

## **Analysis of Simulator-based Training Effectiveness through Driver Performance Measurement**

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### **ABSTRACT**

The Utah Department of Public Safety (UDPS) has applied driving simulators to train state and municipal law enforcement drivers since 2002. They use simulators to teach safe control techniques in potentially dangerous, emergency driving conditions. In 2004 UDPS initiated a process in cooperation with the simulation industry to improve the effectiveness of their simulator application, using lessons learned by their experience. Together, UDPS and industry produced a new Law Enforcement training program, which combines a disciplined training curriculum with four key simulator features:

- Objective measurement of driver performance,
- Feedback that motivates drivers to improve their performance during the training,
- Data for statistical analysis of each driver's performance, and
- Statistical analyses on the overall effectiveness of the driver training curriculum.

UDPS has applied this program, which they named EVOC-101, to train 355 drivers in the course of eight months. This has generated a wealth of data, enabling objective statistical analyses on the effectiveness of their simulator application. Conclusions derived from analyzing this data clearly indicate that:

- Controlling both physical and psychological factors can mitigate the incidence of simulator adaptation syndromes (SAS) to a level that is lower than what normally occurs in real vehicles.
- Recurring, objective feedback greatly affects improvement in driver performance.
- Driver performance measurements establish an objective value for return on investment (ROI).
- The data corroborates a transfer of training from the simulators to real-world vehicles.
- Trainees in this simulator-based curriculum reduced critical errors in intersections—errors affecting vehicle position, speed and acceleration—by over 67%.

This paper analyzes the driver performance measurements collected by EVOC-101 during real application training. Statistical analysis of this data establishes a foundation for objective valuation of the simulator application developed by UDPS, which may be of interest in a variety of driving simulator applications.

### **ABOUT THE AUTHORS**

**Darrell Turpin** is co-founder and CTO of Applied Simulation Technologies. Since the mid 1980s, he has worked continuously in developing and adapting driving simulator technologies for research and training applications. He was the project engineer for Evans & Sutherland's driving simulation program and provided technical direction as CTO for both I-Sim Corp and GE Driver Development. He optimized design specifications for various simulators by correlating human psycho-motor cueing requirements with simulator subsystem technologies. His designs for roadway database structures, tire-to-road interaction models, driver measurement, and modular real-time vehicle dynamics have been incorporated into many commercial and emergency vehicle driver training simulators used throughout the USA. He co-authored with the University of Iowa, the initial Feasibility Study for the Federal DOT's National Advanced Driving Simulator (NADS), and participated in the NADS design and construction. Mr. Turpin has published several industry papers on driving simulation, spanning 30 years of engineering, design and integration management experience. He specializes in real-time simulation systems, 3D computer graphics, immersive/interactive training environments, and electrical and process control systems. He received a BS Cum Laude in Electrical Engineering from Brigham Young University and is a licensed Registered Professional Engineer.

**Reginald Welles** has managed the research and development of advanced driving simulator technologies since the mid 1980s, and has accumulated a wealth of experience in adapting driving simulator technologies for specific applications, including the automotive industry, research universities, commercial trucking and emergency vehicle training. His R&D efforts led to technology agreements with Eaton Corporation to improve the Transmission Shifter Simulator and with Goodyear to develop tire data for integration into real-time simulator models. He participated in the Federal DOT's NADS program. Additional responsibilities included conducting a research team at the Sky Lab facility at the University of Mainz, Germany under Prof. Rudolf J. von Baumgarten, M.D. in the early classification studies of human factors issues to be considered in driving simulator designs. Mr. Welles served as program manager for Evans&Sutherland's driving simulation group, and as President and CEO of I-Sim and GEDD. He has published several papers on driving simulator applications through 33 years of engineering and management experience, having emphasis in real-time driving simulation systems, 3D computer graphics, immersive/interactive training environments and satellite tracking and communications systems. He has a BS in Aeronautical Engineering from San Jose State University, and an MBA. He is a former Army Officer

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## INTRODUCTION

The Utah Department of Public Safety (UDPS) operates a driver training facility immediately adjacent to a regional Army training facility at Camp Williams, Utah County, Utah. These neighboring facilities have parallel responsibilities in that the training at both facilities affects the safety and the survivability of each trainee. UDPS deployed a new cadet training program in 2005 that may apply to military training because both the rubric and the pedagogy applied at the UDPS facility could be applied to training military drivers.

