A Graduate Case Study – Integration of Capstone Concepts in Engineering Management

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Assessment and Capstone Case Projects

Many master in engineering management programs are considering accreditation by ABET, ASEM or similar organizations as a means to demonstrate and assure quality. In many assessment systems, a capstone project is employed to provide a consistent and controlled opportunity for students to demonstrate proficiency in key learning outcomes. This paper contributes to the literature in this area by proposing a case study that contains content related to several key topical areas including economic analysis, risk, decision complexity, and simulation.

Learning objectives for the capstone exercise include:

- System thinking with identification of interrelationships to develop a total cost equation
- Structured decision analysis
- Statistical methods and trend analysis
- Engineering economics
- Written and oral (Presentation) communication skills

The case study is presented below and the authors solicit input and involvement to analyze the capability of the case to elicit responses from students that substantiate the learning objectives. In particular, the nature of the capstone case concept is to provide an open opportunity for students to demonstrate the program learning objectives. Consequently, in particular at the graduate level, the case must present a reasonable level of ambiguity coupled with adequate data to support reasonable solutions.

Problem overview

NASA currently has active research programs in turbulence sensing. You are a NASA research manager and have been tasked with examining the question of continuing funding for research in turbulence sensing systems. You must develop and substantiate a case to support continued funding or discontinuation of support for this research

Your case analysis should include a thorough examination of the following issues:

- Identify an analytical equation to structure your decision analysis
- Explicitly state your approach to valuing the terms of your equation.

- Explain the intangible elements you believe are important.
- Document a recommendation
- Identify sensitivity and risk approaches

Critical information for your analysis is included in the next sections.

Case Introduction

Turbulence is a significant issue in aviation safety. The Federal Aviation Administration (FAA) reports [1] that between 1981 and 1997, there were 342 reports of turbulence affecting flights of major air carriers and they resulted in three deaths, eighty serious injuries, and 769 minor injuries. Lindsey [2] indicates that encounters with turbulence account for 62% of all US air carrier accidents when weather is a factor and another FAA report [3] indicates this number may be as high as 79%.

In recognition of the importance of turbulence mitigation in improving aviation safety, the National Aviation and Space Administration's (NASA) Aviation Safety Program identified turbulence detection and mitigation as a focused research area. NASA defined the objective of this research task as development of highly reliable turbulence detection technologies for commercial transport aircraft to sense dangerous turbulence with sufficient time warning so that defensive measures can be implemented and prevent passenger and crew injuries. A number of forward turbulence detection technologies are being studied as possible solutions including enhanced X - band radar for storm and moisture based turbulence and laser based LIDAR (Light Detecting and Ranging) systems for clear air turbulence. Wake turbulence is related to the vortex created by aircraft taking off or in flight and is also clear air oriented.

These technologies may improve flight safety but also present investment cost and benefit questions that have not been quantified. Consequently, it is not clear whether these systems are financially feasible by demonstrating a business case in which the benefits exceed the costs. In evaluating this question, there are two possible avenues for introduction of these technologies. The first involves implementation through regulatory mandate to improve aviation safety. In this scenario, FAA standards [4] or benefit and cost analysis would guide the decision model. The second possibility is that these technologies will be successful as commercial products through a direct customer driven decision. In this case, the business feasibility decision must be structured using actual cost savings and expenditures as viewed by a for – profit business such as an airline. If market driven adoption is feasible, it presents the opportunity for a more short - term impact to improve safety compared to a longer term process involving regulatory mandate.

As previously mentioned, forward turbulence sensing technology improves flight safety but also presents investment and cost implications. The following elements generally describe the system costs and benefits.

Investment: The non- recurring cost to purchase and install the necessary sensing hardware and software required by the specific turbulence sensing system.

Operating cost: The annual (recurring) cost to maintain and operate the sensing system.

Savings: Savings include two areas of financial benefit. The first addresses reduction of annual costs related to passenger and flight attendant injuries from unanticipated turbulence. The second area involves annual savings related to operational factors such as aircraft damage, diversions, and increased flying time caused by the inability to sense turbulence accurately.

Intangible Benefits: Intangible benefits describe strategic or market based benefits that are not easily "monetized" but may influence the adoption decision. Intangible benefits are of limited impact if the net system benefits term is positive without inclusion of intangible benefit values. On the other hand, if the net system benefits are negative without this term, then the intangible benefits may be important criteria in a decision to implement turbulence sensing technology. Major elements of these intangible decision factors include:

- Competitive advantage in marketing customer satisfaction or safety / comfort that may accrue to firms that adopt forward sensing turbulence technology.
- Ultra long distance flights may require that passengers safely enjoy extended out of seat periods and forward turbulence sensing may be an operational necessity.
- Current air traffic control limits route choices and aircraft often follow one another on specified routes. This results in a "first - plane - at- risk" system that warns subsequent aircraft of turbulence in the flight path. In the future, "free flight" will allow aircraft to choose from a wide range of routes and, as a result, every aircraft will be a potential "first plane at risk" in unknown turbulence areas.

