

Operational Decision-Making: Integrating New Concepts into the Paradigm

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ABSTRACT

Over the past 8 years, the authors have been developing a training-oriented paradigm for operational decision-making in the cockpit. While our emphasis has been on the civil aviation side, both the paradigm, and any training developed from it, can be easily adapted for the business or general aviation venues. The paradigm began to form during an aeronautical decision-making workshop in 1992 (Lofaro, Adams and Adams; 1992) and, has been developed around an expanding set of interrelated concepts. The set expansion resulted from the authors continuing to wrestle with what were the processes and the critical components for real-time operational decision-making, as well as the relationships among decision-making, CRM and SA. The first component was the "rising risk continuum" (Lofaro and Smith, 1993), as embedded in event sets for LOFT. Later, the concepts/components of "critical mission impact areas" and the "critical mission factors" (Lofaro and Smith, 1998) that composed these areas were added. In the paradigm, the "pilot as risk manager" (Smith and Hastie, 1992; Lofaro and Smith, 1998; 1999) was the both the overlay and glue for the components. Here, we will present what we consider the final components for a complete paradigm: The operational envelope, risk location and situation knowledge. This paper will endeavor to present these components as parts of the process in which rising risk, the critical mission impact areas, the critical mission factors, and the pilot as risk manager all functionally interplay.

INTRODUCTION

Aviation, since 1978, has grappled, on and off, with pilot and crew decision-making. Ground breaking work was done in what was then called 'pilot judgement' by people such as Ruffell-Smith, Jensen and Bennell. However, the emphases on CRM and SA blocked out large-scale efforts in decision-making R&D, training development and delivery. This was especially true for pilots/crews of major carriers, with their highly complex, automated craft and their responsibility for hundreds of lives each time they fly. While many realized aeronautical decision-making's (ADM) importance and worth, not much R&D money was made available for decision-making; compared to CRM and SA, it was a poor relation. Some eight or more years ago, the authors, with others, began what we considered a long overdue and necessary

re-look at pilot judgement/pilot decision-making/aeronautical decision-making. During this eight to ten year period, ADM was a back burner issue since the common wisdom held that good pilots made good decisions almost naturally, aided by (some) increased experience. The facile assumption that additional experience alone will teach pilots to make better decisions has proven to be a dangerous fallacy. Experience can be a nasty teacher, often giving the test before, or without, giving the lessons and materials needed for the test. Experience can also reinforce poor decisions and behaviors that seemingly "worked" (blind luck?) in certain situations. We also had the commonly accepted view that ADM is but one of the components of CRM. This was, and is, a gross error. CRM, with its emphases on communication and team function, is a major enabler of good decisions and, as such, is a part of decision making, not vice-versa. Our focus was decision-making in the operational, air carrier environment; we termed this operational decision-making (ODM). As we identified and developed components of our ODM paradigm, we came to believe that certain of our ideas were of a breakthrough nature; breakthrough in that they are the necessary enablers for the development of an ODM training program. We believed, and still believe, that decision making is the primary function of a pilot and that good decision making skills are the primary tool in a pilot's safety arsenal. We see decision making as THE key pilot activity; this is one breakthrough concept. The issue still is: How can a Captain command and lead if he/she is not prepared (trained and practiced) to make the best decision possible?

SEA-CHANGES

In 1996/7, at American, Delta and United, there were realizations that CRM was not the silver bullet; that the relationship between CRM and safety - which was and is the prime rationale offered for teaching CRM - had not been proven; that CRM is a process, not an outcome. (Sprogis, 1997), (Maurino, 1999). American Airlines, in July of 1996, set aside some of CRM as they were doing it (Ewell and Chidester, 1996). American's new focus is on preparing flight crews for the daily challenges of normal and abnormal operations encountered flying the line. Delta Airlines, in the same time frame, revamped their "CRM for New Captains" course and called it "In Command." As with American, Delta is emphasizing leadership, responsibility and performance. Lastly, even

United Airlines' version of CRM, called C-L-R, where the C is for Command and the L is Leadership, had changed aspects of this training in 1997.

Operational Decision-Making: a New Window of Opportunity?

