Providing Effective and Efficient Training: A Model for Comparing Simulator Improvements

Justin H. Prost
Lumir Research Institute
1304 E. Redmon Dr., Tempe, AZ 85283
480-773-5241
Justin.Prost@lumirresearch.com

Brian T. Schreiber
Lumir Research Institute
195 Bluff Avenue, Grayslake, IL 60030
847-946-2171
Brian.Schreiber@lumirresearch.com

Winston Bennett, Jr.
Air Force Research Laboratory
6030 South Kent Street, Mesa, AZ 85212
480-988-9773
Winston.Bennett@mesa.afmc.af.mil

Kenneth Kleinlein
Air Force Research Laboratory
6030 South Kent Street, Mesa, AZ 85212
480-988-9773
Kenneth.Kleinlein@mesa.afmc.af.mil

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ABSTRACT: *Training programs for warfighters have become increasingly dependent on the use of simulation systems, made necessary by the growing costs of live flight training. The transition to a greater dependence on simulators has required an increase in concerns about the ability of simulators to provide effective training. Research in the area of simulator fidelity has focused primarily on training capabilities, evaluating current systems for strengths and weaknesses. The evaluation of current systems is an essential component in providing the best possible training environment to pilots; however, the impact of improvements is of equal importance. An informed decision about which changes will have the greatest benefit for warfighter readiness would provide a means of maximizing the return on the investment in the development of the system and creating the most efficient and effective training environment possible. The current work presents a process by which system deficiencies and potential solutions are identified and then integrated into quantitative models based on multiple factors. The factors included in the model are potential for improvement, training gaps, extent to which solutions address deficiencies, material costs of solutions, and time costs of solutions. A project manager and engineers provided feedback in three areas: the extent to which a solution addresses a deficiency, the cost of the technology, and the engineering hours involved in the change. Three models were computed and compared across solutions, revealing the utility of the empirical process. The models included in the comparison varied the weights within and across factors, establishing the importance of determining appropriate weightings. The process and algorithm presented in the current work have far reaching practical applications as a tool for assisting in the decision-making process during development and improvement of training technologies. Ultimately, a cost-benefit decision-making process will provide an effective tool for maximizing training benefits during the improvement of simulation systems.*

1. Introduction

The use of simulators to supplement live-flight training has been established as an effective and cost efficient method for increasing warfighter readiness [1,2,3]. Aging aircraft and budget constraints have increased the dependence on simulation systems as a training method. The growing demand for simulation systems to provide suitable training across the diversity of skills required for combat readiness has encouraged technological advances

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14. ABSTRACT

Training programs for warfighters have become increasingly dependent on the use of simulation systems, made necessary by the growing costs of live flight training. The transition to a greater dependence on simulators has required an increase in concerns about the ability of simulators to provide effective training. Research in the area of simulator fidelity has focused primarily on training capabilities, evaluating current systems for strengths and weaknesses. The evaluation of current systems is an essential component in providing the best possible training environment to pilots; however, the impact of improvements is of equal importance. An informed decision about which changes will have the greatest benefit for warfighter readiness would provide a means of maximizing the return on the investment in the development of the system and creating the most efficient and effective training environment possible. The current work presents a process by which system deficiencies and potential solutions are identified and then integrated into quantitative models based on multiple factors. The factors included in the model are potential for improvement, training gaps, extent to which solutions address deficiencies, material costs of solutions, and time costs of solutions. A project manager and engineers provided feedback in three areas: the extent to which a solution addresses a deficiency, the cost of the technology, and the engineering hours involved in the change. Three models were computed and compared across solutions, revealing the utility of the empirical process. The models included in the comparison varied the weights within and across factors, establishing the importance of determining appropriate weightings. The process and algorithm presented in the current work have far reaching practical applications as a tool for assisting in the decision-making process during development and improvement of training technologies. Ultimately, a cost-benefit decision-making process will provide an effective tool for maximizing training benefits during the improvement of simulation systems.