Are forward sensing turbulence systems a feasible alternative to reduce aviation injuries? Should NASA continue funding research in this area if the goal is to produce a system (or systems) that has high potential for introduction into the market place? Data to support analysis of this question follows.

Turbulence Related Injuries

In either a regulatory driven or market driven adoption scenario, a starting point for assessing the feasibility of turbulence sensing technologies is evaluation of the injury impact of turbulence. This section examines data from two sources that may be useful to assess turbulence related injuries: crew reports for a recent 13 month period from a major airline and National Transportation Safety Board (NTSB) data.

Since this data distinguishes between various categories of injuries, it is important to define these differences. The NTSB defines an accident as an event that results in serious injury or substantial damage to aircraft occurring from the time of aircraft boarding till the last person leaves. A serious injury is one that involves one or more of the following: hospitalization for more than 48 hours, a major bone fracture, severe hemorrhage, nerve, muscle, or tendon damage, involvement of an internal organ, or second or third degree burns on more than 5% of the body. On the other hand, an incident (or event) is more broadly defined as anything reported that threatens or may threaten safety. Incidents may include both accidents with major injuries and lesser events with either minor injuries or no injuries at all. Minor injuries are those that do not meet the previous criteria.

Airline Crew Reports

A major airline provided copies of turbulence related crew reports covering a recent thirteen-month period. These reports were examined and injury data was extracted. The results are summarized in Table 1. This airline represents about 20% of the major transport market both in the number of aircraft and flight hours.

Table 1 Injuries from Airline Crew Reports

	Clear Air	Wake	Convective	Total
Turbulence events	32	29	124	185
Injury events	25	21	87	133
Minor flight attendant injuries	29	31	101	161
Serious flight attendant injuries	4	0	5	9
Minor passenger injuries	4	3	21	28
Serious passenger injuries	0	2	2	4

National Transportation Safety Board Reports

The NTSB maintains flight safety records that provide historical information to identify possible trends involving either the rate at which turbulence accidents occur or the number of injuries that occur in these events. Trends in either of these areas could increase or decrease the level of injuries over time and influence the business case for turbulence sensing technologies. This analysis focuses on NTSB reports for Part 121 air carriers, generally defined as major airlines and cargo haulers that fly large transport aircraft, since this aviation segment is the primary market target for the turbulence sensing technologies. The NTSB documented 167 reports involving turbulence from January 1983 to November 1999 for Part 121 carriers and 131 were classified as accidents. Table 2 summarizes that information.

Cost of Injuries

It is possible that forward sensing technology may be implemented either as a regulatory requirement to improve flight safety or as a result of market driven demand by airlines to reduce costs. Consequently, there may be two different perspectives for the cost impact of turbulence injuries for the transport sector: cost -benefit method using FAA standards (regulatory view) and approaches that represent business - oriented costs (market driven).

To evaluate effectiveness of regulatory requirements the FAA [4] published guidelines for economic analysis that stipulate use of specific costs for fatality and injury. These costs were developed by establishing a value that consumers are "willing to pay" (WTP) to reduce the probability of fatality or injury. Since this WTP cost reflects only the value that a group of individuals places on avoiding injury, the FAA method adds other direct costs to the WTP value such as legal and emergency medical expenditures to develop a total cost. For a fatality, the FAA identifies $2.7M as the cost benchmark.

The WTP values for injuries are based on evaluating the loss of quality or quantity of life incurred by the injury as a fraction of the fatality cost. For example, the WTP cost of a minor injury is evaluated as 0.2% of the loss of life cost and medical and legal costs are then added to this value. Table 3 summarizes the minor and serious injury costs developed by the FAA along with the fatality cost. The FAA does not differentiate injury costs between flight attendants and passengers.

Table 2 NTSB Report Summary

Year	Number Accidents	Passenger Fatalities	Passenger Serious	Passenger Minor	Passengers on Board	Flight Attendant Serious	Flight Attendant Minor	Flight Attendants On board	Pilots On Board	Total Fatalities	Total Serious	Total Minor	Total on Board	Industry flight hours
1983	4	0	2	6	276	3	1	13	10	0	5	7	299	7,298,799
1984	5	0	2	5	498	3	5	29	13	0	5	10	540	8,165,124
1985	4	0	3	19	228	4	2	18	9	0	7	21	255	8,709,894
1986	8	0	6	29	986	6	18	47	18	0	12	47	1051	9,976,104
1987	8	1	10	68	882	5	9	39	20	1	15	77	941	10,645,192
1988	7	0	2	8	957	5	11	46	15	0	7	19	1018	11,140,548
1989	3	0	8	21	368	1	2	21	8	0	9	23	397	11,274,543
1990	5	1	4	61	532	4	8	24	11	1	8	69	567	12,150,116
1991	6	0	4	21	648	3	4	32	12	0	7	25	692	11,780,610
1992	5	0	1	0	520	3	1	23	12	0	4	1	555	12,359,715
1993	9	0	3	18	932	8	8	48	18	0	11	26	998	12,706,206
1994	5	0	0	0	860	5	3	33	11	0	5	3	904	13,124,315
1995	11	0	7	10	1371	7	1	68	23	0	14	11	1462	13,505,257
1996	10	0	6	27	1030	7	3	34	20	0	13	30	1084	13,746,112
1997	14	1	15	21	2135	10	17	101	30	1	25	38	2266	15,838,109
1998	12	0	5	22	1517	9	8	68	26	0	14	30	1611	16,846,063
1999	15	0	5	87	1637	10	20	74	31	0	15	107	1742	17,428,000
	131	3	82	407	15147	92	117	712	283	3	174	524	16142	