In the new millennium, there now seems to be a heightened level of recognition of both the role and the importance of decision-making in aviation safety. In July of 2000, *Aviation Week and Space Technology* printed four somewhat interrelated articles on pilot/crew errors and decision-making. These articles presented audit information, research and analyses along with current "fixes." Some findings include flight crews ignoring increased evidence that the original flight plan was no longer appropriate; tactical DM (what we would call operational DM) errors as the second most prevalent crew error in crew-involved accidents; pilot perception of risk as a key factor in safety. Several other vital points were that: (1) it is a fallacy that crew error can be eliminated via sufficient vigilance and, (2) there is a need to emphasize managing the consequences of error. The proposed 'fixes' that were offered encompass risk and error management training as well as new decision-making training. All in all, these articles showed us that many of the components of ODM we have developed and published since 1992 were on target. However, we believe that there were critical components missing, as well as a coherent structure, or model embedding the components. It is with some sense of vindication of our views, and the hope that what we offer can be of aid in the struggle for aviation safety, that we present this paper.

Components of the ODM Model

The focus of ODM is on enabling the pilot's primary role, that of risk manager by use of the rising risk continuum, thus essentially redefining the role of the pilot (this is another breakthrough concept). Safety becomes the operational aspect of successful mission completion through risk management; ODM is the key to successful risk management. The ODM training program we are developing is based on (the breakthrough) concept that all operational decisions have the same decision-making structure. Thus, formal decision making training/structure is the necessary first step in ODM training. It is this (training) first step that will enable the pilot to effectively use the ODM components in his/her decisional processes. Integrated and embedded throughout the model is the pilot's role as risk manager. The other components are:

- A. The Operational Envelope/Risk Location
- B. The Critical Mission Impact Areas and the Critical Mission Factors which comprise the Impact Areas/Risk Location.
- C. Situational Knowledge/Risk Location
- D. Cumulative effects/Risk Location/ the Rising Risk Continuum
- E. Risk Location Action Response

Thus, ODM training, built around these components, is the process by which optimal ODM is achieved and, with it, optimal risk management and successful mission completion. While the author's have developed preliminary ODM training modules, space precludes anything but this mention of them. *Finally, it must be strongly noted that all of these components are so intertwined that any separation or sequencing of them is artificial, since it will become apparent that to speak of any one component brings in the others. Actually, there is no sequence per se. Rather, there is a constant interplay and branching across the components; perhaps a continuously rotating spiral best describes the process the pilot is involved in.* However, for the purposes of presentation, we will treat each one separately.

Risk Management: Risk and Flying the Line

"Mission completion and risk management"--completing the mission of flying the public, because of its economic benefits, but do so in a way that does not place people or equipment at undue risk--should be the goals of any airline pilot. Risk management is critical to the retention of the flying public customer base and the long-term viability of the industry and, risk management is the key operational activity that works hand in glove with mission execution skills. By risk, we mean specific risk or danger to the aircraft, passengers and crew, and the corporation. High risk is defined as the likelihood or high probability of injury, damage or death. Moderate risk, if left unchecked, could continue to rise and/or likely result in significant flight trajectory deviations. Low risk is a normal situation where routine, normal procedures are sufficient. When risk rises on the risk continuum (see Figure II), effective risk reduction strategies need to be employed to keep risk within manageable limits. Central to a completed, and safe, mission is the concept of the pilot as risk manager; the under girding for our model. Yet, it seems that the ability to support the airline captain in the recognition and management of risk while having advanced somewhat, is still sub-optimal. The current system of certifying pilots and aircraft, airlines and training organizations is not predicated on the employment of risk management skills; neither does it seem very supportive of organizations that desire to do this. However, as said earlier, the millennium appears to be bringing a sea change in this arena.

