10% (23 out of 224)
How (Data)			79% (15 out of 19)	100% (13 out of 13)	13% (28 out of 228)

SOP Step Types

The analysis uncovered four main types of SOP steps as seen in table 3. The Action-Only step, which consists of a (1) trigger, and a (2) action, was the most prevalent type of SOP steps. The Decision-Action step, which consists of a (1) trigger, (2) decide and (3) action, was the second most prevalent type among the 224 steps analyzed. The Action with Waiting and Verification step consists of (1) trigger, (2) action, (3) waiting, and (4) verification, and the Decision-Action with Waiting and Verification consists of (1) trigger, (2) decide, (3) action, (4) waiting and (5) verification.

The SOP step score, or the quality of the description of an SOP step, depends on the number of elements present (I.e., trigger, decide, action, waiting, and verification), depending on the type of SOP step. For example, Action Only steps do not require a decision, therefore, the SOP step score depends on the presence of a Trigger and an Action, while the Decision-Action step score depends on the presence of a Trigger, a Decision and an Action. Table 5 summarizes the results by SOP step type.

Table 5 Summary of Results by Step Type

Statistic	Action Only	Decision-Action	Action with Waiting-Verification	Decision-Action with Waiting-Verification
Min	1	3	2	6
Mode	3	6	6	7
Median	3	5	6	7
Mean	3	5	5	7
Max	6	6	9	8
Number of Elements Required for SOP Step	6	9	12	15
Average SOP Step Score	47%	53%	43%	46%

Action Only

Sixty-three percent (63%) of all SOP steps were Action Only steps. This type of SOP steps only requires an action and a decision. The trigger was present only 37% of the time, and the source of the data (the output display) was specified 4% of the time. The average SOP step score was 47%, meaning about half of the elements were present in an SOP step on average.

Decision-Action

Twenty-two percent (22%) of the SOP steps in the analysis were Decision-Action steps. For this step type, the triggering conditions were specified 68% of the time, but the source of the data for the trigger (i.e., the output device) was never stated. The average SOP step score was 53%, the highest score of all SOP step types.

Action with Waiting-Verification

Nine percent (9%) of the SOP steps were Action with Waiting - Verification steps. These steps have the form of (1) Trigger, (2) Action, (3) Waiting, and (4) Verification. Five percent (5%) of the SOPs steps in this category contained a trigger, the data for the trigger, and the source of the trigger. Eleven percent (11%) of the steps contained a waiting requirement, and ninety-five percent (95%) contained a verification action.

Decision-Action with Waiting-Verification

Six percent (6%) of the SOP steps were Decision-Action with Waiting – Verification steps. Twenty-three percent (23%) of the steps contained a trigger, but the data and the source of the data were never explicitly stated in the steps. As for the action in the step, this step type explicitly stated the physical motion required ninety-two percent (92%) of the time, more than any other SOP step type. Also, this step type did not contain any waiting requirements, although it did specify how to verify specific conditions have been met.

SOP Step Trigger Conditions

Forty percent (40%) of all the SOP Steps in the analysis, regardless of type, included explicit information on the conditions that trigger the SOP Step. In many cases, the condition is a natural follow on the previous SOP step and doesn't need be described in the SOP. Twenty-one percent (21%) of all SOP steps specified the data, i.e., what the pilot senses to trigger the step, and only 3% specified where that data is displayed within the cockpit.

SOP Step Decisions

Twenty-eight percent (28%) of the SOP steps identified a decision that must be made by the pilot. While the decisions were explicitly identified in the SOP step, the data required for the decision was explicitly stated only 6% of the time, and no decision specified the source of the data (0%).

SOP Step Actions

All of the SOP steps included an action (100%). However, only fifty-four percent (54%) of the steps specified the physical motion required to complete the step i.e., *push.*

SOP Steps Waiting

Only one percent (1%) of the SOPs contained a waiting requirement. Waiting requirements are needed for Action with Waiting – Verification and Decision-Action with Waiting – Verification steps. When the waiting requirement was specified, the data and the source of the data required for waiting was not specified (0%).

SOP Steps Verification

Fourteen percent (14%) of the steps contained a verification element, and thirteen percent (13%) specified the data needed for verification and ten percent (10%) specified where the verification would be completed.

5. CONCLUSIONS

An analysis of SOPs/SOP Steps was conducted by annotating the SOPS Steps according to an SOP model. The SOP model identifies the canonical, complete set of information that would be required to be explicitly stated in the SOP/SOP Step in order to automate the execution of the SOP.

Three main finding were concluded from the analysis:

(1) Four types of SOP steps emerged from the analysis; (1) Action Only, (2) Decision-Action, (3) Action with Waiting-Verification, and (4) Decision-Action with Waiting-Verification.
(2) On average, forty-seven percent (47%) of the canonical structure was present in the SOP steps.
    a. The SOPs/SOP Steps take advantage of *aeronautical knowledge* of the pilots. Information that is obvious in the context of the Navigation Procedure, phase of flight, maneuver was omitted.
    b. The SOPs/SOP Steps take advantage of the pilot's "System Description" knowledge of where output devices (i.e., instruments) and input devices (e.g., knobs, buttons levers, etc.) are located in the cockpit. They also take advantage of

the pilots' knowledge of how to interpret the display graphics and how to use the input device.

