Article Review

The Impact of Crew Resource Management Training on Operational Skill of Aircraft Operation Student: A Comparison Between Simulation-Based and Theoretical Learning

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Abstract

Crew Resource Management (CRM) is a critical training method in aviation aimed at improving teamwork, communication, risk management, and decision-making to minimize human error, a significant contributor to aviation accidents. While theoretical training builds foundational knowledge, it often lacks practical application necessary to develop operational skills in real scenarios. This study compares CRM training through simulation using the FLOPS Simulator with traditional theoretical instruction, focusing on their impact on Aircraft Operations students' skills. This quasi-experimental study investigated the effects of theoretical and simulation-based CRM training on operational skills among 24 Aircraft Operations students. Initial CRM knowledge was assessed through a theory test, followed by a first simulation to evaluate students practical CRM skills. Observations and interviews captured their challenges and experiences. A second simulation assessed improvements in operational skills, with data analyzed using descriptive statistics and qualitative insights from interviews. Results indicate that simulation-based CRM training significantly enhances operational skills, particularly in communication, teamwork, risk management, and decision-making, compared to theoretical training. Simulation provides a more immersive learning experience, allowing the application of CRM principles in near-real operational conditions. This study, conducted at a single institution, highlights the need for broader research involving multiple institutions and long-term assessments to further validate findings. By addressing gaps in CRM training, this research underscores the effectiveness of simulation in aviation education and its potential to improve CRM training practices

Keywords: *Crew Resource Management, FLOPS Simulator, Simulation-Based Learning, Theoretical Learning*

INTRODUCTION

The aviation industry places immense value on safety and efficiency, and Flight Operations Officers (FOOs) play a pivotal role in maintaining these standards. FOOs are responsible for various critical tasks such as flight planning, weather assessment, fuel calculation, and providing safety briefings, all of which contribute to the smooth and safe execution of flights (Parhizkar et al., 2023). Given the complexities and high stakes of this role, students in the Aircraft Operations Program at institutions like the Indonesian Civil Aviation Academy must develop comprehensive operational skills. Following ICAO's Competency-Based Training and Assessment (CBTA) (Van Kempen et al., 2022) standards, FOOs must be equipped with not only technical knowledge but also practical skills to manage flights safely and efficiently (Schillinger et al., 2022).

In aviation education, students of the Aircraft Operations program must not only understand the theory behind CRM (Brown et al., 2021) but also be able to apply it in real-life operational situations. While theoretical learning provides foundational knowledge (de Zwart et al., 2023), the application of CRM principles in practical environments through simulations (Del-Pozo-Puñal et al., 2023) is crucial for developing operational skills. A core component of this training is Crew Resource Management (CRM) (Redjem et al., 2025), a program developed to enhance teamwork,

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communication, decision-making, and risk management, thereby reducing human error, a primary cause of aviation accidents. Studies reveal that over 80% of aviation accidents are due to human factors, especially during critical phases like takeoff and landing. Originally designed for cockpit crew interactions, CRM has expanded its scope to improve collaborative functioning across broader aviation teams, including ground personnel and FOOs, which ensures operational safety across all phases of flight (Chernikova et al., 2025).

Over time, CRM training has evolved, with the integration of technologies like simulators proving to be highly effective. Simulation-based learning (Rowan et al., 2025) allows aircrews to practice real-world scenarios in a controlled environment, where they can experience the demands of real-time decision-making and coordination. Simulators, such as the FLOPS Simulator (Matthews et al., 2025), enable students to engage with realistic operational challenges and practice CRM principles in a risk-free setting. FLOPS (Flight Optimization System) is a simulation software developed by NASA to analyze and optimize aircraft design, particularly in terms of aerodynamic performance, propulsion, and fuel efficiency. This immersive approach to training is essential for developing the decision-making, communication, and situational awareness skills needed by FOOs to manage risks and coordinate effectively with flight crews (Lamont et al., 2025).

However, existing CRM training methods often rely heavily on theoretical learning (Dittrich et al., 2025), which, while building foundational knowledge, lacks the depth of practical application. Recent studies indicate that traditional classroom-based instruction (Klar et al., 2024) may fall short in preparing students for high-stakes environments. While theoretical CRM training is instrumental (Takabatake et al., 2025) in understanding the core principles, simulation-based training offers (Baigorri & Mallor, 2025) a more robust platform for skill enhancement, especially in managing the pressures FOOs face in real-world operational scenarios. Despite the demonstrated effectiveness of simulators, the aviation education field has limited research comparing the effectiveness of CRM training methods (Jakonen et al., 2023), specifically simulation-based versus theoretical instruction, in enhancing the operational competencies of Aircraft Operations students.

This study aims to evaluate the impact of CRM training (Arteaga et al., 2024) delivered through simulation versus traditional theoretical instruction on the operational skills of Aircraft Operations students. By examining improvements in communication, decision-making, and risk management, this research seeks to identify the most effective training method. The study's findings are expected to guide future CRM training methodologies (De Schepper et al., 2021) and support the development of more effective training facilities within aviation academies (Kułakowski & Nowakowski, 2019), thereby better preparing FOOs to handle the complexities of real-time operations (Pawar et al., 2024).

LITERATURE REVIEW

Crew Resource Management (CRM) and Its Development in Aviation Safety

Crew Resource Management (CRM) was first developed in response to the high number of aviation accidents caused by human error, which, according to van Grevenstein et al. (2021), accounted for more than 80% of total flight incidents, especially during critical phases such as takeoff and landing. Early CRM training focused on enhancing communication skills, decision-making, and teamwork among pilots as an effort to minimize human errors (Rojas Trejos et al., 2025). Over time, the scope of CRM has expanded not only to cockpit crews but also to include other personnel such as cabin crew and Flight Operations Officers (FOO), emphasizing the importance of cross-functional collaboration. Havinga et al. (2017) state that CRM currently aims to enhance interactions between various roles in flight operations, in order to strengthen overall operational safety.