Risk Management: Situation Knowledge and Risk location

The continuous task of the pilot is risk identification by his/her situation knowledge and consequently, accomplishing (ever-changing) risk location. Accurate and timely risk location is the only way to achieve both accurate and timely action response to risk. Situation knowledge and risk location are both interrelated, breakthrough concepts. Situation knowledge is that part of the structure of ODM that consists of the continually changing set of elements (knowledge bits) which

comprise the pilot's awareness of: 1. The critical mission impact area(s) in which the aircraft is located and, which of the critical components of this area(s) are in play and, 2. The resultant of these components "tells" the pilot what is the cumulative effect of the critical mission factors in play. Using the resultant of the cumulative effects of the critical mission factors, the pilot can locate the aircraft in the operational envelope and, translate that position into the aircraft's location on the rising risk continuum (both of these are elements of risk location). As said, accurate risk location is the key, when in a rising risk situation, to making the optimal selection of an alternative to the original mission plan

Risk Management: The Operational Envelope and Risk Location

We will work from outside of the model inwards, then return to the outside. The first--and last-- component in the spiral process is a graphical representation of the boundary conditions in a mission. This is the pilot's "world" and we term it the operational envelope, as does the military. It gives, to use a hackneyed phrase, the big picture; the ops envelope is the context in which all the ODM paradigm's components are activated. The operational envelope gives a rather straightforward way to grasp the pilot's task universe, is a breakthrough concept and, a necessary part of any ODM training program. The ability to locate oneself within the ops envelope results from the pilot's situation knowledge and ability to do accurate risk location. It would seem that civil aviation has never taken this larger view of the envelope because it has focused on discrete data points instead of on the big picture. Even today, we find that Airbus and Boeing are working software for flight control computers that are aimed at keeping the aircraft from exceeding a predetermined flight envelope (*Aviation Week and Space Technology*, August 28, 2000). However, these efforts focus on alarms and/or software to stop overstress, possibly dangerous pitch angles and over-banking; in essence, these deal with a small, specific set of discrete flight control errors, not decision-making. The ops envelope can be visualized as a square; the sides being Adverse Conditions; Restricted Visibility; Mission Critical Alerts & Warnings; and System and Human Limitations, as arranged below in Figure I:

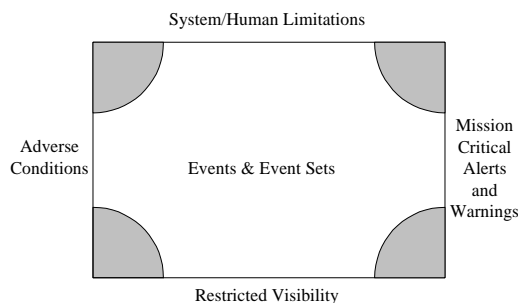


Figure I The Operational Envelope

The first risk management aspect of the operational envelope is that, at the very center, is a smaller rectangle of normal flight conditions. Within this inner rectangle, normal SOP's will suffice. However, single events such as freezing rain, or event sets, such as contamination and strong crosswinds, encountered during flight may drive a pilot/crew out of that inner rectangle and towards of the edges/boundaries. If that happens, there may still be guidelines on what to do. But, the second aspect is that, while each event/factor may be able to be handled by itself (to keep the aircraft inside the edges/boundaries of the envelope), how do we handle the combined/cumulative effect, i.e., the resultant of multiple events/factors? Certainly, cumulative effects will effect one's position in the ops envelope and, thereby, on the rising risk continuum. The cumulative effects of an event set, composed of Critical Mission Factors, can drive a pilot towards, and then into, one of the four corners (pun intended, as you are really "cornered."). The closer you are to a corner, the more the risk has risen. The boundary corner has also changed shape (becoming a triangle, with the hypotenuse being the new boundary line). Thus, the corner boundary lines are replaced by the new line (the hypotenuse), and are moved in/closer so that, if you are actually in the corner, you have crossed the new boundary line and are outside of the envelope. A typical corner could be low ceilings and visibility (restricted visibility) with a slippery runway and strong crosswind (adverse conditions). As the resultant of combined factors in the event set drives us toward a corner, we first encounter what we term a "gray zone" where we are still within the envelope, but close to a corner. If near/in a corner, in a gray zone, there exists no SOP's or procedures. The same is true if forced out of the envelope. What must be used is to use our situation knowledge to accurately develop the resultant of the combined critical factors and locate ourselves (risk location) in or outside the ops envelope. Next, we must translate our ops envelope location into our location on the risk continuum. Once we locate ourselves accurately on the risk continuum, taking into account the cumulative effect of being in, or very near, a corner, with all the factors that are in play, we can formulate and execute optimum decisions. Again, when we encounter this phenomenon of cumulative effect and rising risk (gray zones/corners), the needed decisions do not lend themselves to simply following procedures. (An example will be provided later).