The structure of the new pedagogy at UDPS involves three types of training, including:

- Classroom instruction
- Simulator-based skills development
- Test-track driving experience.

This paper focuses on the second step of this process—skills development using driving simulators.

UDPS first began using driving simulators in 2002. By 2004 UDPS desired to improve the effectiveness of its simulator-based training. In 2005 it applied new software tools that provided three essential features:

- A driver performance measurement system,
- Task-oriented driving simulator scenarios, and
- A highly structured training curriculum.

UDPS used these new tools to train 355 drivers in 2005. The tools provided a wealth of objective data in scoring each driver's performance, and in measuring the overall effectiveness of the training process. This paper summarizes the findings of that field data. Because that data is objective, it provides a measure of the value of this training program.

## STATEMENT OF CHALLENGES

UDPS principally trains emergency vehicle operators (EVO drivers) at its test track facility. The principal challenge for all EVO drivers is to learn how to balance urgency with due regard for safety. In order to balance the demand for speed with the demand to prevent

accidents, EVO drivers must develop skills to recognize dynamic conditions and to proceed safely as those conditions change. These challenges are analogous to a military deployment requiring speed on one hand, balanced by the demand for skill in compliance with policy and procedural regulations that protect personnel and public safety on the other hand.

## Gaming Deficiency

When UDPS first began using driving simulators to train state and municipal law enforcement drivers in 2002 the initial justification for investing in simulators derived from military and commercial pilot training.

However, the initial approach at UDPS essentially followed the paradigm of playing simulator games. They observed that “the military has a long and complex relationship between computer games and simulation and training,” and they assumed that simulation needed to stimulate interest and excitement in the process of giving experience to the trainees.<sup>1</sup> They placed cadets directly into interesting, but highly demanding scenarios in which the cadets discovered the hazards through trial-and-error experience. Cadets would inevitably make serious mistakes due to lack of experience, but it was assumed that they would learn the rules of engagement through experiencing a variety of scenario exercises.

After using simulators for two years, UDPS rejected the trial-and-error gaming approach, as there was never enough time to practice all the principles behind the rules of engagement. They recognized “the critical role that situation *awareness* played in effective tactical performance,”<sup>2</sup> but they also recognized that their cadets needed to *practice* situational *behaviors*. Gaming scenarios simply didn't provide that practice. They concluded that the exercises should not demand skilled behaviors before those skills had been taught.

Secondly, the gaming process was totally dependent upon an instructor to give assessments, evaluations of performance, and then to give feedback to each trainee. The trainer bore a huge burden, but could provide only

hit-and-miss, subjective feedback. Studies have shown that providing performance measurement feedback is essential to trainee learning,<sup>3</sup> but in gaming, objective feedback is often missed and may be impossible. UDPS determined that their driver training needed to provide objective performance feedback in each exercise.

UDPS also observed that some drivers in gaming scenarios made radical maneuvers that they would not attempt to do in a real vehicle. That behavior suggests a potential for negative effect in real-world driving. UDPS determined to eliminate that possibility. They noted that “simulators are most effective when placed in conjunction with expert performance models and augmented with instructional supports.”<sup>4</sup> They determined to limit the trainees’ practice maneuvers within the bounds of an expert performance model.

In addition, UDPS determined that high-speed gaming maneuvers in the simulator contributed to simulator adaptation syndromes (SAS), or driver discomfort. Severe SAS had caused some trainees to withdraw from the training. UDPS determined that radical visual motion cues without real body motion cues had to be minimized to prevent trainee dropout due to SAS.

