Snowplow Simulator Training Evaluation:

Potential Fuel & Drivetrain Maintenance Cost Reduction

Final Report 635

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16. Abstract –
The Arizona Department of Transportation (ADOT) introduced simulator-based training in 2004, when maintenance crews in five rural districts received a third-party snowplow safety topics course on the L-3 TranSim VS III simulator. In 2005, a simulator was deployed in the Globe District, initiating a training program for the 60-plus snowplow operators there. Local volunteer trainers, all experienced plow operators, went through a "Train the Trainer" course from L-3 staff. On that basis, in early 2006, all of the district's drivers took a Fuel Management Driving Techniques (FMDT) course on proper shifting techniques for better fuel economy.

The goal of this study was to identify the benefits of simulator-based training in fuel economy and driveline repair costs for ADOT's heavy vehicle fleet. It focused on the Globe District, to assess: (1) Potential improvements to fuel economy, recorded in the simulator training session, (2) Driver performance in the real-world environment, in terms of fuel economy, (3) Changes in fuel economy and repair costs related to proper driving / shifting skills.

The project attempted to measure fuel performance in a real-world driving environment by establishing a 168-mile round-trip test route between two maintenance yards, on a winding route with many steep grades. Test runs were done with five newly-hired drivers, both before and after the fuel training, in both automatic and manual-shift plow trucks. For the manual transmission fuel runs, on average, a 4.5% improvement was seen.

Three years of district fuel and repair histories were reviewed for periods before and after the 2006 training. Five significant "high-mileage" work activity areas were studied. Results were mixed due to many variables, but the critical "snow and ice activity" category did show some improved fuel economy for early 2007. However, the records showed no clear reduction in driveline repairs for January-March '07, but noted that an additional cost of repairs is the time that trucks needing extensive work are out of service.

This study used Kirkpatrick's four-level evaluation model to assess if the training improved fuel economy in the Globe District. At the *Reaction* level, results are positive; crews say the training did increase awareness and change driving behaviors with regard to fuel efficiency. At the *Learning* level, results show some drivers improved but others did worse in post-testing. At the *Performance* level, the results are promising: drivers of manual-shift trucks achieved improvements in fuel economy. At the *Results* level, aggregate fuel economy figures also show a discernable difference in pre-training and post-training fuel efficiency for key winter maintenance tasks.

This study confirmed that operational training can best be measured in quantitative terms, but with challenges. Future ADOT efforts to evaluate simulator training results must first strive to better integrate field data. Training must focus on improved manual gear shifting, and on "best practices" for automatics. The most benefit may come from fully integrating simulators into ADOT's field training program, which requires strong agency support. Key future requirements are (1) A state-level champion who can enhance simulator training, (2) A new fuel vs. work effort reporting system, (3) Formal recognition and incentives for the volunteer local training teams.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS					APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	When You Know	Multiply By	To Find	Symbol	Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH					**LENGTH**		
in	inches	25.4	millimeters	mm	mm	millimeters	0.039	inches	in
ft	feet	0.305	meters	m	m	meters	3.28	feet	ft
yd	yards	0.914	meters	m	m	meters	1.09	yards	yd
mi	miles	1.61	kilometers	km	km	kilometers	0.621	miles	mi
		AREA					**AREA**		
in^2	square inches	645.2	square millimeters	mm^2	mm^2	square millimeters	0.0016	square inches	in^2
ft^2	square feet	0.093	square meters	m^2	m^2	square meters	10.764	square feet	ft^2
yd^2	square yards	0.836	square meters	m^2	m^2	square meters	1.195	square yards	yd^2
ac	acres	0.405	hectares	ha	ha	hectares	2.47	acres	ac
mi^2	square miles	2.59	square kilometers	km^2	km^2	square kilometers	0.386	square miles	mi^2
		VOLUME					**VOLUME**		
fl oz	fluid ounces	29.57	milliliters	mL	mL	milliliters	0.034	fluid ounces	fl oz
gal	gallons	3.785	liters	L	L	liters	0.264	gallons	gal
ft^3	cubic feet	0.028	cubic meters	m^3	m^3	cubic meters	35.315	cubic feet	ft^3
yd^3	cubic yards	0.765	cubic meters	m^3	m^3	cubic meters	1.308	cubic yards	yd^3
	NOTE: Volumes greater than 1000L shall be shown in m^3.								
		MASS					**MASS**		
oz	ounces	28.35	grams	g	g	grams	0.035	ounces	oz
lb	pounds	0.454	kilograms	kg	kg	kilograms	2.205	pounds	lb
T	short tons (2000lb)	0.907	megagrams (or "metric ton")	mg (or "t")	Mg	megagrams (or "metric ton")	1.102	short tons (2000lb)	T
		TEMPERATURE (exact)					**TEMPERATURE (exact)**		
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celsius temperature	°C	°C	Celsius temperature	1.8C + 32	Fahrenheit temperature	°F
		ILLUMINATION					**ILLUMINATION**		
fc	foot-candles	10.76	lux	lx	lx	lux	0.0929	foot-candles	fc
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2	cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE AND PRESSURE OR STRESS					**FORCE AND PRESSURE OR STRESS**		
lbf	poundforce	4.45	Newtons	N	N	Newtons	0.225	poundforce	lbf
lbf/in^2	poundforce per square inch	6.89	kilopascals	KPa	kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380

