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A Study on Transfer Effectiveness and Appropriate Training Hours in Airplanes Simulators

Sugjoon Yoon
Taejun Park
Jung-hoon Lee
Jinkook Kim

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I. Background

- This Paper is to answer questions, which are typical concerns of simulator customers and operators:
  - Appropriate Training Hours
  - Transfer Effectiveness
  - Cost Reduction Effects
  - Appropriate Quantity of Airplane Simulators

- This study reviews and analyzes Technical papers and reports on simulator training effectiveness as well as relevant regulations of FAA (Federal Aviation Administration).

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I. Background

- Reviews of technical papers and reports on training effectiveness are summarized as follow:
  - Typical TER (Training Effective Ratio) is over 0.33.
  - Motion platform contributes to transfer of training for unintended maneuvers due to turbulences and engine outs.
  - Most training centers and schools, either military or civil, allocate 30% ~ 50% of whole training hours in simulators, which agrees to FAR (Federal Aviation Regulations) policies in Part 61 and 141.
  - Most civil transport airlines operate FSTD(Flight Simulation Training Devices) with ratios between 1:10 and 1:20 (FSTD : Airplane).

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II. Analyses of Training Effectiveness Studies

1. Operating Costs of Flight Training Simulators

- Simulator Operation Statistics
  - Operating costs of flight training simulators are between 5% and 20% of those of actual airplanes.
  - The variable operating costs per hour for aircrafts in operational units and simulators are shown graphically in the figure.
  - Relative costs of simulated versus actual flight hours are between 3.3% and 14%.

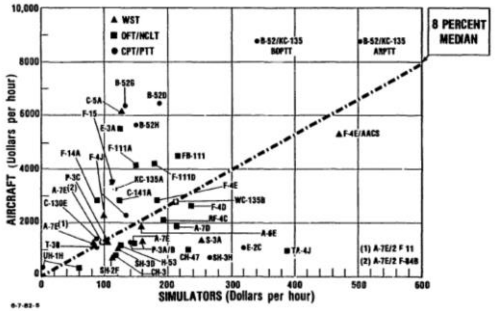

Fig 1. Variable Operating Costs per Hour for 39 Flight Simulators and Aircraft, FY 1980 and FY 1981

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II. Analyses of Training Effectiveness Studies

1. Operating Costs of Flight Training Simulators

- Efforts to reduce training costs through flight training simulators:
  - US Army saved $68M of flight training expenses in FY 1994.
  - US Navy allocated 40 flight hours in training simulators and 77 hours in actual F/A-18 airplanes.
  - US Air Force Air Mobility Command has a plan to replace up to 50% flight hours in pilots using training simulators.

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II. Analyses of Training Effectiveness Studies

2. Transfer Effectiveness Ratio (TER)

- A standard index explaining benefits of simulator training is Transfer Effective Ratio(TER).
- TER is a ratio of reduced flight hours or iterations in an actual airplane to the training hours or iterations in a flight simulator:

$$TER = \frac{C - E}{E_{simulator}}$$

- C = The control group task iterations in an actual airplane
- E = The experimental group task iterations in an actual airplane
- $E_{Simulator}$ = The experimental group task iterations in a simulator

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II. Analyses of Training Effectiveness Studies

2. Transfer Effectiveness Ratio (TER)

- Compute Method about TER of a flight training simulator
  - Divide into two groups to compute a TER of a flight simulator
    - 1st Group(Control Group) : A control group goes through a conventional pilot training process without simulator training.
    - 2nd Group(Experimental Group) : an experimental group undergoes additional simulator hours and iterations.
  - After completion of flight training, two groups are compared in flight skills.
- Meaning of the TER value
  - TER of 0.5 implies that 2 flight simulator hours have effects to reduce 1 hour in an actual aircraft.

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II. Analyses of Training Effectiveness Studies

2. Transfer Effectiveness Ratio (TER)

- Results of the TER
  - Comparison studies of TER for military flight simulators show that TER is over 0.33 for 59% of mission flights.
    - These results can be interpreted as 3 simulator flight hours replace 1 actual flight hours in 59% of whole mission flight training.
  - Orlansky et al analyzed 34 training effectiveness studies
    - The average TER turns out to be 0.48 for 34 training effectiveness studies.
  - Thus a larger TER indicates more effectiveness in replacing actual flight hours.