15. SUBJECT TERMS

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in simulators. The advances include improvements to the training experience within a given simulation system and advances in networking systems together to increase the scope of the training environment [4]. Rapid changes in available technology permit increasingly sophisticated system development and improvement. Although simulation training is designed to address very specific training demands for pilot readiness and the need for effective training is great, the method of improvement of our simulation systems often lacks evidence-based decision-making [5].

In previous research, the authors presented a method of incorporating research into models to inform decision-making [5]. The goal of the method is to provide an empirical process to inform decision-making regarding improvements to simulation systems. The process can be structured to maximize training benefits, while maintaining an accounting of system and budget constraints. The method leveraged work from a competency-based approach to training, in which the skills, knowledge, and experiences required for pilots to become combat mission ready are identified [6]. The experiences from the Mission Essential Competencies (MEC) approach were used to evaluate the current training capabilities and deficiencies of a Deployable Tactical Trainer (DTT) under development at the Air Force Research Laboratory (AFRL). Study findings revealed that the incorporation of multiple factors into decision-making models affected the relative importance of identified deficiencies.

Prost, Schreiber, and Bennett [5] compared three models to investigate the utility of quantifying research data for the decision-making process. The models investigated included a frequency model, an improvement model, and an improvement model that accounted for training gaps. The frequency model computed the number of times that a deficiency was identified as the primary detriment to training across all MEC experiences. The model allowed for a direct comparison of deficiencies by comparing the proportion of endorsements for each deficiency relative to the total number of responses. The improvement model weighted the frequencies by the degree to which each MEC experience could be improved for the simulation system. Finally, the improvement model that accounted for training gaps weighted the frequencies by the improvement score and an additional weighting based on whether or not the experience represented a training gap. Results of the study showed that a comparison across models revealed differential importance of the deficiencies, depending on whether or not factors were included in the models. The identification of system deficiencies and the quantification of the impact of the deficiencies on the training capabilities of the system provided an important step in building a data-driven process to assist decision-making. The final step in the development of the process is to extend the work from the identification and modeling of the deficiencies to address potential solutions.

2. Current Work

The current study presents a process for identifying, evaluating, and comparing deficiencies of a simulation system, and consequently the solutions for addressing those deficiencies. The purpose of the process is to provide project managers, researchers, and engineers with a tool to quantify the factors that influence the improvement process. Ideally, simulator system improvements should maximize increases in training capabilities while considering factors such as current training gaps, the degree to which a solution addresses a deficiency in the system, cost of improvements, and integration of the solutions into the current system.

The work presented below specifically focuses on integrating 1) the extent to which a solution addresses a deficiency and 2) the costs involved in the solution into previous models that evaluated room for improvement and training gaps. Costs taken into consideration include material costs and time costs. To examine the effects of the two factors of interest in this study on the empirically driven decision-making process, data from previous studies on room for improvement and training gaps will be included in the current study for the air-to-air skill area. The air-to-air skill area will be examined in the current study for presentation purposes only, although the process would extend to the entire set of skills in a practical application.

The evidence-based decision-making process is examined by comparing multiple models to determine the effect of adding factors for consideration. The models can be divided into two classes: Deficiency Models and Solution Models. Deficiency Models come from previous work comparing factors important in determining the impact of identified deficiencies [5]. Solution Models were developed for the current study as a means of producing quantifiable scores for each solution. The scores for each model represent the magnitude of training improvement that would be realized by the integration of the solution for one model, and then the improvement relative to the costs for the other two models. The purpose of the presentation of the Solution Models in the current study is to illustrate the ability to quantify the effect of improvements, relative to costs, in such a way that the solutions can be directly compared. The capacity of the proposed process to quantify the factors involved in the decision-making process can remove some of the guesswork from the development and improvement of simulation systems.

3. Method

The current study integrates engineer survey information about technological changes to a deployable trainer into a modeling framework for evaluating the effect of deficiencies on a system. Due to the integration of new factors into an existing model, some data presented below is from previously published work [5].