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TAC members and stakeholders during the term of this study were: Alan Hansen, Annie Parris, Bill Harmon, Bill Kohn, Carl Eyrich, Chuck Willis, Cindy Eiserman, Cynthia Mills, Danny Russell, David Sikes, Dawn Palmer, Dell Jenkins, Dennis Halachoff, Dennis Johnson, Diane Minton, Doug Forstie, Erika Blankenship, George Garcia Jr., Jeanne Sunda, Jerry Barnes, Jerry Massie, Jo Ann Noriega, John Harper, Larry Addison, Randy Routhier, Richard Powers, Rose Gabaldon, Sonya Herrera, Sue Olson, Tom Engel, and project manager Steve Owen of ADOT's Arizona Transportation Research Center.

Members of the ASU interdisciplinary team were: Mary Kihl, Professor, School of Planning, principal investigator; Donald Herring, Clinical Professor, Department of Industrial Design, co-principal investigator; Peter Wolf, Lecturer, College of Design, investigator; Mike Finn, graduate assistant, School of Planning, and Peng Yang, graduate assistant, Department of Industrial Design.

Authors' note:
This research project, like ASU's previous SPR 585 simulator training study for ATRC, was conceived and guided by Dr. Mary Rambo Kihl. Sadly, Dr. Kihl passed away in October 2007, just as this work was concluding. In completing this report, the project team has been guided by her vision, focus, and insight. Her many contributions to transportation research will be missed.

ACRONYMS & ABBREVIATIONS

ADOT	Arizona Department of Transportation
ASU	Arizona State University
ATRC	ADOT's Arizona Transportation Research Center
BTW	Behind-the-Wheel
CBT	Computer-Based Training
CDL	Commercial Driver's License
DOT	Department of Transportation
DPS	Arizona Department of Public Safety (Highway Patrol)
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
ITD	Intermodal Transportation Division of ADOT
L-3	L-3 Communications — parent company of MPRI Ship Analytics, the supplier of the TranSim VS III simulators and training to ADOT during 2004-07.
MPG	Miles per Gallon
MPH	Miles per Hour
OJT	On-the-Job Training
ORG	The primary local-level ADOT highway maintenance unit (yard/camp/office).
PECOS	"PeCoS" or "PECOS" **(**PErformance COntrolled System**)** is ADOT's proprietary highway maintenance activity records system.
SIPDE	Defensive-driving training model presented by L-3 (Search, Identify, Predict, Decide and Execute).
SWG	ADOT Simulator Working Group – pilot district of Globe, plus Flagstaff, Holbrook, and (pending installation) Safford.