### Summary Challenges

UDPS challenged the simulation and training industry in 2004 to help them address issues C1 to C5:

- C1.** Scenarios must provide an incremental skills-development sequence. Trainees must practice skills and judgments progressively from easy to complex.
- C2.** Trainers must be able to give consistent objective feedback to every trainee, based on the trainee’s performance in completing all of the required tasks.
- C3.** The process must eliminate all gaming during training exercises. Trainees must be focused on developing skills in the simulators at all times.
- C4.** The training process must control dropout from the training course due to trainee discomfort (SAS).
- C5.** The process must objectively measure the trainees’ skills, and the effectiveness of the training itself.

UDPS developed answers to each of these issues.

## CURRICULUM DEVELOPMENT

UDPS had begun analysis of EVO skills requirements several years before using simulators. UDPS surveyed hundreds of EVO instructors and training agencies throughout the United States. International input came from foreign agencies that had used the UDPS training facilities. UDPS also reviewed local and national case law affecting EVO operations in relation to widely accepted standards. Ultimately, UDPS itemized a list of specific tasks and conditions that EVO drivers needed to learn in order to comply with *standards* promoted by authoritative law enforcement bodies, including IADLEST, ALERT, FLETC, and CA, AZ, and UT POST organizations.

That study itemized three categories of tasks that EVO drivers needed to learn. UDPS assigned a weighted score value to each type of task so that when a trainee completed a specific task, a relative value for that task could be added to a summary score for that exercise. They determined that several different tasks of each type were required. The three types of tasks included:

- 1. Important** 1 point -for tasks that facilitate timely task completion. Example: “EV should attain speed > 45 mph at mid block when there is no traffic.”
- 2. Priority** 3 points -for tasks to conform to legal, policy, and procedural requirements. Example: “EV must change siren pitch approaching intersection”
- 3. Critical** 5 points -for tasks involving direct exposure to risk for accident. Example: “EV must stop completely before entering intersection w/ red light.”

### Lesson Plan Development

UDPS then designed 15 scenarios in a lesson plan that they named *Through Intersections Analysis*. They designed each scenario to be a practice exercise in performing the tasks in their task analysis. The sequence of scenarios advanced in difficulty from simple traffic at the start to complex, performance-demanding conditions in the end. UDPS asked industry to code these scenarios for two PatrolSim™ PSII+ driving simulators.

Industry provided a new software application called *EVOC-101* to measure each task, and to score each driver in completing each task in the lesson plan. The program provided feedback to each trainee so they could review their performance after each scenario. The trainees attempted to improve their performance in successive exercises at the same time that the successive scenarios presented new traffic challenges.

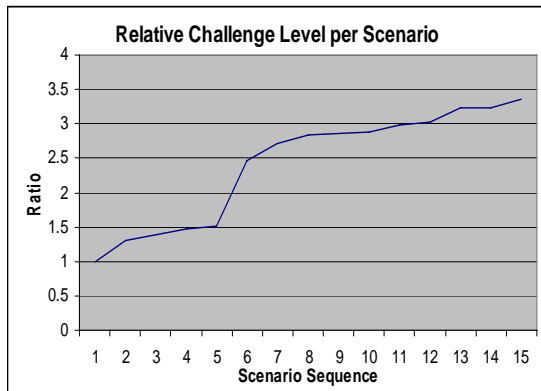
### Development of Progressive Difficulty

While encoding these scenarios, the developers determined that there were five principle issues affecting scenario complexity. These included:  
**Test points** possible in required tests. (TotPts)  
**Fixed objects** to be scanned for information. (NoFO)  
**Moving objects** presenting potential conflicts.(NoMO)  
**Specific conflicts** demanding avoidance. (NoConflicts)  
**Precision points** required in maneuvering. (Precision)

The developers defined a numerical formula to characterize the complexity, or challenge level given to the driver. The formula sums the contribution of these five issues to characterize the scenario *challenge level*.

$$\text{Challenge Level} = \text{TotPts}/3 + \text{NoFO}/2 + \text{NoMO} + \text{NoConflicts} + \text{Precision}.$$

Figure 1 below uses the above formula to compare the increasing difficulty of each scenario in the lesson plan relative to the first scenario in the lesson plan. The last training scenario appears to be approximately 3.4 times more challenging than the first scenario.