The Role of Simulation-Based Learning in CRM Training

CRM training generally combines theoretical and practical learning (Chan & Li, 2022). Although the theoretical approach provides a conceptual understanding of CRM principles (Folke & Melin, 2024), research shows that this method often fails to replicate the operational pressures and complexities of real situations (Palupi et al., 2021). Adkins et al. (2015) argue that although theory plays an important role in shaping initial understanding, this approach has not sufficiently prepared students, especially FOO, to face emergencies and make quick decisions in the field.

To address these limitations, simulation-based approaches are increasingly being viewed as a more effective solution. Simulation, such as that provided by the FLOPS Simulator, offers realistic scenarios that allow participants to practice CRM skills in situations resembling actual operational conditions (Vlaskamp et al., 2025). Simulation-based learning allows students to experience team communication dynamics, situational awareness, and quick decision-making in a controlled environment. This is very important for FOO, as it can enhance the ability to respond to emergencies efficiently, an ability that is difficult to achieve through theoretical training alone (Korte & Yorke-Smith, 2025).

Comparative Studies on CRM Training Effectiveness

Although the benefits of simulation-based training are widely recognized (Hasselsteen et al., 2024), few studies directly compare its effectiveness with theoretical learning in enhancing CRM competencies. One of the main challenges is the limited access to high-quality simulators, which restricts students' opportunities to gain adequate practical experience. Moreover, variability in the quality and intensity of simulation training also affects the consistency of training outcomes (Maimunah, 2018).

This review indicates that there is still a gap in research regarding the direct comparison between theoretical learning and simulation in the context of CRM education, particularly for students in the aircraft operations study program. Therefore, this research is aimed at empirically evaluating the impact of both approaches on the development of students' operational skills, with a focus on the effectiveness of CRM training in the context of aviation vocational education.

RESEARCH METHOD

This study employed a quasi-experimental design. According to Arikunto (2021), a representative sample size is very important for internal validity. Therefore, the purposive sampling technique was used in this study to ensure the representation of Crew Resource Management (CRM). To evaluate the impact of theoretical and simulation-based Crew Resource Management (CRM) training on the operational skills of Aircraft Operations students. The research involved 24 students enrolled in the Aircraft Operations Program, aiming to assess the progression of their skills through theory-based learning and two sequential simulations.

Training is conducted using simulators like FLOPS (Flight Optimization System), which presents operational scenarios realistically. The simulation scenarios include various situations commonly faced in the aviation world, such as flight delays, adverse weather affecting routes, technical disruptions, and the need for cross-team coordination. In this simulation, participants are asked to complete operational tasks in groups, honing their communication skills, decision-making, and situational awareness according to CRM principles.

Suhardi and Hidayat (2023), a quasi-experiment is a method that does not include a control group, which limits its ability to fully control external variables that may influence the experiment's implementation. This research uses two types of instruments, namely questionnaires and tests, to measure the respondents' perceptions and technical abilities.

Participants

The participants were 24 students from the Aircraft Operations Program. All participants underwent theoretical CRM training (MacLeod, 2021) before entering the simulation phase. This ensured they had foundational knowledge of CRM principles such as teamwork, communication, decision-making, and risk management. This research involves 24 students from the air operations program who were purposively selected. Purposive sampling is appropriately used in this research because the researcher has specific criteria regarding who can provide relevant and meaningful data. In the context of research on the effectiveness of simulation-based Crew Resource Management (CRM) training, only participants who have truly undergone the training, specifically, FOO (Flight Operation Officer) students directly involved in the simulation sessions, possess the relevant experience, knowledge, and context to answer the research questions.

One of the limitations in this study is that the number of respondents who provided qualitative data through open-ended responses is not as large as the total number of participants. Out of the 24 students who participated and filled out the quantitative questionnaire, only 11 provided complete and analyzable open-ended responses. This happened because open-ended questions are optional and require deeper reflective engagement, which not all participants are willing to do.

Nevertheless, the qualitative data obtained still provide significant added value to the analysis, as the responses come from participants who have truly experienced the simulation and are able to articulate their experiences in sufficient detail. The themes that emerged from the open-ended responses are also consistent with the quantitative data results, thereby supporting the validity of the findings through a triangulation approach.

Study Procedure

The research was conducted in three phases: theoretical training, simulation 1, and simulation 2.

1. Theoretical Training Phase
   According to Amalia and Arthur (2023), a test is a tool or procedure used to assess or measure something in a specific context, following predetermined methods and rules.
   a. Participants attended classroom-based CRM instruction covering essential concepts;
   b. Participant was also given the task to finish the flight plan individually and then learning how to brief about the flight plan they made;
   c. A standardized theory test was administered to measure their understanding of CRM principles. The results served as a baseline to assess their preparedness for real scenarios.
2. Simulation 1 (Initial Assessment)
   a. Students participated in the first simulation, designed to mimic real aviation scenarios. The simulation assessed their ability to apply theoretical knowledge in operational settings. In the simulation group of participants given a task to do an operational task in a team, the participants will facings real scenarios. Participants were given tests in teams, which were different from previous tests and exercises, which were completed individually.
   b. Data collection:
      1) Questionnaire**:** A structured questionnaire was administered after the simulation to evaluate the students experiences and challenges in applying CRM skills.
      2) Open-Ended Responses**:** Students provided written feedback on the difficulties or challenges they faced during the simulation. These responses were analyzed qualitatively to gain insights into areas needing improvement.
3. Simulation 2 (Evaluation of Improvement)
   a. A second simulation was conducted with an increased level of difficulty to evaluate the impact of experience gained in simulation 1.

b. Data collection:
   1) Questionnaire: A post-simulation questionnaire measured the improvement in CRM skills, focusing on teamwork, communication, decision-making, and risk management.
   2) Comparative Analysis: Performance metrics from simulation 1 and simulation 2 were compared to assess skill development and the effectiveness of simulation-based learning.