Risk Management: The Critical Mission Impact Areas, Components and Risk Location

Critical to mission success is the ability to operate in the adverse conditions listed below while, simultaneously, executing the mission plan and managing risk. The need to have the capability to operate under adverse conditions and thus provide reliable transportation is self-evident. But this leaves unanswered what actually causes a rising risk; what are the "risk drivers"? We must first look to identifying, defining and understanding the critical mission impact areas that engender risk. A mission

impact area, if encountered, will engender risk and, if action is not taken, will cause the risk to rise; an impact area demands that action be taken. Mission impact areas are generalized categories that contain critical mission factors as more specific sub-areas, or components, subordinate to mission impact areas. Many of these areas and factors can be found in an air carrier's Flight Operations Manual, but are often scattered throughout, not connected and usually are data specific, stand-alone events/conditions. Until now no attempt has been made to organize this body of knowledge. But, most importantly, we are aware of no previous attempts to place it in a risk management/ODM context. The organization of such data into the operationally useful structures of mission impact areas (and, the break-out of such areas into critical factors) stem from both Captain Smith's work in AQP and from his development of a Mission Performance Model for integrated CRM (Lofaro, 1992). We have identified eleven areas (see **bold** type in Table I) which encompass both the traditional "phase of flight" template and specific events or operations. The specific mission components are clustered into these 11 areas; any of the components/factors cause risk and rising risk (See Table I).

Note: As one rule of thumb here--any factor encountered on a mission will cause the risk to rise; two factors generally will result in moderate risk; the interplay of three or more factors usually results in a high-risk situation.

Also, please notice that the mission is relatively complex. This complexity may have caused many to avoid a high level of specificity in decision making. This is analogous to abandoned efforts in CRM to define technical (flight skills) behavioral markers for crew performance and then develop a template to integrate these markers with the existing human factors crew performance markers (Lofaro, 1992). But, our position here is that one cannot and must not succumb to avoiding complex issues if we truly want a viable air transportation system for the this millennium.

Risk management: Cumulative effects, Risk Location and Rising risk

So, it can be seen that the pilot must, in order to do risk location, have an awareness of the cumulative effect

on the plane of those factors listed in Table I that are in play. As risk will rise under virtually any set of adverse conditions, risk management demands that the crew execute, in a timely fashion, specific mitigation procedures to prevent "risk migration to the right". Rising risk refers to the fact that, if the problems went unnoticed and/or the decisions were not accurate, timely and appropriate, the risk to the successful completion of the flight could rise to the point where the flight might actually crash. Figure II shows that when the crew's perception of risk is low, the original plan is executed to completion. When the risk rises to a moderate level, modifications to the original plan must be implemented in order to maintain an acceptable "location" on the risk dimension. When the risk rises further to some critical threshold, the original flight plan needs to be discontinued and the mission is aborted. In sum: If the risk rises, the captain, working with dispatch and other crew members, either (1) continues with the mission as originally planned for low risk situations; (2) modifies the mission plans as needed in moderate risk situations; or (3) abandons the mission altogether for high risk situations

Continue with The mission	Continue with modification to the mission	Discontinue the mission
Low	Moderate	High

Figure II: Rising Risk Continuum

Risk management: Risk Location and the Operational Envelope

We return to the ops envelope--the big picture. As was said, all the paradigm's components are intertwined, and the pilot is using them by a process of mentally rotating through them in a constantly moving spiral. The pilot must always ensure that his risk location encompasses not only the Critical Mission factors but, the plane's location in--or, more dangerous, outside the ops envelope, and the risk factors in play due to that position as well. This is what we have termed "cumulative effects." By returning to the ops envelope focus, the pilot can accurately place/locate the plane on the rising risk continuum, then take the needed action. Risk location in/out of the ops envelope, translated into risk location on the rising risk continuum, are the keys to risk management.