3.1 Evaluators

Ratings from previous research by seven F-16 subject matter experts (SMEs) were used in the current study. The SMEs completed two surveys. One was an evaluation of the fidelity of the DTT, and the other was an evaluation of the deficiencies of the DTT. In addition to the data from previous work, three evaluators participated in the current study by providing responses to a survey designed to assess aspects of integrating new technology to resolve deficiencies of the DTT. All evaluators were provided with detailed documentation of system components, capabilities, and limitations, and were provided multiple opportunities to fly various missions in the system before providing system ratings.

The seven evaluators from the previous research were all male, all recently retired (3 years on average) F-16 pilots from the United States Air Force (USAF), and had an average number of operational F-16 flight hours of 2,119 (average total flight hours of 3,495) [5].

The project manager overseeing the development of the DTT completed the survey for the current study. The solutions provided were identified and discussed with two additional engineers working on the development of the DTT. All participating individuals have been involved in the development of the DTT since the first working system.

3.2 Surveys

Data were used from a total of three surveys. Two of the surveys, the Fidelity and Deficiency surveys, were administered during previous research. The final Solutions survey was developed specifically to expand the previous model. The two surveys administered in the context of previous research are briefly described below (and can be seen in more detail in Reference 5). The survey used in the current research is described in greater detail below.

Responses to two surveys (previously described as Fidelity and Deficiency surveys) were used. The surveys were constructed by leveraging MEC research for the F-16. The original surveys used 197 items: 70 air-to-ground (A/G) MEC experiences, 55 suppression of enemy air defense (SEAD) MEC experiences, 45 air-to-air (A/A) MEC experiences, and 27 bold face EPs for the F-16. The current work focuses specifically on the A/A skill area of the system; therefore, the fidelity survey data from the 45 items in that skill area were included in the current data set.

The Fidelity Survey consisted of SMEs providing each of the items on the survey with a rating from 0 through 5, on the following scale:

0= N/A (Capability to experience does not exist)
1= Capability to experience exists, but is very poor
2= Capability to experience exists, but is poor
3= Capability to experience exists, but is marginal
4= Capability to experience exists, and is good
5= Capability to experience exists, and is very good

The Deficiency Survey asked SMEs to identify the deficiency with the greatest influence on each of the 197 survey items. Respondents could choose from a list of 17 deficiencies that were previously identified. For the purposes of this study, because the focus was on the air-to-air skill area, the top five deficiencies for A/A were included. The most influential deficiencies for the A/A skill area were:

1) Limited out-the-window (OTW) capability
2) No helmet mounted sight (HMS) capability
3) No EP instructor/operator station
4) No electronic countermeasure (ECM) capability
5) Software issue, no weapon system capability

The Solutions survey was designed to investigate the potential solutions for each of the deficiencies. Surveys solicited identification of the three most promising solutions available for each of the top five deficiencies in the A/A skill area. Respondents then evaluated a series of qualities for each of the solutions identified. The following were the questions presented for each solution:

1) To what extent does the proposed solution remedy the deficiency?
2) What is the projected cost in dollars for the solution?
3) What is the projected cost in time for the solution?

The Solutions survey attempted to identify the utility and cost of each particular solution. To understand the cost of each solution, it was important to further differentiate costs along the dimensions of material and time.

3.3 Apparatus: Current DTT system (taken from [5])

The DTT system (see Figure 1) that was evaluated consisted of the following major hardware/software functionalities:

Hardware: F-16 cockpit shell with three out-the-window 30-inch displays, the actual F-16 stick/throttle, and simulation of all cockpit displays and switch functions on a high resolution 23" interactive touch screen display.

Image generator was an SDS International AAcuity® PC-IG system. Brief/debrief included SmartBoard and two 50-inch displays for Head-Up Display, Radar Warning Receiver, and Multi-Function Display.