4. Data Collection Tools
   a. Theory Test Scores: The theory test is given as a basis for students to have a theoretical understanding of CRM concepts.
   b. Questionnaires: The instrument was validated through content validity testing, and reliability testing was conducted using Cronbach's Alpha with a value of 0.60, indicating high internal consistency.
   c. Objective Performance Data (Time Efficiency): from the first Pre-Simulation test that has been done in 2 tests and time efficiency data from simulations 1 and 2
   d. Open-Ended Feedback: Provided qualitative insights into specific challenges faced by students during the simulations.

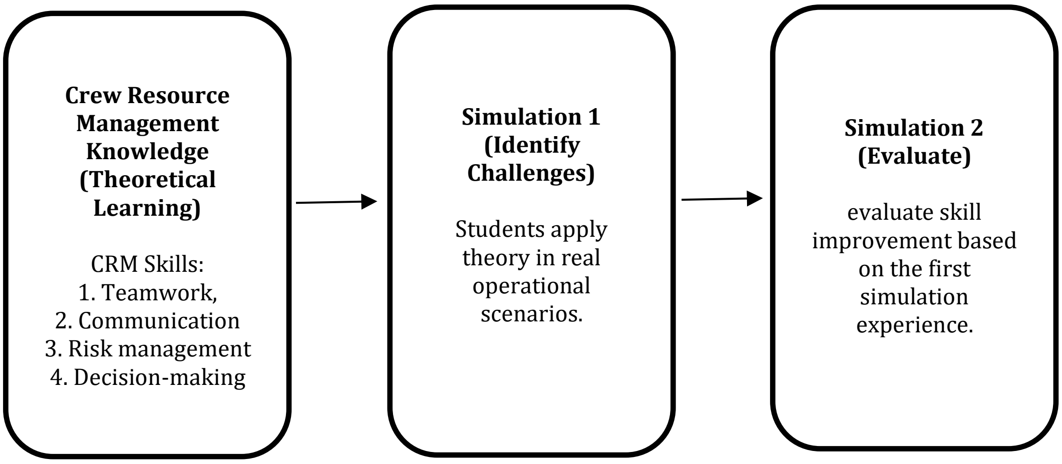

Figure 1. Framework

C. Data Analysis
   1. Quantitative Analysis: Paired t-tests were performed to compare the performance between simulation 1 and simulation 2, highlighting significant improvements. The paired t-test was conducted using SPSS version 26. The significance value (p-value) was set at 0.05. The assumption of normality was tested with the Shapiro-Wilk test before conducting the t-test analysis.
   2. Qualitative Analysis: Open-ended feedback was analyzed to identify recurring challenges and recommendations for future training.
   3. This research uses a mixed methods approach with quantitative data collection through questionnaires and qualitative data through open-ended questions. To ensure more comprehensive and valid results, a method triangulation strategy was used, which involves comparing and integrating findings from both types of data. Quantitative results are used to identify general trends in participants' perceptions of the effectiveness of simulation-based CRM training. Meanwhile, qualitative data is used to strengthen and deepen the interpretation of quantitative results through participants' narrative experiences. This integration strategy allows researchers to gain a more comprehensive understanding and bridge numerical aspects with the behavioral context and perceptions of participants.

FINDINGS AND DISCUSSION

Respondent Description

This study involved 24 respondents who were students of the Aircraft Operations Study Program at the Indonesian Aviation Academy in Banyuwangi. The respondents were purposively selected as they had experience in both theoretical learning and simulation training relevant to the study. The objective was to evaluate the effectiveness of Crew Resource Management (CRM) training in enhancing operational skills.

1. Respondent Characteristics
   a. Number of Respondents: A total of 24 students participated in the study.
   b. Study Program: All respondents were from the Aircraft Operations Study Program.
   c. Educational Background: The respondents were semester 3 students who had completed CRM theoretical training and met the criteria to participate in the simulation phases.
2. Average score of students

Table 1. Aircraft Operation Theoretical Test Score

Program Study	Average Score	
(24) Aircraft Operation Student	71,89384921	B-

Validity Test

Validity Test: (Amalia & Arthur, 2023). To determine the validity of this item until now is the most widely used technique. If the calculated r is greater than the table r, then it can be said to be valid, but if the calculated r is less than the table r, then it is said to be invalid.

1. If the calculated R value > R Table, then the statement is "Valid."
2. If the R Nose Value < R Table, then the statement is "Invalid."
3. R Table with 24 Respondents = 0.404

Table 2. Questionnaire (Simulation 1)

VALIDITY	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11
CORREL	0,455	0,566	0,662	0,627	0,503	0,726	0,639	0,719	0,653	0,704	0,653
R TABLE	0.404	0.404	0.404	0.404	0.404	0.404	0.404	0.404	0.404	0.404	0.404
DECISION	VALID	VALID	VALID	VALID	VALID	VALID	VALID	VALID	VALID	VALID	VALID

Table 3. Questionnaire (Simulation 2)

VALIDITY	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11
CORREL	0,807	0,836	0,531	0,725	0,525	0,770	0,643	0,621	0,660	0,817	0,651
R TABLE	0.404	0.404	0.404	0.404	0.404	0.404	0.404	0.404	0.404	0.404	0.404
DECISION	VALID	VALID	VALID	VALID	VALID	VALID	VALID	VALID	VALID	VALID	VALID

Reliability Test

Reliability refers to whether an instrument can be trusted to meet the established criteria.