**Figure 1. Scenario Challenge Level**

UDPS developed two additional final-test scenarios for this lesson plan. Each test scenario involves four successive intersections, each one of which is as difficult as any intersection in any lesson plan scenario. This series of intersections presents a gauntlet challenge that requires trainees to demonstrate consistency in applying lessons learned in the training. Using the above formula, the test scenarios are 10 times more challenging than the first scenario in the lesson plan. UDPS requires trainees to pass one of the two final test scenarios with a score of > 80% and < 3 critical errors during the test exercise. These exercises and tests answer training challenge **C1**.

### TRAINING PROCESS

Table 1 illustrates the performance feedback report that the *EVOC-101* program generates after each scenario.

**Table 1. Driver Performance Feedback Report**

<p>Driver: 140TM21 No: 140 Date: 10/21/2005 Time: 9:02:54 AM                  Scenario Name: int105sbc1 Operator: EVO Trainer</p> <p>TEST 1: PASS. EV must cross intersection &lt; 35 mph                  TEST 2: PASS. EV must activate siren 400 ft bef intersection                  TEST 3: PASS. EV road pos &lt; 1m from turn lane line &gt; 200 ft .                  TEST 4: PASS. EV siren pitch must change 400-200 ft bef. int.                  TEST 5: PASS. EV must flash headlamps 400 - 200 ft bef. int.                  TEST 6: PASS. EV Speed &lt; 35 mph from. 200 ft bef. int.                  TEST 8: PASS. AND: &lt;75% brake actuation during decl.                  TEST 9: FAILED @ time = 37.4 sec. CRITICAL! Points=5                  EV must stop bet w 100 ft &amp; the int. cross walk                  TEST 10: FAILED @ time = 43.8 sec. CRITICAL! Points=5                  EV must cross the intersection &lt; 15 mph                  TEST 11: PASS. EV Siren pitch must not change crossing int.                  TEST 12: FAILED @ time = 45.2 sec. Points=3                  EV must center up in the #1 lane exiting intersection                  TEST 13: PASS. EV must control accel &lt; 0.40G after int.                  TEST 14: FAILED @ time = 50.8 sec. CRITICAL! Points=5                  EV must accel smoothly &gt; 0.09G after int.</p> <p>SUMMARY:                  Total Critical = 3                  SCORE = 33/51. Percent = 64.7                  Drive Time = 48.5 sec.</p>
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This report illustrates an important characteristic about the scoring process. All tests are purely Boolean in that they are either passed or failed. UDPS defined every task in terms of limits in a performance model, and the *EVOC-101* program tests driver performance relative to those limits. This establishes a totally objective scoring process that completely answers challenge **C2**.

### Compliance Constraints

The *EVOC-101* program automatically terminates each scenario and records the performance data after making the last test defined for that scenario. This prevents the trainee from gaming or wasting time after the exercise. The program prevents driving anywhere outside of the prescribed corridor for the scenario sequence. It also tests for timeliness in completing stages of any scenario, to assure driver diligence in emulating an emergency response. Failure to comply with any of these test constraints automatically terminates the exercise in a *compliance error*. Typically that scenario will be scored as *zero*—the same as if a collision had occurred. The trainer would then remind the trainee of the consequence that zero-score would have on the trainee’s overall average performance score for the day. This process served to answer challenge **C3**.

### Trainee Demographics

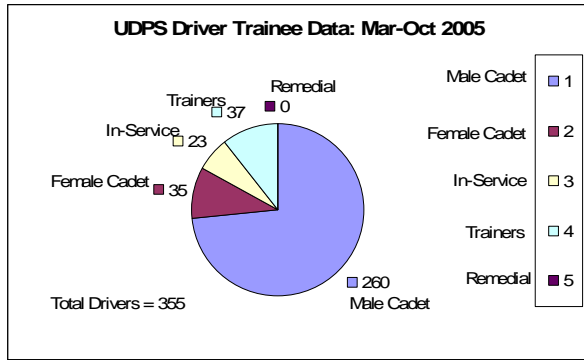


Figure 2. Trainee Demographic for 2005

The program records demographic data about each trainee as well as the trainees’ performance scores. Among 355 trainees measured, there were exactly two trainees who did not complete the full training course due to discomfort in the simulators, i.e., due to SAS.