Table 3 FAA Injury Values Per Victim

Classification	Willingness to Pay	Emergency / Medical	Legal / Court	Total Value
Death	$2.7M	Not a significant addition to WTP value		$2.7M
Minor injury	$34,000	$2,000	$2,500	$38,500
Serious Injury	$482,000	$27,600	$12,200	$521,800

The FAA injury values in Table 3 represent the cost of turbulence injuries that supports a possible regulatory decision to implement forward turbulence systems in the commercial transport fleet. However, airline decision makers would not employ WTP based costs in assessing the financial benefits of turbulence sensing systems in a capital investment analysis based on cost reduction. In the analysis of a decision on whether to purchase new turbulence sensing technology, corporate decision makers will employ business costs and it is not possible to relate the FAA regulatory oriented values to actual business costs and expenses. Consequently, it is necessary to estimate the actual business costs that are related to injuries to evaluate the market driven feasibility of turbulence sensing technology. To benchmark these business costs, the next section presents results of an industry survey that estimated turbulence injury costs from the viewpoint of airline industry decision makers.

Injury Cost Survey

The risk managers of the major airlines were hesitant to release information related to costs of injuries due to confidentiality and competitive considerations. However, several agreed to complete an anonymous survey involving selection of intervals in which they believed the real cost figure was contained. These results are presented in Table 4 and represent the "out of pocket" costs of serious and minor injuries for both flight attendants and passengers.

Table 4 Summary of Injury Cost Estimates- Industry Survey

	0 - $100,000	$100,000 - $200,000	$200,000 - $300,000	$300,000 - $400,000	More than $400,000
Serious Flight Attendant Injury	3	2	1	0	1
Serious Passenger Injury	1	3	0	1	0

	0 - $25,000	$25,000 - $50,000	$50,000 - $75,000	$75,000 - $100,000	More then $100,000
Minor Flight Attendant Injury	4	1	1	0	0
Minor Passenger Injury	4	1	0	0	1

Other Potential Decision Factors

Forward sensing turbulence systems impact other turbulence related operational costs and the following paragraphs examine these factors:

- Fuel Savings: Search [5] examined the impact of turbulence on commercial transport operations. This analysis found that 5% of flights are prevented from flying at the optimum elevation by turbulence resulting in an industry loss of $16,000,000 annually. Approximately 15% of this loss was estimated as avoidable with improved turbulence detection for a possible annual industry saving of $595 per aircraft.
- Aircraft damage: Lindsey [6] studied aircraft damage in turbulence events and found that no aircraft damage occurred in 83% of turbulence events. In 13%, minor interior damage occurred such as cart, galley, or cabin items. In the remaining cases, substantial damage occurred but was not related to the type of turbulence avoidance that forward sensing systems will improve. Examples include hard landings that damaged the undercarriage or tail of the aircraft and hail damage to the windscreen and radar dome. This analysis indicates that it is not likely that forward sensing systems will significantly reduce aircraft damage costs.
- Diversions: The crew report data showed that diversions occur in 3.25% of turbulence events. Using this proportion and the total of 568 turbulence events from Table 1, eighteen flights is an annual estimate for the number of turbulence related diversions in the commercial transport sector. A previous study [7] estimated an average diversion cost of $75,000 and this results in an industry cost of $1.35M for turbulence related diversions. If this value is allocated to a theoretical airline with a 20% share of passenger miles and a 600 aircraft fleet, $450 per year can be allocated to each aircraft as the diversion cost of

turbulence.

Summary
Turbulence injuries are a major factor in airline safety and several technologies have the potential to mitigate the injuries that turbulence causes. To evaluate and prioritize research activities to develop one or several of these alternatives into products that can be successful in the commercial transport sector, based on either a regulatory or a market driven adoption scenario, a decision analysis is needed. This case presented data on the populations that are being injured, the cost of those injuries, and the total annual cost impact of turbulence injuries in the commercial transport sector.

The data presented in this paper is currently being used to analyze the business case for forward sensing technologies and these results will be the subject of a future paper. Current research in the area of aviation safety should involve a cooperative effort that combines the airline industry, the research community, and sensing system developers to more accurately define the exact circumstances of turbulence injuries and the technical features necessary for a forward sensing product to prevent them. In addition, more exact ranges of injury costs are needed to precisely balance these possible product features with the cost reductions they produce.

As a NASA research manager, develop a report with a supporting presentation that addresses your recommendation addressing the question of continuing funding for research in turbulence sensing systems. You must develop and substantiate a case to support continued funding or discontinuation of support for this research.

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