1. If the Cronbach's Alpha value is > 0,60, then it is "Reliable."
2. If the Cronbach's Alpha value is < 0,60, then it is "Not Reliable."

Table 4. Questionnaire (Simulation 1)

RELIABILITAS	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	VAR. TOTAL
VARIAN	0,346	0,476	0,303	0,457	0,288	0,505	0,636	0,667	0,717	0,696	0,346	23,549
NUMBER OF VARs	5,437											
VAR. TOTAL	23,549											
DECISION	0,846						RELIABEL					

Table 5. Questionnaire (Simulation 2)

RELIABILITAS	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	VAR. TOTAL
VARIAN	0,303	0,201	0,216	0,319	0,259	0,259	0,406	0,312	0,288	0,428	0,370	17,450
NUMBER OF VARs	3,366											
VAR. TOTAL	17,450											
DECISION	0,888						RELIABEL					

Descriptive Statistics

The Paired Samples Statistics section provides the mean, number of samples (N), standard deviation (Std. Deviation), and standard error of the mean (Std. Error Mean) for each pair of variables.

Table 6. Descriptive Statistics

Pair	Mean Simulasi 1	Mean Simulasi 2	Std. Deviation (Simulasi 1)	Std. Deviation (Simulasi 2)
Teamwork	3.875	4.458	0.797	0.508
Communication	3.833	4.458	0.816	0.508
Risk Management	3.750	4.167	0.847	0.637
Decision Making	3.500	4.333	0.834	0.565

Interpretation:

1. The mean value for simulation 2 is higher than simulation 1 in all aspects (Teamwork, Communication, Risk Management, Decision Making).
2. The smaller standard deviation in simulation 2 indicates more consistent results compared to simulation 1.

T-Test and Significance

The Paired Samples Test section provides the Mean Difference, t-statistic, df (degrees of freedom), and p-value.

Table 7. Paired Samples Test

					95% Confidence Interval of the Difference				Significance	
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	Df	One-Sided p	Two-Sided p
Pair 1	Teamwork Simulation 2- Teamwork Simulation 1	,58333	,82970	,16936	,23298	,93369	3,444	23	,001	,002
Pair 2	Communication Simulation 2- Communication Simulation 1	,62500	1,05552	,21546	,17929	1,07071	2,901	23	,004	,008
Pair 3	Risk Management	,41667	1,10007	,22455	,04785	,88118	1,856	23	,038	,076

					95% Confidence Interval of the Difference				Significance	
	Simulation 2-Risk Management Simulation 1									
Pair 4	Decision Making Simulation 2-Decision Making Simulation 1	,83333	,81650	,16667	,48856	1,17811	5,000	23	< ,001	< ,001

Interpretation:

1. Teamwork (p = 0.002): p-value ≤ 0.05 → Significant. There is a significant mean difference between simulation 1 and simulation 2 in the aspect of teamwork.
2. Communication (p = 0.008): p-value ≤ 0.05 → Significant. There is a significant mean difference in the aspect of communication.
3. Risk Management (p = 0.076): p-value > 0.05 → Not significant. There is no significant mean difference in the aspect of risk management.
4. Decision Making (p < 0.001): p-value ≤ 0.05 → Very significant. There is a significant mean difference in the aspect of decision-making.

T-value: The t-value indicates how far the mean differs from 0. The larger the t-value, the larger the difference. Mean Difference: This value shows the difference in means between two groups (e.g., simulation 1 and simulation 2). A positive value means that the mean of simulation 2 is higher than that of simulation 1.

Effect Size (Cohan's d)

The Paired Samples Effect Sizes section provides effect sizes, such as Cohen's d to see how big the difference is between groups. An effect size is a statistical measure used to assess how big a difference there is between two groups or the effect of a treatment, regardless of sample size. In the context of your research, an effect size helps explain the extent to which the difference between the first and second simulations is practically significant, not just statistically significant.

Table 8. Paired Samples Effect Sizes

					95% Confidence Interval	
			Standardizer[3]	Point Estimate	Lower	Upper
Pair 1	Teamwork Simulation 2-Teamwork Simulation 1	Cohen's d	,82970	,703	,249	1,145
		Hedges' correction	,85804	,680	,241	1,107
Pair 2	Communication Simulation 2-Communication Simulation 1	Cohen's d	1,05552	,592	,152	1,021
		Hedges' correction	1,09158	,573	,147	,988
Pair 3	Risk Management Simulation 2-Risk Management Simulation 1	Cohen's d	1,10007	,379	- ,040	,790
		Hedges' correction	1,13764	,366	- ,038	,763

					95% Confidence Interval	
Pair 4	Decision Making Simulation 2- Decision Making Simulation 1	Cohen's d	,81650	1,021	,517	1,509
		Hedges' correction	,84438	,987	,500	1,460

Interpretation:

1. Pairs: Each row represents a comparison between two conditions:
    a. Pair 1: Teamwork (Simulation 1 vs. Simulation 2)
    b. Pair 2: Communication (Simulation 1 vs. Simulation 2)
    c. Pair 3: Risk Management (Simulation 1 vs. Simulation 2)
    d. Pair 4: Decision Making (Simulation 1 vs. Simulation 2)
2. Standardized Cohen's d:
    a. Measures the effect size by showing the magnitude of the difference between the two simulations.
    b. Larger values indicate stronger effects.
3. Hedges' correction:
    a. Adjusted version of Cohen's d to correct for small sample sizes (like your 24 participants).
    b. Useful to ensure reliable results in smaller datasets.
4. Point Estimate:
    a. Indicates the average difference between the two conditions.
    b. Negative values show a decrease from Simulation 1 to Simulation 2.
5. 95% Confidence Interval (Lower & Upper):
    a. Range within which the true effect size is likely to fall.
    b. If the interval includes zero, the effect might not be statistically significant.