Investigation determined that both individuals brought with them genetic or digestive pathologies that were the primary sources of discomfort. The first trainee had a genetic inner-ear condition that caused immediate nausea in many situations, especially when exposed to unusual motion. The second trainee came to the training session after lunch and indicated discomfort at the start due to “pepperoni indigestion.”

Overall, two cases out of 355 trainees represents a SAS dropout rate less than 1.0%. The previous simulator training dropout rate had exceeded 12%. In effect UDPS noted a 10-fold decrease in SAS dropout rate, and found the new rate to be less than the dropout rate for trainees driving real vehicles on the test track! Clearly, the new process resolved challenge C4.

### SAS Reduction Steps

UDPS applied several steps to attain that reduction. The process involved addressing both psychological and physiological aspects of SAS, simultaneously.

Psychologically, UDPS applied three steps to mitigate SAS. First, it replaced the word “sickness” with the word “adaptation” in all references to the subject of discomfort in the simulator. This placed the subject of discomfort in a positive, proactive perspective. Second, UDPS instructed the trainees that adaptation was normal and to be expected. Each trainee was instructed that they had the capacity to adapt over time.

Third, UDPS informed the trainees that their scores in performance during the training would affect eligibility for EVO employment. This obviously served as strong personal motivation to learn to adapt to the simulation.

Physiologically, UDPS also applied three steps. First it controlled the simulator environment to be < 68°F, and provided constant air-flow onto the drivers’ face and upper torso. Second, it made each scenario very short and direct, from 30 to 60 seconds, maximum. Third, the logistics of the training process rotated drivers in and out of the simulators after every three scenarios, thereby giving each driver “downtime” after each simulator exposure. These steps facilitated adaptation.

### TRAINING PERFORMANCE MEASUREMENTS

The program automatically generates a driver performance report and score, as shown in Table 1, for each scenario driven by each trainee. At the conclusion of the training, the program tools provide another summary report that averages each trainee’s performance over all the scenarios in the lesson plan.

### Statistical Analysis

The tools include statistical analysis features that evaluate all the different driver’s average scores and compare individual performance to the normal average score for the given population of trainees. Figure 3 illustrates the distribution of average lesson plan scores for all 355 drivers in this sample population.

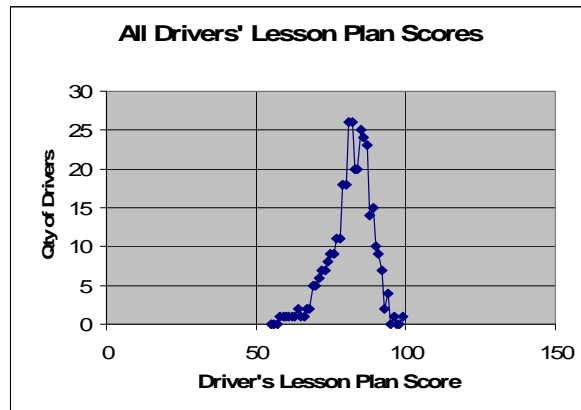
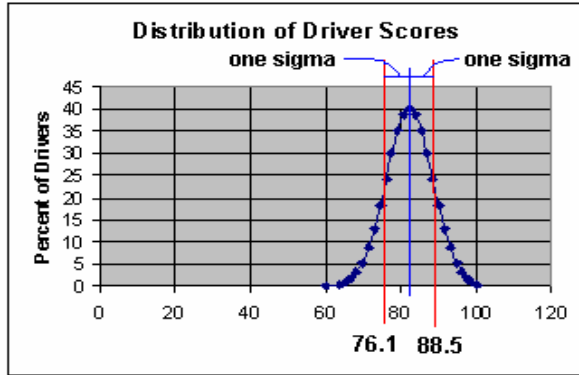


Figure 3. Distribution of Trainee Average Scores

This is a classic “normal distribution” of scores that invites a classical statistical analysis. The distribution for cadets-only is nearly identical. The mean for cadets is 82.3% and the standard deviation is 6.2 points.