(3) The SOPs/SOP Steps also took advantage of the obviousness of the verification after an action was taken (e.g., a button is backlit once it is pressed.) SOP Steps that included a verification required the operator to wait until an event occurred, but the waiting requirement was rarely specified.

These findings uncover the importance of analyzing the tradeoff between having complete SOPs (i.e., complete with all aspects of the canonical structure) and having cluttered SOPs with respect to the time, cost, and quality of training.

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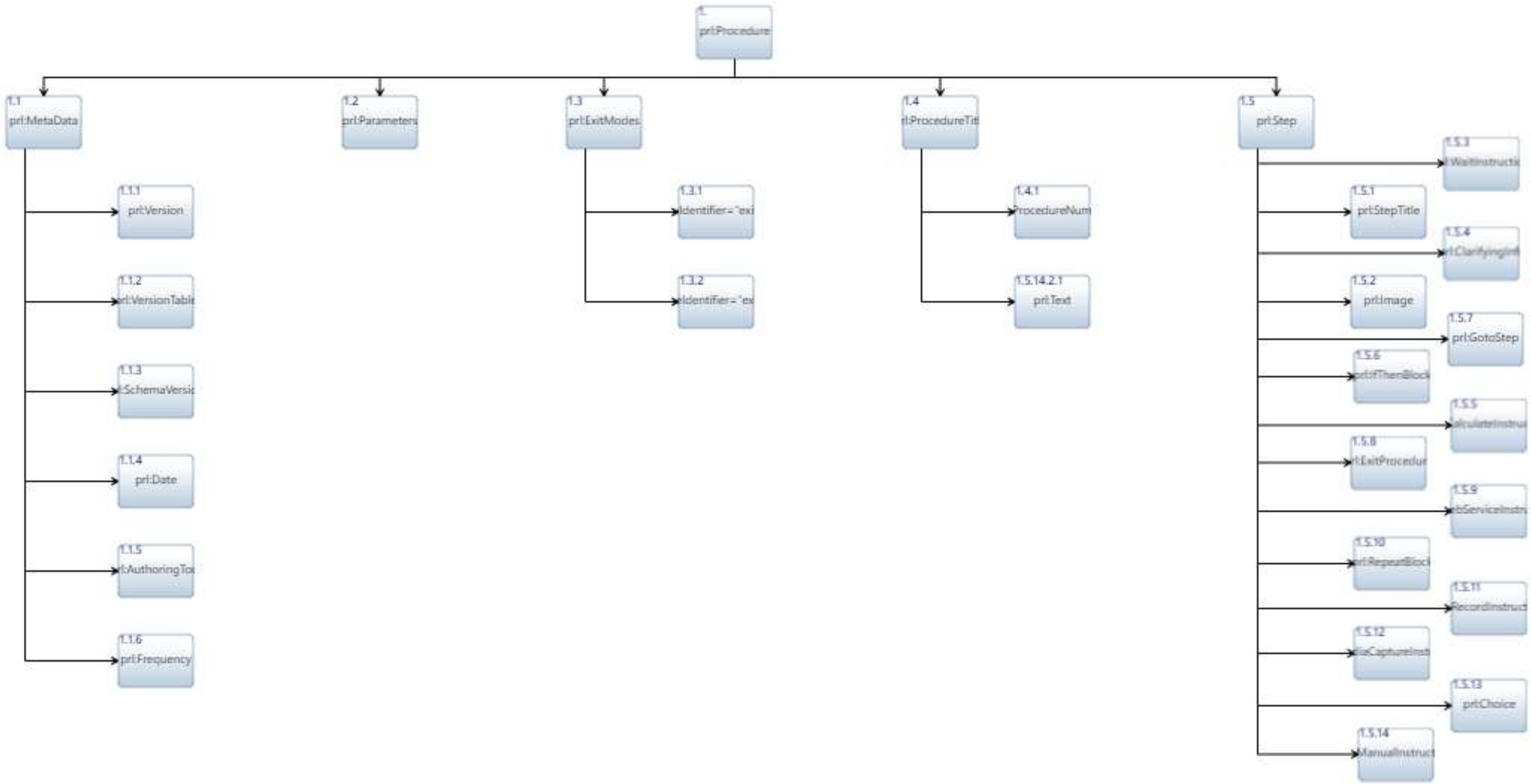
Appendix A: Procedure Representation Language



Courtesy of Lilleigh Stevie, Spec Innovation

Appendix B: List of Action (How) Items Extracted from Analysis

- Monitor/Scan/Read/Observe
- Position
- Push
- Release
- Push and Hold
- Leave
- Check, Observe
- Rotate
- Select