Interpretasi Nilai Cohen's d:

1. $d < 0.2$: Very small effect size (not practically significant).
2. $0.2 \le d < 0.5$: Small effect size (small difference).
3. $0.5 \le d < 0.8$: Medium effect size (significant difference).
4. $d \ge 0.8$: Large effect size (very practically significant difference).

   from: https://miniwebtool.com/id/cohens-d-calculator/

$$d = \frac{\text{Mean Difference}}{\text{Standard Deviation of Differences}}$$

Pair 1: Teamwork

1. Cohen's d = 0.703 (Medium effect): Indicates a strong improvement in teamwork skills from Simulation 1 to Simulation 2.
2. Confidence Interval (0.249, 1.145): The interval does not include zero, meaning the improvement is statistically significant.
3. Implication: Simulation-based training had a substantial impact on teamwork skills.

Pair 2: Communication

1. Cohen's d = 0,592 (Medium effect): Communication skills significantly improved between simulations.
2. Confidence Interval (0.152, 1.021): The improvement is statistically significant.
3. Implication: CRM simulation have enhanced communication skills.

Pair 3: Risk Management

1. Cohen's d = 0,379 (Small effect): Significant improvement in risk management skills.
2. Confidence Interval (-0.040, 0.790): Includes zero, which means the result may not be statistically significant.
3. Implication: While the effect size is small, the statistical evidence for improvement is weaker.

Pair 4: Decision Making

1. Cohen's d = 1.021 (large effect): Substantial improvement in decision-making skills.
2. Confidence Interval (0.517, 1.509): The interval does not include zero, so the result is statistically significant.
3. Implication**:** Decision-making strongly improved considerably with simulation training

Summary

1. Significant Improvement:
   There was a significant improvement in Teamwork, Communication, and Decision Making between simulation 1 and simulation 2. Risk Management did not show a significant improvement, although the average increased.
2. Recommendations for Further Analysis:
   Use these results to conclude that the simulation improved overall CRM skills. For aspects with no significant difference (Risk Management), consider whether additional training is needed.
3. Average Time between every Simulation:
   This test was conducted by 24 aircraft operation students and guided by 2 instructors to guide and assess, in the first pre-simulation it was done by giving flight plan questions to each student (individually) and then briefing the instructors so that the instructors assessed the results of the flight plan made, then the Simulation was conducted in teams where this test was given more complex problems so that it required teamwork, to mimic more real operation scenarios.

Table 9. Average Time

Test	Average Time
Pre-Simulation Flight Plan Test 1 (Individual)	03:10:25
Pre-Simulation Flight Plan Test 2 (Individual)	03:29:35
Simulation (Teamwork) 1	01:24:00
Simulation (Teamwork) 2	01:16:30

Data Interpretation

1. Pre-Simulation Flight Plan Test 1 (Individual): The average completion time is 03:10:25.
2. Pre-Simulation Flight plan Test 2 (Individual): The average completion time is 03:29:35, indicating an increase in time compared to Flight Plan Test 1.
3. Simulation with Teamworking (Group):
   a. The first teamwork simulation has an average time of 01:24:00.
   b. The second teamwork simulation has an average time of 01:16:30, showing a decrease in completion time compared to the first teamwork simulation.

Analysis

1. Pre-Simulation Flight Plan (Test 1 and Test 2): The increase in time for Flight Plan Test 2 compared to Simulation Test 1 (+19 minutes 10 seconds) that the second test had a higher difficulty level or additional tasks. This increase might indicate that students were challenged to apply more operational skills, even though it required more time.

2. Teamworking Simulations (Group): The reduced time in the second teamwork simulation (-7 minutes 30 seconds) demonstrates improved efficiency in teamwork. This improvement indicates that after gaining experience from the first teamwork simulation, students were able to collaborate and perform tasks more effectively.
3. Comparison Between Individual and Teamwork Simulations: The individual simulations took significantly longer than the teamwork simulations, even during the first teamwork simulation (03:10:25 vs. 01:24:00). This highlights that teamwork enhances task efficiency, a key focus of Crew Resource Management (CRM) training.

Qualitative Analysis

Open-ended feedback was thematically analyzed to identify recurring challenges and recommendations for future training.

Table 10. Interview Result

Respondent	What are your suggestions for improving the simulation experience to be more effective in implementing CRM? (Open-ended)	In your opinion, are there any other aspects of CRM training that need to be improved to make it more applicable in real operational situations? (Open-ended)
Respondent 1	Carry it out consistently so you get used to it, and ultimately you can understand it better.	All the mentioned aspects of CRM training are sufficient to implement and should be continuously improved.
Respondent 2	-	Learning methods need to be balanced between simulation and theory to achieve maximum learning results.
Respondent 3	Ask participants to write a personal reflection about their experience after each simulation. This can help them realize which CRM skills they have developed or need improvement.	In operational situations, decisions often have to be made quickly and without complete information. Training can include time elements or limited information conditions to hone participants' ability to make quick and effective decisions.
Respondent 4	My suggestion to improve CRM implementation is to do alternating assignments, such as combining individual assignments with teamwork, which can train someone to learn CRM implementation both individually and in groups.	In terms of delivering the material, whether in practice or in classroom learning, so that it can facilitate the application of CRM training in real operational situations. In addition, it can also train a person's habits to become accustomed to applying CRM in real operational situations.