**Figure 4. Normalized Cadet Scoring Distribution**

Figure 4 illustrates a classic bell-curve representation of the normal distribution of cadet scores in this study. Those drivers whose average score is more than one standard deviation (one sigma) outside the normal average are of particular interest. UDPS looks at those individuals to remand for further evaluation and/or additional training. UDPS has used this data to make *objective recommendations* for those whose scores are more than two standard deviations below the average to seek another type of employment.

**Individual Score Comparison Report**

The tools provide an individual summary report for each trainee. This report summarizes five specific areas of scoring, including the average:

- Score (as noted above),
- Number of critical errors per scenario,
- Time duration of scenario completion,
- Number of collisions.

**Table 2. Individual Scoring Summary Report**

Driver No: 123	Alias: 123IM11	Name: Ima Kopp
Driven Date: 3/24/2005		(pseudonym)
Report Date: 10/20/2005		

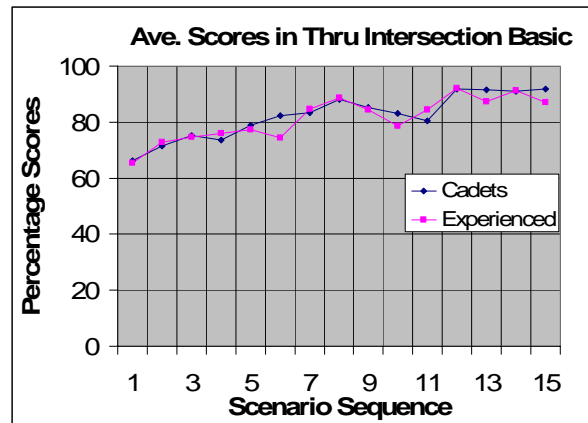
	Score	Critical	Time	Collisions
Driver	86.9	0.857	50.2	0.071
Normal	82.3	1.131	49.7	0.020
Percentile	71.0	65.46	48.7	9.575

The score values for the normal average of the cadet population appears immediately below the individual driver’s score. If the driver scored exactly the same as the normal average score, that driver would be in the 50<sup>th</sup> %-ile (the median) of the population. In the case shown in Table 2, the driver had a better than average score and placed in the 71<sup>st</sup> %-ile in that category. In

the case of critical errors this driver also did better than the median cadet score of 1.13 critical errors/scenario. However, the average drive-time was a little slower than the median, and this driver had one collision during the exercises. Less than 10% of the drivers experienced any collision during the training, so that one collision placed this driver in the lower 10%-ile in that category of scoring.

**Training Program Evaluation Reports**

The statistical analysis tools provided in the EVOC-101 program facilitate many different combinations of data summaries, including averages for different segments of the population, for different specific scenarios, and for different sessions of training. Figure 5 illustrates the overall effectiveness of the training program for two segments of the population.

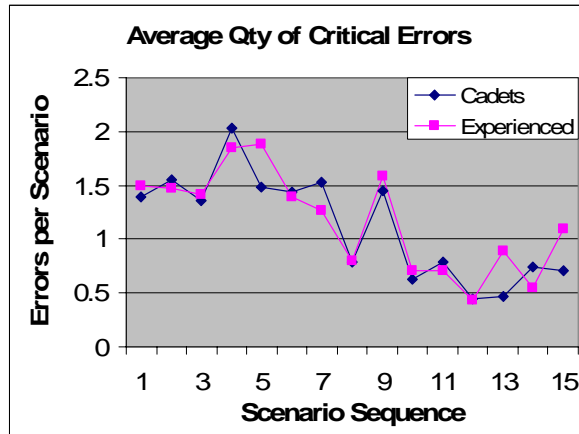


**Figure 5. Average Scenario Scores**

This summary graph shows that both cadets and more experienced officers improved performance nearly equally through the course of the training. Evidently, the skills being trained in the simulator are equally important to both segments of the population. UDPS used this objective observation to justify the allocation of more simulator-based training time this year (2006).