Table I
Components of the Critical Mission Impact Areas

<ul style="list-style-type: none"> ● Delay of the Operation <ul style="list-style-type: none"> - Hold Over - Holding - Windshear - Wake Turbulence ● Adverse Weather <ul style="list-style-type: none"> - Slippery - Clutter - Contamination - Icing Aloft - Convective Activity - Freezing Precipitation - (Volcanic Ash) ● Performance Limited Operations <ul style="list-style-type: none"> - Clutter - Takeoff Data - Cruise Data - Landing - MEL ● Approach Operations <ul style="list-style-type: none"> - Non-Precision - Precision - Low Visibility - VFR - Approach in Adverse Conditions - Raw Data - Noise Abatement - Non-Precision Hand Flown 	<ul style="list-style-type: none"> ● Landing Maneuver <ul style="list-style-type: none"> - From Non-Precision - No G/S - Crosswind - Abnormal Flaps - Engine Out (50%) ● Single Engine Operations <ul style="list-style-type: none"> - Take Off Alternate Selection - "t" Procedure - V-1 Cut - V-2 Cut - Divert from Cruise (ETOPS) - SE Hand Flown Precision - SE Auto Pilot Flown Precision - SE Non-Precision Approach - SE Landing Maneuver - SE Missed Approach - Engine Fail on Missed - Engine Fail on Final - SE Visual ● Divert/Reject/Abandon <ul style="list-style-type: none"> - RTO - Rejected Landing - Missed Approach (Auto Manual) - Emergency Descent - Divert Take Off Alternate - Divert to Destination Alternate 	<ul style="list-style-type: none"> ● Emergency/High Risk <ul style="list-style-type: none"> - Controllability (Upset) - Windshear - Fire (Engine, Cargo, Cabin) - Bomb Threat - Sick PAX - Decompression - Evacuation - Ditching - Partial Gear - Dual Engine Flameout - Traffic Conflict-TCAS - Runway Incursion - Terrain ● International <ul style="list-style-type: none"> - Class II - Area - ETOPS - Re-dispatch - Supervised Entry Route Mod ● Departure Operations <ul style="list-style-type: none"> - RW Change ● Adverse Wind <ul style="list-style-type: none"> - Windshear - Crosswind/Tailwind/Braking Action - Turbulence - High Winds Aloft
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Putting it Together: an Example

A 767 pilot encounters Winter Ops on approach to SLC due to an advancing Pacific Cold Front; ATIS indicates both restricted visibility and a strong crosswind. Did either factor place the aircraft outside the envelope? The answer is, in this example, no, as the visibility is above minimums and the reported crosswind still is within the performance capability of the aircraft. Remembering our rule of thumb, however, we see that the cumulative effect of the two factors gives a resultant which does produce a higher risk than either factor taken individually. This cumulative effect (resultant) shows the actual risk location to be in a gray, corner area, near the envelope boundary. Placing this cumulative resultant on the Risk Continuum, the pilot locates the plane as being in a Moderate (high moderate) risk area. Since the response action demanded by Moderate risk is to modify the mission plan, the pilot does so by re-configuring the aircraft for Winter Ops; by selecting the most favorable runway; by stabilizing early and so on. At the same time, the pilot increases vigilance for a third critical mission

factor, which would push the risk to High and force the mission to be abandoned.

CONCLUSION

ODM is the focal point where SA and CRM data are used, enabling the pilot to fulfill his role of risk manager by optimally making the needed decisions. We admit that we have presented but a skeletal outline of the operational envelope (e.g., we believe there are some 20 mission critical alerts and warnings), mission impact areas and their component factors, situation knowledge, and most importantly, risk location and translation to the risk continuum. To use the paradigm to develop ODM training, more complete definitions/descriptions of all of these are needed; space precluded this. The same is true of the interrelationships among the model's components. Finally, there is the issue of measures (quantitative and qualitative) of decision success; a problem that has long bedeviled both CRM and SA. All of these things need to be accomplished to develop a complete ODM training program. But, as said, we have and/or are working all of these areas.

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