Respondent	What are your suggestions for improving the simulation experience to be more effective in implementing CRM? (Open-ended)	In your opinion, are there any other aspects of CRM training that need to be improved to make it more applicable in real operational situations? (Open-ended)
Respondent 5	CRM facilities should be adjusted to the real conditions in the field, the circumstances, panic situations, limited time, needs between crews, and so on.	Don't know because I haven't studied the exact CRM requirements standards so I can't judge what the shortcomings are.
Respondent 6	My advice when faced with many problems, we must remain calm and handle them one by one according to existing procedures.	From me, nothing exactly needs to improve
Respondent 7	design simulation scenarios that mimic real situations in the field in order to understand the real challenges.	Yes, such as teaching clear communication so that team members feel comfortable sharing critical information without feeling intimidated.
Respondent 8	Need training more often	Self confidencesaspect
Respondent 9	understand how to make proper decision-making	-
Respondent 10	additional facilities in the flops simulation	-
Respondent 11	conduct scheduled evaluations	Mental health aspect

Based on the open-ended feedback and suggestions provided by respondents, several key points can be synthesized to support the discussion and findings. The following are the results of open-ended interviews related to CRM (Crew Resource Management) training:

Key Themes and Implications for CRM Training:

1. Consistency and Habit Formation: Respondents emphasized the importance of consistent implementation of CRM training to ensure that participants become accustomed to applying CRM principles effectively in real operational scenarios. This suggests that regular practice, not just in simulation but also integrated into theoretical learning, is essential to reinforce CRM habits.
2. Balance Between Theory and Simulation: Several respondents highlighted the need for a balanced approach to learning, combining theoretical knowledge with practical simulations. This aligns with the findings in your research, indicating that while simulations improve teamwork, communication, and decision-making skills, theoretical grounding is still crucial.
3. Realistic Scenarios and Time Constraints: A frequent recommendation was to design simulation scenarios that mimic real operational challenges, including time pressure, panic situations, and incomplete information. This would enhance the realism and applicability of CRM training in preparing participants for real-world challenges, supporting the integration of stress-inducing variables into training.

4. Reflection and Feedback Mechanisms: Suggestions to include post-simulation reflections or evaluations point to the value of self-awareness in learning. By reflecting on what went well and what could be improved, participants can better internalize CRM principles and identify areas for personal development.
5. Specific Areas for Improvement: Teamwork and Communication: Some respondents stressed the importance of fostering an environment where team members feel comfortable sharing critical information. This implies that CRM training should also focus on interpersonal dynamics and communication techniques. Decision-Making Under Pressure: Training programs could incorporate scenarios that require quick decision-making to simulate real-world operational constraints. This would improve participants' situational awareness and ability to prioritize under pressure.
6. Facilities and Tools: Some respondents suggested that CRM facilities and simulators should closely replicate actual field conditions, further emphasizing the importance of realism in training. Upgrading simulation tools, such as FLOPS simulators, to better reflect operational environments could enhance the overall training experience.
7. Psychological and Mental Health Considerations: The mention of mental health underscores the need to integrate aspects of stress management and emotional resilience into CRM training, ensuring participants can maintain focus and effectiveness during high-pressure situations.
8. Frequency of Training: Several respondents recommended increasing the frequency of training sessions. This aligns with the notion that regular exposure to CRM principles in different contexts helps reinforce learning and builds participant confidence.

Discussion

This study assessed the impact of Crew Resource Management (CRM) training on the operational skills of Aircraft Operations students, with a focus on comparing simulation-based and theoretical learning. The findings from the questionnaires, performance time, and instructor-supervised evaluations provide a nuanced understanding of how these training methods influence teamwork, communication, decision-making, and risk management competencies.

1. The Role of Theoretical Learning as a Baseline
   The results from the theoretical test demonstrated that students had acquired foundational knowledge of CRM principles, including teamwork, communication, and risk management. These results were used as a baseline to confirm their readiness to engage in simulation exercises. While theoretical instruction plays a vital role in providing foundational knowledge, the results from Simulation Test 1 revealed that transitioning from theoretical understanding to practical application posed significant challenges for many students.
2. Impact of Simulation on Teamwork, Communication, and Decision-Making
   The analysis of paired t-tests and effect sizes (Cohen's d) between Simulation Test 1 and Simulation Test 2 showed significant improvements in all CRM competencies, with moderate to large effect sizes for teamwork, communication, decision-making, and risk management.
   a. Teamwork: The average time for group-based simulations significantly decreased from the first session (01:24:00) to the second (01:16:30), indicating enhanced collaboration and task efficiency.
   b. Communication and Decision-Making: Questionnaire responses highlighted notable progress in students' ability to communicate effectively and make timely decisions, especially under the increased complexity of Simulation 2.
   c. Risk Management: Although there is an improvement in performance, the analysis results show a weak statistical correlation (e.g., $r = 0.25$) between the results of Simulation 1 and Simulation 2. This indicates variability in participant performance from one simulation to

the next, likely due to situational factors or differences in individual readiness.