II. Analyses of Training Effectiveness Studies

3. An Optimal Ratio between Actual and Simulator Flight Training Hours

- Dufaur set simulation portion of a flight training curriculum
  - Initial Course : 30%
  - Familiarization Course : 80% (and more)
  - instrument, navigation and terrain flight training Course : 50%
- Criteria for determining an Optimal Ratio
  - Training Progress
  - Training Duration

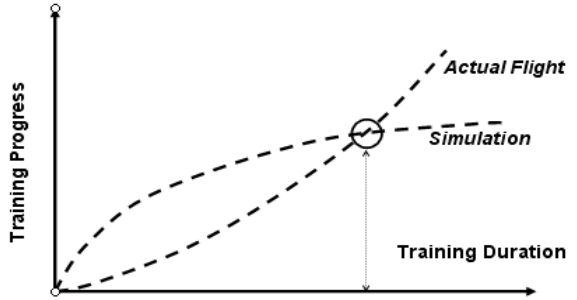

Fig 2. Determining the correct simulation ratio

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II. Analyses of Training Effectiveness Studies

3. An Optimal Ratio between Actual and Simulator Flight Training Hours

- Comparison of ratio between actual and simulator flight training hours
  - US Army : 43.25%
  - Turkish Army : 49.18%
  - Korean Aerospace Industries : 56%
- Determining a ratio between flight training hours using an actual aircraft and a simulator is a subjective matter. However, in a case study, the ratio above was about 40% ~ 50%.

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II. Analyses of Training Effectiveness Studies

4. TER Comparison between FFS and FTD

- Case Study
  - Background : As a part of Federal Administration Administration/Volpe Center Flight Simulator Fidelity Requirements Program, training effectiveness of a 6 DOF motion system in FFS was investigated.
  - Two groups of pilots were tested in a FFS and a FTD with 1 DOF heave motion seat.

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II. Analyses of Training Effectiveness Studies

4. TER Comparison between FFS (Full Flight Simulator) and FTD (Flight Training Device)
   - Conclusion of case study
     - Contribution of motion systems in pilot training show that motion systems are effective in training especially when an airplane is affected by unexpected disturbances such as turbulences, engine outs, emergencies, and marginal stabilities.
     - But, no apparent proof was identified, showing the advantage of 6 DOF (Degrees of Freedom) motion in transfer of training.
     - motion systems, either 6 DOF or 1 DOF, do not contribute much to intended flights of pilots.

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III. Simulator Training Hours and Cost Reduction Effects

1. Permissible FSTD Training Hours by FAA

Pilot Certificates	Minimum Flight Hours	Maximum FSTD Hours	Ratios of Flight Hours in FSTD to Aircraft
Private pilot certificate	35	7	0.20
IFR	35	17	0.49
Commercial pilot certificate	120	36	0.30
Rotorcraft pilot certificate	115	25	0.22
Multi-engine rating	25	10.5	0.42
ATP certificate	25	12.5	0.50
Flight instructor certificate	25	2.5	0.10
Instrument flight instructor rating	15	1.5	0.10

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III. Simulator Training Hours and Cost Reduction Effects

2. FSTDs and Airplane in Civil Airlines and Korean Air Force

Airline/Military Service	Number of Aircrafts	Number of FSTD	Ratios of Aircrafts to FSTD	Reference Year
Korean Air	165	8 FFS	20.6 : 1	2017
Asiana Airlines	84	5 FFS	168 : 1	2016
American Airlines	956	44 FFS	21.7 : 1 FFS	2016
		14 FTD	16.5 : 1 FSTD	
Air France	221	18 FFS	12.3 : 1 FFS	2016
		2 FTD	11.1 : 1 FSTD	
Korean Air Force (F-16 Only)	166	20 FSTD	8.3 : 1	2015

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III. Simulator Training Hours and Cost Reduction Effects

3. Necessary Quantity of FSTD and Cost Reduction Analysis

- Method for calculating necessary quantity
  - Assumption
    - 100 airplanes
    - Permissible flight hours per month : 20 hours
    - Operation Ratio for Training : 0.5
  - Permissible flight Hours per Year : 12,000 hours
    - 100 airplanes x 20 hours(permissible flight hours per month) x 12 months x 0.5 (Operation Ratio for Training) = 12,000 hours