Figure 1. Example of DTT simulation system

Software: The system uses classified Block 30 (SCU 5p) actual operational F-16 software. One database is currently installed and available. Debrief software has the ability to link and time-synchronize video recordings from multiple players. It also has the ability to network through Distributed Interactive Simulation (DIS) or High Level Architecture (HLA) standards. It has chaff/flare capability, but no ECM. Some classified weapons systems are available, such as Joint Direct Attack Munition (JDAM).

3.4 Procedure

The Solutions Survey was given to the project manager for the DTT project. The project manager was asked to collaborate with appropriate engineers to complete the survey. Survey responses were entered into a spreadsheet for analysis. Previous data was combined with the Solutions Survey data to compute multiple models for comparison. Solution Models were computed using data from the Improvement and Training Gap Deficiency Model and responses from the Solutions Survey. Computation of models was based on including one additional factor for each model.

There were a total of six factors included in the models presented. The first three factors (Deficiency Factors) were from previous research, but necessary to compute the current models (taken from Reference 5). The factors were defined as follows:

Deficiency Factors:

- Deficiency Evaluation was based on the frequency of response for each deficiency by the evaluators for each skill.
- Fidelity Evaluation was based on the proportion of improvement possible for each skill, calculated as five minus the average fidelity rating for the skill divided by five.
- Training Gap Evaluation was based on MEC research [6] establishing the training gaps for the skills. The weightings were 1 for no gap, 2 for potential gap, and 3 for gap.

Solution Factors:

- Extent of Solution was based on a survey response from 0 to 5 (Not at All to Completely).
- Dollar Cost was based on a survey response from 0 to 5 (Prohibitive to Minimal).
- Time Cost was based on a survey response from 0 to 5 (Prohibitive to Minimal).

Using the data available from previous survey collection and the data collected in this study, a series of models was computed and then compared. A total of six models were computed. Of the six models, three were Deficiency Models and three were Solutions Models.

Model 1: Frequency Model. In Model 1, the proportions presented represent the total frequency of responses for a deficiency across all items, divided by the total number of responses (description from [5]).

Model 2: Improvement Model. In Model 2, the proportions presented are the sum of the weighted scores for each deficiency divided by the total score across all deficiencies and items. The weighted scores in Model 2 are computed by multiplying the frequency of a deficiency response by the proportion for improvement potential (description from [5]).

Model 3: Improvement and Training Gap Model. In Model 3, the proportions presented are the sum of the weighted scores for each deficiency divided by the total score across all deficiencies and items. These weighted scores were computed by first multiplying the frequency of a deficiency response by the proportion for improvement potential, and then multiplying that product by a weight identifying the level of training gap present for each skill (description from [5]).

Model 4: Extent of Deficiency Resolution Model. In Model 4, solutions are presented for each of the deficiencies. A score is given to each solution based on the Model 3 score representing the impact of the deficiency on the system. Each solution score for Model 4 uses the corresponding Model 3 deficiency score, weighted by the extent to which the solution resolves the deficiency. The extent of the resolution is calculated as the proportion of the maximum resolution, based on the ratings provided (i.e., the rating divided by 5).

Model 5: Material Cost of Solution Model. In Model 5, the score for each solution is calculated as the Model 4 score weighted by the dollar cost rating for the solution.

The weighting for dollar cost was calculated as a proportion of the minimal cost, based on the rating for dollar cost (i.e., rating divided by 5). The resulting score represents the amount of improvement relative to monetary costs.

Model 6: Time Cost of Solution Model. In Model 6, solution scores were calculated using Model 5 score weighted by the time cost rating for the solution. The weighting for time cost was calculated as a proportion of the minimal cost, based on the rating for time cost (i.e., rating divided by 5). The resulting score represents the amount of improvement relative to monetary and time costs, allowing for comparison across solutions.

4. Results

Analyses comparing the relative importance of the deficiencies for each of the Deficiency Models were conducted previously [5]. Table 1presents the proportion of the total deficiency score for each model that could be attributed to the specific deficiencies.