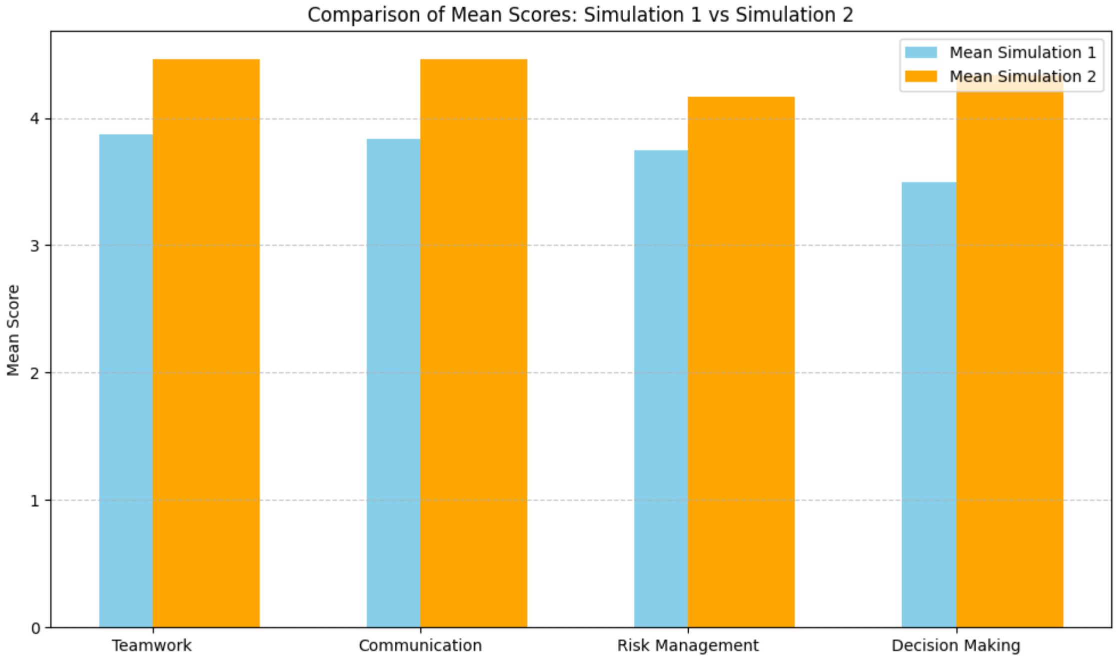

Figure 2. Diagram Comparison of Mean Scores

The effect size (Cohen's d) values further reinforce the positive impact of the simulation-based training, with moderate to large effects across all evaluated skill areas. This underscores that the applied scenarios provided in Simulation 2 were instrumental in developing students' abilities to manage operational tasks under increased complexity.

3. Objective Performance Data (Time Efficiency)
   The average time data from simulations conducted individually and in teams reveals important insights:
   a. Students required more time on Simulation 2 (03:29:00) compared to Simulation 1 (03:10:00). This increase aligns with the higher difficulty level of Simulation 2, which included more complex scenarios and challenges. Despite the longer duration, the observed skill improvement indicates that students were able to engage more thoroughly with the advanced tasks, likely due to the iterative learning process.
   b. In contrast, when teamwork was introduced, the average completion time decreased significantly (Simulation with Teamworking: 01:24:00 and 01:16:30). This reduction demonstrates that collaborative environments fostered more efficient problem-solving and task completion, validating the importance of teamwork as a core CRM competency.

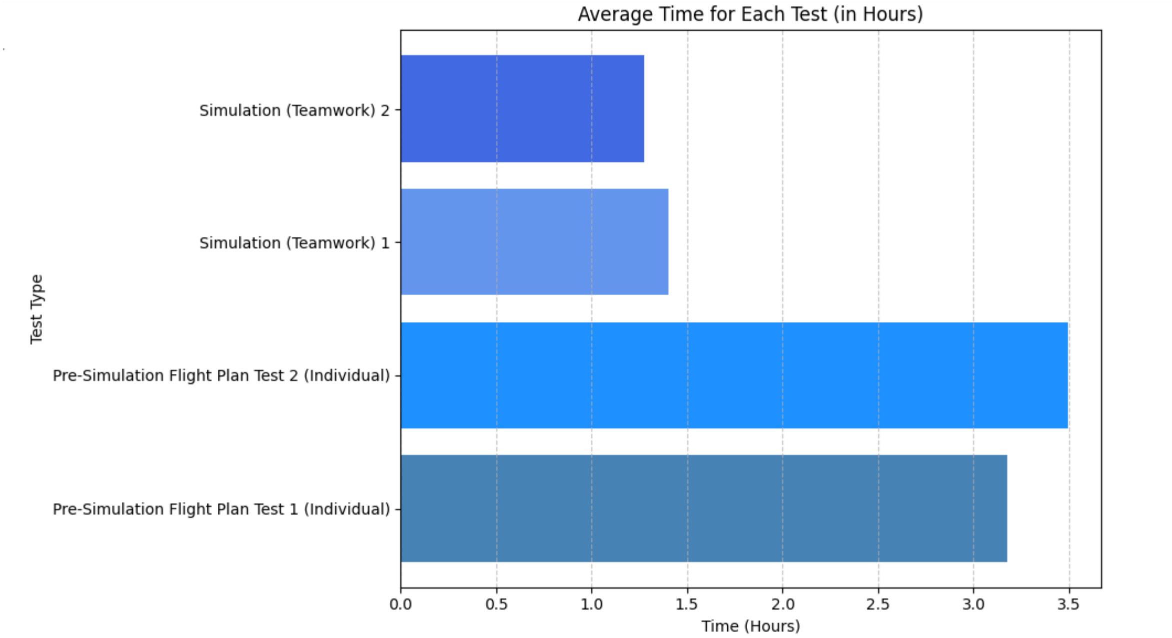

Figure 3. Diagram Average Time for Each Test (in hours)

These findings were validated by licensed FOO instructors, who supervised and evaluated all simulations, ensuring the reliability of the recorded data. This external oversight minimizes potential response bias from the questionnaires and reinforces the objective credibility of the time data.

4. Addressing Response Bias
   While the self-reported questionnaire results provide valuable insights into perceived improvements, they are inherently susceptible to response bias. However, the inclusion of objective performance metrics (Average Time between every Test & Simulation) verified by professional instructors mitigates this limitation. The integration of both subjective and objective data adds robustness to the findings, offering a comprehensive perspective on student development.
5. Feedback and Challenges Identified
   The open-ended responses from students revealed challenges such as difficulty in decision-making under pressure and communication barriers during the first simulation. These insights were addressed in the second simulation, where students showed marked improvement in these areas. Respondents also emphasized the importance of realistic scenarios and consistent training to bridge the gap between theoretical knowledge and operational practice.