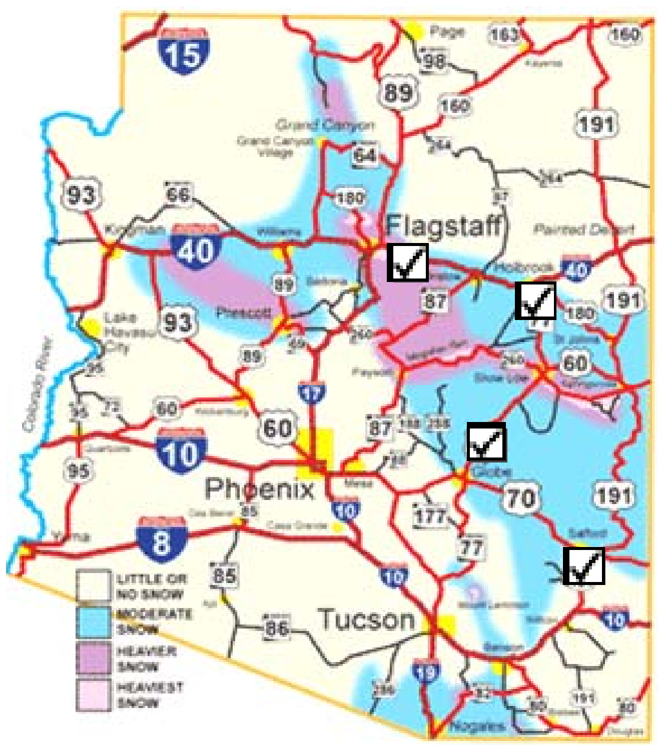
EXECUTIVE SUMMARY

SIMULATOR-BASED DRIVER TRAINING

Driving simulators are used in a variety of applications, including cars, large trucks, and off-road equipment. As more realistic training programs have been developed, simulators are in use to train snowplow drivers in many states such as Pennsylvania, Utah, and Iowa. The Arizona Department of Transportation (ADOT) introduced simulator-based training in late 2004, when maintenance crews in five rural districts took a brief snowplow safety topics course on the TransSim VS III, with third-party trainers from L-3 Communications.

ADOT's Arizona Transportation Research Center (ATRC) initiated project SPR 585 in mid-2004, to evaluate simulator training. Arizona State University assessed results of the initial training in the Globe District, and recommended refinements to the program. ASU documented the success of the training, and enthusiasm of the trainees, in ATRC Final Report 585.

In late 2005, ADOT purchased its first L-3 simulator and deployed it in the Globe District, initiating a far more extensive field training pilot program for its 60-plus snowplow drivers. Local ADOT volunteer trainers, all experienced snowplow operators, were given a "Train the Trainer" course by L-3 staff. Then, all Globe District crews took a four-hour basic driver awareness and space management course, with lectures and simulator snowplowing scenarios.



ADOT has installed two additional L-3 simulators in the Holbrook and Flagstaff districts, further expanding the training program for 2006-07. These two districts used the original simulator-based driver awareness course to initially train all of their plow operators before the 2007-08 snow season. Eight new operators hired in Globe over the past year were also trained using this snowplow driver awareness course. A fourth unit has also been purchased for the Safford District, to be installed in 2008.

The Simulator and FMDT Training

In early 2006, Globe trainers presented the L-3 Fuel Management Driving Techniques (FMDT) course to all drivers in the district. The same trainees who had taken safety awareness classes in the fall were now instructed on proper gear shifting techniques for better fuel economy with the FMDT training module. In this course the primary focus was on shifting of manual transmissions (M/T) more smoothly and efficiently using the gear shift, clutch, and accelerator, rather than on the overall driving experience as in previous simulator classes. Other information on automatic transmission (A/T) efficiency is included in computer-based and lecture segments of the class.

The objective of this new 2006-07 research project was to assess the benefits of simulator-based FMDT training in terms of fuel economy and routine repair costs for ADOT's heavy vehicle fleet. The study is focused on the Globe Maintenance District, with the first simulator deployed by ADOT. The FMDT course was given to all equipment operators in the Globe District in Spring 2006, and also to the District's new drivers in fall 2006 and spring-summer 2007.

The full benefits of simulator-based training will emerge only over time, but this study offers an initial assessment from Globe District records. The focus of this study was on:

1. Potential improvements to fuel economy, recorded in the simulator training session.
2. Driver performance in the real-world environment, in terms of fuel economy.
3. Changes in fuel economy and repair costs, related to proper driving/shifting skills.