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III. Simulator Training Hours and Cost Reduction Effects

3. Necessary Quantity of FSTD and Cost Reduction Analysis

- Method for calculating necessary quantity
  - Simulator Training Hours per Year : 12,000R hours
    - 12,000 hours (Permissible Flight Hours per Year) x R (Simulator Training Ratio) = 12,000R hours
  - Operation Hours of a Simulator per Year : 200D hours
    - Daily Operation Hours : D hours
    - Operation Days : 200 days
    - Operation Hours of a Simulators per Year : D hours x 200 days = 200D hours

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III. Simulator Training Hours and Cost Reduction Effects

3. Necessary Quantity of FSTD and Cost Reduction Analysis

- Method for calculating necessary quantity
  - Number of Necessary Simulators : 60R/D
    - Simulator Training Hours per Year / Operation Hours of a Simulator per Year = 12,000R/200D = 60R/D
    - Example) If R = 0.3, D = 0.7 : The number of necessary simulators becomes 2.57
  - FSTD hours per pilot
    - Assuming 2.5 pilots per Airplane
    - 2.5 Pilots per airplane x 100 airplanes = 250 pilots
    - Average Simulator Training Hours per Pilot : 12,000R hours/250 pilots x 2 (2 Seats per Simulator) = 96R hours
    - Actual Flight Hours per Pilot : 12,000 hour/250 pilots x 2 (2 Seats per Airplane)= 96 hours

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III. Simulator Training Hours and Cost Reduction Effects

3. Necessary Quantity of FSTD and Cost Reduction Analysis

- Case Study
  - Case Study 1
    - FAR Part 141 requires minimum 120 flight hours for a commercial pilot certificate, where up to 36 FSTD hours are allowed.
    - Then 24 hours have to be trained in FSTD.
    - If R=0.3, then 28.8 (96 x 0.3) hours come out of FSTD to exceed the minimum flight hour requirements, satisfying the limit of 36 FSTD hours.

III. Simulator Training Hours and Cost Reduction Effects

3. Necessary Quantity of FSTD and Cost Reduction Analysis

- Case Study
  - Case Study 2
    - FAR Part 141 requires minimum 115 flight hours for a rotorcraft pilot certificate, where up to 25 FSTD hours are allowed.
    - Then 19 hours have to be trained in FSTD.
    - If R=0.22, then 21.1 (96 x 0.22) hours come out of FSTD to exceed the minimum flight hour requirements, satisfying the limit of 25 FSTD hours.

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III. Simulator Training Hours and Cost Reduction Effects

3. Necessary Quantity of FSTD and Cost Reduction Analysis

- Results through Case Studies
  - Experimental results described in this paper cannot be generalized, because the training effects may depend on such factors as simulator specifications, number of trainees, types of airplanes, and so on.
  - Maintaining equivalent training effects, cost reduction ratios can be formularized : Cost Reduction Ratio = R x (1 – E / TER)
    - R : Simulator Training Ratio
    - E : Operating Cost Ratio of Simulators to Actual Airplanes
    - Example)
      IF) R= 0.5, TER=0.33, and E= 0.08, then the cost reduction becomes 38% of actual airplane training.
      If) R= 0.3, TER=0.33, and E= 0.08, then the cost reduction becomes 22.8% of actual airplane training.

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IV. Conclusions

- This study is to answer questions regarding appropriate training hours, transfer effectiveness, and cost reduction effects of airplane simulators, which are typical concerns of simulator customers and operators.

- The papers and reports show similar trends with different figures, which is inherent nature of experimental studies.

- The primary contribution of this study is to formulate rules to determine appropriate simulator training hours and cost reduction ratios based on the previous works on TER reviewed in this paper.

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IV. Conclusions

- From the conservative perspectives, the following observations are summarized
  - Mean simulator operating cost per hour is 8% of actual airplanes.
  - Typical TER (Transfer Effective Ratio) is over 0.33.
  - Motion platforms contribute to transfer of training for unintended maneuvers due to turbulences and engine outs.
  - Most training centers and schools, either military or civil, allocate 30%~50% training hours in simulators, which agrees to FAR Part 61 and 141.
  - Most civil transport airlines operate FSTD with ratios between 1:10 and 1:20 (FSTD: Airplanes).

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