Table 1. Proportion of total score attributable to each deficiency for air-to-air experiences for each of the three Deficiency Models

	Model 1	Model 2	Model 3
Limited OTW	0.54	0.47	0.47
No HMS	0.10	0.09	0.09
No EP	0.09	0.13	0.09
No ECM	0.06	0.08	0.07
No Weaps	0.05	0.08	0.15

The first part of the Solution Survey task on the air-to-air skill area of the F-16 simulation system was to identify potential solutions for each of the deficiencies. The project manager and engineers identified up to three solutions for each deficiency. The following solutions were those presented and then evaluated by participants.

Limited out-the-window field of vision:

- Procure and integrate a mini-DART;
- Procure and integrate a DART system;
- Partial Dome.

No Helmet Mounted Sight Capabilities:

- Procure and implement a currently available solution with mini-DART;
- Procure and implement a currently available solution with DART;
- Partner with AF developed system utilizing actual operational HMCS helmets and commercial video cards.

No emergency procedure instructor/operator station:

- Integrate existing MTT IOS;
- Develop/Write IOS.

No electronic countermeasure capabilities:

- Propose and make software changes and program enhancements to cockpit code to support and implement physics based ECM such as an external ECM pod, decoys, EMI on FCR, etc.;
- Rather than using physics based modeling, implement simulation and emulation.

Missing weapons in the database:

- Integrate available code to support desired weapons;
- Develop and write code to support a specific weapon capability.

The next step in the analyses of the Solutions Models was to take survey ratings and transform them for incorporation into models. Table 2 presents the ratings provided for each solution to Solutions Survey questions. The ratings represent the value reached by consensus for the project manager and engineers participating in the evaluation.

Table 2. Ratings for Solutions Survey questions across proposed solutions.

		Survey Ratings		
		Extent	Dollar	Time
Limited OTW	Mini-DART	3	1	4
	DART	5	0	3
	Partial Dome	2	2	1
No HMS	Available with mini-DART	3	1	5
	Available with DART	5	1	5
	Partner with AF and commercial cards	5	3	3
No EP	Use existing IOS	5	5	4
	Develop IOS	5	4	1
No ECM	Implement physics based software	4	4	0
	Implement simulation and emulation	2	3	1
No Weaps	Integrate available code	5	5	4
	Develop code	5	5	1

The Solutions Survey scores were transformed and incorporated into the corresponding models. Three models were computed using the Deficiency Model 3 scores and the weights from the Solutions Survey ratings. Table 3 presents the model scores for each solution across the three models computed. The model scores represent the potential improvement to the system for a solution.

The large change in model scores, from model 4 to models 5 and 6, is the introduction of costs. The deficiency of limited out-the-window visuals, although having the greatest impact on the system, is also the most cost intensive deficiency to address.

Table 3. Model scores for each solution across the three models evaluated.

		Model Scores		
		Model 4	Model 5	Model 6
Limited OTW	Mini-DART	0.28	0.06	0.04
	DART	0.47	0.00	0.00
	Partial Dome	0.19	0.07	0.01
No HMS	Available with mini-DART	0.05	0.01	0.01
	Available with DART	0.09	0.02	0.02
	Partner with AF and commercial cards	0.09	0.05	0.03
No EP	Use existing IOS	0.09	0.09	0.07
	Develop IOS	0.09	0.07	0.01
No ECM	Implement physics based software	0.05	0.04	0.00
	Implement simulation and emulation	0.03	0.02	0.00
No Weaps	Integrate available code	0.15	0.15	0.12
	Develop code	0.15	0.15	0.03

5. Summary

The results of the current study build on previous research to provide a more comprehensive model for evaluating the influence of simulation improvements. Previous findings showed the importance of considering how much improvement could be gained for target training experiences and whether or not training experiences were in areas with current training gaps. The results from the previous study found that the relative importance of the deficiencies of a system varied when considering those two factors. The current study incorporates additional important factors to the previous model: the extent to which a solution addresses a deficiency and the cost of the solution [5].