This study used Kirkpatrick's four-level evaluation model to assess whether the FMDT training improved fuel economy in the Globe District. At the *Reaction* level (Level 1), the results look positive; drivers and supervisors said in interviews and follow-up surveys that the training has increased awareness and changed driving behaviors related to fuel efficiency. At the *Learning* level (Level 2), the results are similar to those of Project 585: some drivers improved, but others did worse in the post-training scenarios.

At the *Performance* level (Level 3), the field results are promising, as drivers of the manual-shift trucks achieved, on average, a 4.5% improvement in fuel economy. But, at the *Results* level (Level 4), the aggregate fuel economy figures by season for the 10 trucks studied in detail shows no discernable difference between pre-training and post-training fuel economy for the primary winter maintenance tasks.

Ideally, this study would have demonstrated clear fuel economy improvements at the Learning, Performance, and Results levels of evaluation. The outcome did not fully meet expectations, but does offer some insights that suggest areas of promise:

Level 2: Learning
The experienced drivers (10 or more years of truck driving) achieved the greatest improvement in estimated fuel economy, as indicated by the simulator's before and after training reports. This is encouraging, in that it suggests that the FMDT course can benefit even drivers who have many years of real-world experience — and had extensive driver training over those years. However, the FMDT training, as currently conducted, did not have the same impact on novices. It may be that novice drivers, if given more practice time, would be able to achieve similar results.

Level 3: Performance
The improvements achieved by drivers of the manual shift trucks, averaging 4.5%, is substantial. If this is applied to every M/T truck in the Globe District, potential savings also are substantial. The savings become even greater when all M/T trucks are considered for all of ADOT. In fiscal year 2006, ADOT burned 1,079,068 gallons of diesel fuel, at a cost of nearly $2.8 million.

Although these numbers are fleet-wide — and include all types of diesel-powered vehicles, including many A/T vehicles — it is clear that even a modest improvement in fuel economy has the potential to yield significant dividends (especially as fuel costs continue to rise).

Level 4: Results

Due to the several factors noted previously that can mask improvements in post-training fuel economy, the results of the aggregate fuel study are largely inconclusive. Still, the approach taken has revealed some useful insights, as described in the following sections.

EVALUATION AREA 1: Potential Fuel Savings

This evaluation used data from Globe's inaugural FMDT simulator training course in 2006, using the simulator to estimate fuel consumption during a specific driving task. Initially, trainees shifted up through the gears from a standstill to 60 mph, then stopped, as a "pre-test." They then took the FMDT class, in which proper gear shifting was emphasized. After their training, drivers again "drove" the zero-to-sixty run, as a "post-test." Each trainee's mileage was displayed on the trainer's screen; simulated fuel economy was expected to improve in the post-test scenario.

While some drivers improved, others achieved worse fuel economy in post-test simulator runs. These results indicated problems with FMDT software updates, and possible inconsistencies in training for the three districts. These are issues that ADOT's Simulator Working Group (SWG) was formed to address, as the simulator training expands in the state.

It may be that the simulator software was the culprit; in addition to issues with recording fuel-run figures, trainers also faced intermittent problems with the actual shifting of the simulator. It is also possible that the cause of the unexpected fuel test results may be as simple as not having adequate practice time in the simulator. Again, these are among the issues that are addressed in the recommendations of this report, and will continue to be addressed in the future by the SWG.

EVALUATION AREA 2: Globe to Show Low Fuel-Test Runs

The project also endeavored to measure fuel performance in a real-world driving environment. ADOT field staff and the research team established a rural highway test route on US 60, from Globe to the Show Low maintenance yard and back, a 168-mile, four-hour round trip. The route was through the Salt River Canyon, a winding road with many steep grades.

The same two Mack snowplow trucks were used throughout the study: a 2005 model with an automatic transmission and a 1999 unit with a manual shift. Both trucks had GPS telemetry and engine computers to record elapsed time, distance, and fuel consumption. Each truck was "fully dressed" with rear spreader and snowplow blade, and loaded with sand equal to a typical load of de-icer. Five newly-hired Globe drivers each made a total of four roundtrip fuel efficiency runs. Each driver made two trips prior to FMDT training (one in the M/T truck, and one with the A/T). These trips were repeated in each truck after taking the FMDT training course. Two experienced driver-trainers also made initial test runs, to establish a baseline miles-per-gallon mark.