   "In operational situations, decisions often have to be made quickly and without complete information. Training can include time elements or limited information conditions to hone participants' ability to make quick and effective decisions." Responden 3.

   "Need training more often." Responden 8.

   "Mental health aspect." Responden 11.

6. Study Implications
   This study highlights the efficacy of simulation-based CRM training in enhancing operational skills beyond what theoretical instruction alone can achieve. The findings align with the broader

literature, underscoring the importance of experiential learning in aviation education. The integration of realistic, instructor-supervised simulations and teamwork scenarios equips students with the practical skills needed to meet the demands of real scenario operations.

7. The results of this study indicate that simulation-based CRM training has a positive impact on improving communication skills, teamwork, and decision-making among FOO students. This is in line with the findings of Salas et al. (2006), which assert that team-based and simulation training significantly enhance crew work effectiveness through intensive practice in situations resembling real operational conditions. Simulation creates a safe learning environment where participants can experience operational pressure without direct risk to safety. The improvement in participants' understanding of risk management in the simulation is also in line with the study by Hamman et al. (2017), which found that dynamic scenarios such as flight delays or extreme weather conditions can enhance situational awareness and participants' ability to manage operational pressure. In the context of this research, participants reported that the simulation helped them realize the importance of cross-functional coordination, especially in emergencies. However, the results showing a weak correlation between the performance of Simulation 1 and Simulation 2 reflect the variability in learning outcomes, which was also found in the study by Brannick et al. (2001). They mentioned that the effectiveness of CRM training is often influenced by individual factors, such as stress levels, prior experience, and the ability to adapt to different simulations. This reinforces the finding that simulations need to be designed with consideration of the diverse characteristics of participants to ensure more uniform learning outcomes. From a methodological standpoint, the integration of quantitative and qualitative data is carried out through triangulation, where quantitative results provide an overview of training effectiveness, while qualitative data from open-ended responses offer a deeper context. This strategy supports the validity of the findings by showing that the improvement in perceptions of CRM capabilities is not only reflected in the scores but also in the narratives of participants' experiences.

CONCLUSION

This study evaluated the impact of Crew Resource Management (CRM) training on the operational skills of Aircraft Operations students, focusing on the comparison between simulation-based and theoretical learning. The research objectives were to assess how these methodologies enhance critical CRM competencies, including teamwork, communication, decision-making, and risk management. The findings demonstrate that simulation-based training significantly improves operational skills compared to theoretical instruction. Simulation 2, which incorporated advanced and realistic scenarios, led to measurable improvements in all skill areas, as evidenced by paired-sample t-tests and effect size analyses. The results highlighted that students developed stronger decision-making and teamwork capabilities when exposed to simulation-based learning, emphasizing the value of hands-on experience in bridging the gap between theory and practice.

In addition, the integration of teamwork simulations showed a marked improvement in time efficiency and collaborative problem-solving, supporting the critical role of teamwork in operational settings. Feedback from respondents reinforced the necessity of realistic scenarios, consistent practice, and reflective evaluations to further enhance training outcomes. By incorporating both quantitative data (performance scores and completion times) and qualitative insights (feedback from participants and observations by instructors), this study provides a comprehensive understanding of CRM training's effectiveness. It also addresses the potential response bias from self-reported questionnaires through objective time performance metrics validated by licensed FOO instructors.

This research advances the field by offering empirical evidence that simulation-based CRM training is essential for developing operational competencies. The findings underline the importance of a balanced approach, integrating theoretical instruction with immersive simulations to prepare students for real-world aviation challenges. Furthermore, the study highlights the need for continuous improvement in training methods and the development of advanced simulation tools to enhance learning outcomes.

Future research should explore larger sample sizes, examine the long-term retention of CRM skills, and incorporate additional variables, such as stress management and leadership, to further enrich CRM training programs. These efforts will support the evolving demands of aviation operations and contribute to the global aim of enhancing safety and efficiency in the industry.

LIMITATION & FURTHER RESEARCH

Limitation

This study has several limitations that should be considered when interpreting the findings:

1. Sample Size: The study involved only 24 respondents from a single aviation academy. While the sample was sufficient to identify trends and draw preliminary conclusions, the small size limits the generalizability of the findings to other institutions or broader populations.
2. Self-Reported Data: A portion of the data was derived from self-reported questionnaires, which are prone to response bias, as participants may overestimate or underestimate their skills. Although this limitation was mitigated by including objective metrics, such as performance times validated by instructors, it may still influence the overall interpretation.
3. Simulation Scope: The simulations were designed for specific scenarios relevant to CRM principles but may not fully encompass the wide variety of challenges encountered in real-world aviation operations. The limited scope of these scenarios may affect the applicability of the findings to more complex operational environments.
4. Short-Term Evaluation: The study assessed improvements in operational skills immediately after training but did not evaluate the long-term retention of CRM competencies. Without long-term research data, the sustainability of the observed improvements remains unclear.

Further Research

To address these limitations and advance the field, future research should focus on:

1. Expanding Sample Size and Diversity: Conducting studies with larger and more diverse samples across multiple aviation academies will improve the generalizability of findings and offer broader insights into CRM training effectiveness.
2. Exploring Long-Term Impacts: Investigating the long-term retention of CRM skills through follow-up evaluations could provide a more comprehensive understanding of the training's enduring impact on operational competencies.
3. Designing More Diverse Scenarios: Expanding the range of simulation scenarios to include emergency responses, multi-crew coordination, and unexpected events will provide a more holistic assessment of CRM training and its effectiveness in real-world conditions.

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