This summary also quantifies the value of the overall training course. Both cadets and more experienced officers begin the simulator-based training process with an average performance score of 67% while executing the most basic scenario requirements. They finished the most difficult, demanding scenarios with an average score of 92%. This represents a 25% increase in performance while the difficulty increased by a factor of 3.4. An objective measure of learning value provided by the training course would be the combination of both effects: 1.25 X 3.4 = 4.25.

This measure indicates that the trainees perform more than 4 times better at the end of the training than when they began the process.



**Figure 6. Reduction in Critical Errors**

Figure 6 presents perhaps the most significant value of this training process. Critical errors are by definition those issues that put the vehicle or the public at risk of accident or injury. Not every critical error will result in an accident, but every accident is caused by a critical error. Therefore, every reduction in critical errors produces an equal reduction in risk for accidents.

The fourth scenario in this lesson plan is the first to present a red light and another vehicle that does not immediately yield right-of-way to the emergency vehicle driving in emergency mode. The average rate of critical errors in that scenario is 2.1 errors per scenario. At the end of the course, cadets finish the last scenario (that is 2.3 times more complex than that fourth scenario) with an average rate of only 0.7 critical errors per scenario. The reduction in critical errors from 2.1 to 0.7 errors per scenario translates to a 67% decrease in risk for accidents. That translates directly to an equal reduction in risk for loss of life and property.

That number represents a truly powerful issue, primarily because that number derives from totally objective measurements of real driver behaviors.

### SUMMARY

The above data demonstrates how the *EVOC-101* program provides objective measures of both driver performance and the overall value of the training curriculum, as noted in challenge C5. The program clearly resolves all five UDPS challenges.

### Epilog

Prior to the application of this program, most of the trainees at the UDPS facility at Camp Williams went directly from classroom instruction to test-track training. Some simulator-based gaming came later. While on the test-track, each cadet would drive a real emergency vehicle with an instructor sitting in the passenger seat holding a clipboard and making checkmarks for errors committed. During that course, the cadets averaged 25 checkmarks per trainee, an average of four of which were for critical errors.

The process changed in 2005. The cadets went from classroom instruction to simulator-based training, and then to the track. While driving on the track in 2005, the cadets averaged only 12 checkmarks per trainee. Less than one of those checkmarks was for a critical error. That difference represents a 75% reduction in critical errors (not to mention a safer environment on the test-track for the drivers and instructors!).

A greater reduction in critical errors on the test-track than in the simulators can be attributed to the fact that the simulators presented much more hazardous conditions than could be recreated safely and reliably using real vehicles on the track. Altogether, UDPS has used a simulator-enhanced curriculum to improve the value of its EVO training in several ways. The objective measure for risk reduction could prove to be very significant in future evaluation of return on investment.

### Projection

The pedagogy described herein applies a process of performance measurements and feedback through progressive scenarios. In general, that process could apply to training drivers of any military vehicle. It will certainly apply to operating any military vehicle where the demand for speed must be balanced by the demand for safety and conformance to regulation. The benefits from this simulator-based training derive from:

- A driver performance measurement system,
- Task-oriented driving simulator scenarios, and
- A highly structured training curriculum.

The UDPS program has recorded each of these processes objectively and has observed demonstrable benefit from their application. Military applications that parallel the discipline of making objective measurements and providing trainee feedback should realize similar improvements in trainee performance.

### **ACKNOWLEDGEMENTS**

EVO Master Training Sergeant Doug Slagowski (retired) in cooperation with UDPS EVO Training Supervisor Doug Larsen designed and developed the principle structure and processes in the ***EVO-101*** program described in this paper. These two EVO trainers have cumulated more than 50 years experience in law enforcement, including more than 33 years of specific service in EVO driver training. The focus of the ***EVO-101*** program on objective measurement and trainee feedback derives directly from that experience.

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