This study faced many challenges typical of real-world research, which made a rigorous before-after comparison impossible. The manual transmission truck consistently overheated, forcing the driver to reduce speed or pull off the road. Drivers of the automatic transmission truck changed their behavior too, sometimes slowing to wait for the driver struggling with the manual truck.

The pre- and post-test runs took place several months apart, in March-August and in September. Ambient temperatures were not consistent, and were not typical working temperatures for a fully dressed snowplow — a factor in the overheating of the manual truck. Due to these challenges, and the small sample size, conclusions must be considered somewhat speculative. Despite the real-world challenges, the evaluation has revealed some promising trends. On the M/T trucks, five trainees posted an average 4.5% improvement in fuel economy following their FMDT training. On the other hand, results for the A/T trucks indicate a 6.1% *decrease* in fuel economy following FMDT training. A number of factors may have contributed to this unexpected result.

EVALUATION AREA 3: Aggregate Fuel Economy and Repair Analysis

Records for 2005, 2006, and 2007 for the entire Globe District heavy truck fleet were reviewed for two three-month quarters, both before and after the FMDT training classes. For both fuel and repairs, the goal was to distinguish winter (Q1) from spring driving (Q2) for assessing the costs, since activities vary considerably by season. Winter of course involves significant snow plowing, while spring driving activity focuses on road maintenance and repair.

The first step was to identify a set of trucks to be studied in detail as regards their fuel economy. FMDT training was given in spring 2006, so records were collected for each of Globe's manual shift trucks from 2005 to 2007. It was essential to focus on trucks that saw consistent heavy use in this period, so a subset of 10 trucks was identified. These trucks saw extensive use in both winter and summer activities, and so would give an accurate picture of fleet fuel economy.

Globe's aggregate fleet fuel consumption data, based on seasonal work activity records by quarter, offers potentially useful information. Data was analyzed for five significant "high-mile" task categories from the ADOT maintenance work performance database (PECOS), comparing pre- to post-training winters. However, no clear trends resulted in these primary task areas.

Specific driving techniques are only one of many factors affecting the frequency and extent of equipment repairs. Age, quality, and exposure of the vehicles themselves are also important factors. Trucks in the Globe fleet are relatively new and, after several relatively mild winters, they generally have not had extensive severe usage yet. Also, some substantial repairs to these trucks may be postponed until late summer, as the trucks are prepared for the winter season. Any such costs would not appear in this study's review of records of the first and second quarters.

Globe fleet records suggest no clear reduction in driveline repairs in the January-March winter quarters of 2005, 06 and 07. In fact, Globe repair costs rose in 2007, the year after the FMDT training, due to one major transmission repair. Excluding that one cost, the total of repairs for the first quarter of 2007 would show a substantial reduction compared to the prior two winters.

An additional cost of repairs is the time that trucks requiring more extensive repairs were out of service; that is a significant opportunity cost. During the winter months, when it is essential that all snowplows are in proper working condition, an equipment repair could interfere with ADOT's commitment to keep roadways clear.

EVALUATION RESULTS

The premise of this study was that any post-training improvements to fuel economy would be evident in a review of the full fleet of trucks operating year-round in the Globe District. The results, however, suggest the fuel consumption picture is even more complex than anticipated. Potential fuel savings will vary, often greatly, with many external factors: transmission type, age and condition, activities, terrain and road conditions, and skills and techniques of the driver. The simulator is intended to address only one of these fuel-related factors: driving technique.

The literature underscores the importance of driving technique, but external factors also play a role — perhaps more for highway agencies than in over-the-road trucking (the focus of many fuel economy studies). Unlike commercial drivers on interstate highways with a standard vehicle and a typical cargo, DOT operators drive a mix of vehicles in a variety of activities on a diverse network of roads. Changes in fuel economy are therefore difficult to accurately capture. Still, focusing specifically on the Globe District's fleet of vehicles and range of operations, did help — at least to some degree — to isolate the role of the driver in fuel management and repairs.