A comparison of the models revealed that a data driven decision-making process is an effective means of differentiating among solutions. Examining changing scores for solutions across models, there is a dramatic shift in the training benefits to the system for solutions. For example, if materials and time costs were not an issue, any solution for the limited OTW field of vision deficiency would address more of the overall training deficiencies of the system for air-to-air experiences than would solutions for other deficiencies. Once materials and time costs are taken into consideration, solutions to other deficiencies are revealed as having a greater effect on the training environment, suggesting that those solutions are more economical. The example presented in this study illustrates the capacity of this process to provide data driven models for comparison; however, an important point of this example is to remember that the weightings used in the current study between and within factors were arbitrarily set to compare models. For example, the weighting given to materials costs was the same as the weighting

To increase the accuracy of the models produced through this process, two changes would be implemented when the process is used in a real world environment. First, rather than using ratings to address questions of cost, true value estimates would be used. The dollar and hour values would transform those factors into continuous variables, rather than discrete ratings. Continuous values for those factors would provide for dramatically greater accuracy in comparison across solutions. The second change would be to transform cost estimates relative to the overall budget. Because budget constraints represent the framework for development, the proportion of the total budget that a solution requires provides a more useful scale for comparison of the effect of solutions. These changes would increase the internal accuracy of the model; however, equally important is the accuracy of the model in regard to including all relevant factors.

The evidence-based decision-making process presented in the current manuscript incorporates multiple sources of data into a single data driven model. The final models examined included information about the current fidelity of a simulation system, the existing training gaps of a system, the extent to which a solution resolves deficiencies, and costs of a solution. For presentation purposes, two costs were presented: material and time costs. A comprehensive model would also include additional solution costs, such as maintenance costs, engineering risk costs, compatibility with current simulator technologies, and pilot training costs. These additional costs, which may also influence the effectiveness and efficiency of training, can be incorporated into models just like the two types of costs included in the current study. Ultimately, multiple data driven models could be compared to determine the best simulator improvements, depending on a wide range of criteria.

The work presented in the current manuscript explores one step in a process for evaluating and improving simulation systems. The growing dependence on simulation systems has introduced many questions about the capabilities of simulation training versus live flight training, as well as situations in which simulation training is effective [8, 9, 10]. The ability to evaluate and improve simulation systems through a precise empirical process will begin to answer questions about how to appropriately supplement training via simulators. Additionally, simulation system improvements can be undertaken more precisely in order to meet the rapidly changing demands on the systems.

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Author Biographies

JUSTIN H. PROST is a Senior Research Scientist with Lumir Research Institute. He completed his Ph.D. in Developmental Psychology at Arizona State University in 2001. Over the last few years he has been involved with simulation training research at the Air Force Research Laboratory in Mesa, AZ.

BRIAN T. SCHREIBER is a Senior Research Scientist with Lumir Research Institute at the Air Force Research Laboratory, Human Effectiveness Directorate Warfighter Readiness Research Division in Mesa, AZ and has an M.S. from the University of Illinois in Champaign-Urbana. For over the past decade, his research has focused on Air Force simulation training techniques and methodologies.

WINSTON BENNETT JR. PhD is a Senior Research Psychologist and team leader for the training systems technology and performance assessment at the Air Force Research Laboratory, Human Effectiveness Directorate Warfighter Readiness Research Division in Mesa, AZ. He received his PhD in Industrial/Organizational Psychology from Texas A&M University in 1995.

KENNETH B KLEINLEIN is a Project Engineer with Lockheed Martin and serves as the DMO Testbed Director and an F-16 Subject Matter Expert at the Air Force Research Laboratory, Warfighter Readiness Research Division in Mesa, AZ and has an MAS from Embry-Riddle Aeronautical University and a BS from the U.S. Air Force Academy. He is an experienced USAF and commercial pilot with more than 5000 hours of flight time including 2500+ hours of fighter experience.