ISSUES & RECOMMENDATIONS

ADOT's Project 585 research distinguished between tactical training (large concepts such as safety awareness) and operational training (more focused skills, such as driving techniques). That study concluded that simulators could be effective in training for both types of skill set, but that measures of effectiveness for each of these types of training are necessarily quite different.

Tactical training can best be measured qualitatively, while operational training can best be measured in quantitative terms. The current study supports this assertion, while at the same time highlighting some of the challenges involved in such quantitative assessments. Future studies should therefore take into consideration the following recommendations:

Data Reporting

It became clear over the course of the aggregate fleet study that the diverse ADOT systems used for recording fuel usage, job activity codes, etc., do not lend themselves to an integrated analysis. Separate systems (fuel logs from one source, driver/vehicle/task records from others) result in separate data sets, which are often difficult to integrate. A single, comprehensive, user-friendly system for reporting this important data would make it easier to monitor fleet performance. Indeed, if the system were user-friendly at the driver level, with feedback on a daily basis, operators would have a very real sense of their fuel consumption. The research suggests that improvements to fuel efficiency are more likely to occur when immediate feedback is provided.

Improved Gear Shifting

Project 585 reported that drivers were not given enough practice time and that "additional training is required to achieve over-learning" — the rehearsal of an action past a minimal skill level in order to perform it correctly in stressful situations. Drivers face many pressures to be productive; training requires resources that otherwise may be applied to ADOT's core mission. Nevertheless, the investment in driving simulators has been substantial. To fully reap the benefits of this investment, new drivers must be allowed (and perhaps *required*) to take the time necessary to develop real expertise in gear shifting technique. This is among the issues to be addressed by ADOT's Simulator Working Group.

Expansion of A/T Training

It was observed that some of the experienced drivers in the fuel-run study would often override the programmed shifting of the automatic transmission (shifting to a lower gear than the one "selected" by the program). This raises questions about "best practices" for driving trucks with automatic transmissions, an increasingly large percentage of ADOT's fleet. As trucks with automatics become more common, it is worthwhile to consider how the proper transmission override techniques can be integrated into the simulator's FMDT program — another issue for the SWG.

Simulator Down Time

During the research, the simulator in Globe frequently needed technical support; there were similar problems in Flagstaff and Holbrook. Screens were inoperable at times, as was the simulator gear shifting feature, an obvious impediment to FMDT training. The effective use of multiple simulators poses challenges for ADOT in general, and for each district in particular. Recent experience may support the argument for having a few mobile simulators (presumably in proper working order) to travel around the state, rather than many simulators in the districts across the state. There are tradeoffs with either approach, and Flagstaff has recently deployed a simulator training trailer.

SUMMARY

Although none of the results reported to date are clear evidence that FMDT training in the Globe District has improved overall fuel economy for its fleet of large trucks, the study *does* provide valuable insights for making such improvements in the future. As was suggested in the Project 585 report, the greatest benefits will come from carefully integrating the simulator training programs into the larger ADOT training program.

Much of this integration has already taken place at the district level; future improvements will require greater accommodation at the management level. Among the key initiatives needed are:

- A state-level champion for simulator training.
- A completely new fuel usage reporting system.
- Formal recognition and incentives for the training Working Group.

I. PROJECT INTRODUCTION

Rising fuel prices, as well as increased environmental concerns have prompted several research studies about how driver training programs might be used to improve fuel efficiency (DfT 2004; Foss 2005; Eco-Drive 2002; Parkes and Rau n.d.; Strayer and Drews 2003; TRL 2005; van der Voort et al. 2001). The potential benefits are significant, especially for trucking companies and government agencies with large fleets, such as the Arizona Department of Transportation (ADOT). One study that used only behind-the-wheel training methods found a 9.4% average miles per gallon improvement (DfT 2004). Interestingly, this study also noted a 30% reduction in gear changes, which, the authors suggest, “means the gear box will need less servicing and is likely to last longer.” Another study, which used a “fuel-efficiency support tool” to provide real-time feedback to drivers, reported improved fuel efficiency of up to 23% in “urban environments” (van der Voort et al. 2001).

Fuel economy is of increasing interest to fleet operators sensitive to the continued high price of diesel fuel. The U.S. trucking industry, which transports 70% of domestic freight, anticipates spending $6.6 billion more for fuel in 2007 than was spent in 2006 (ATA, 2006). The U.S. Department of Energy predicts a continued rise in the base price for diesel fuel in 2008 (USDOE 2007).

For state transportation agencies, escalating fuel costs have changed the way they do business. The Florida Department of Transportation (DOT), for example, was forced to reassess highway construction plans in light of both the soaring costs of construction materials and the fuel costs associated with transport of raw materials and operation of heavy equipment. The rate of increase for the five years from 2001-2006 was ten times that of the 10 years between 1991 and 2000 (FDOT 2007). Responses to this escalation in fuel and construction costs have varied. The North Carolina DOT, for example, adopted alternative fuel vehicles for its motor pool of 8,500 cars, but continues to spend $1 million each month in fueling heavy equipment (Roberts 2004).

Clearly, fleet operators have a greater incentive than ever before to improve their fuel economy. The literature points out that “the biggest potential fuel-saving device in a truck is the driver. . . The general consensus is that an experienced driver — applying the best techniques — can be 35% more fuel efficient than an inexperienced or untrained driver, or one who just doesn’t care” (e-Roadstar 2005).

Progressive Shifting

The primary driving technique credited with saving fuel is progressive gear shifting, which involves shifting gears upward as early as is practical when accelerating. When done properly, progressive shifting results in quicker acceleration, getting the truck up to cruising speed more quickly. At cruising speed, the truck can operate with greatest fuel efficiency. Progressive shifts also reduce wear and tear on the transmission and related components (e-Roadstar, 2005).

Obviously, progressive shifting is focused on the efficient operation of manual transmission (M/T) vehicles. For drivers of automatic transmission (A/T) vehicles, greater fuel efficiency can be achieved by driving at moderate speeds (Smith System 2004). By driving less aggressively on the highway, considerable fuel is saved. One commercial vehicle driver training program noted fuel savings of up to 30% when drivers consistently drive with the flow of traffic (Smith System 2004). In light of these promised fuel savings, many commercial vehicle companies are now adopting progressive shifting training for new drivers, as well as monitoring vehicle speed fleet-wide. Swift Transportation, for example, requires all new hires to practice progressive shifting on a driving simulator as part of their basic classroom training program. (Swift also has the capability to monitor the real-time vehicle speed of many trucks in their fleet, allowing them to observe the real-world behavior of their drivers.)

Simulator Training

Some public and private agencies have begun to investigate how driving simulator training might be used to improve their fleet's fuel efficiency as well (Parkes and Rau n.d.; Strayer and Drews 2003; TRL 2005). One study of trucking in the UK suggests that such training may result in a 16% improvement in "behind the wheel fuel efficiency," although long-term evaluations are still underway (TRL 2005). Another study, this one of drivers hauling mining materials, reported a 2.8% improvement in fuel efficiency (Strayer and Drews 2003). In 2004, researchers from the University of Utah and the Utah DOT studied fuel efficiency of snowplows (Strayer, Drews, and Burns 2004). While they did see improvements in fuel efficiency — especially among "drivers who exhibited the worst pre-training fuel efficiency" (Strayer et al. 2004, p. 21) — they concluded that, "neither the maintenance data nor the fuel data are of sufficient quality to afford a precise comparison between the study and control groups" (Strayer et al. 2004, p. 19).

APPROACHES TO DRIVER TRAINING

Techniques applied to commercial vehicle operation can also be applied to the operation of other large fleets, including departments of transportation. Safety has remained — and will continue to remain — the primary focus for driver training both for commercial vehicles and for departments of transportation. However, the benefit of potential fuel savings puts an additional emphasis on the training of proper gear shifting for these organizations.

The traditional DOT driver training process for new hires involves classroom instruction on key topics, and emphasizes the primary importance of behind-the-wheel (BTW) training with experienced "mentor" drivers. As such, DOT training mirrors typical Commercial Driver's License (CDL) driver training. Inexperienced new drivers who are joining departments of transportation without a CDL cannot drive alone and are required to follow the standard CDL training procedure. The content of the CDL training has remained largely unchanged since the development of the FHWA model curriculum in 1984, and the instructional methods (including lectures and supervised driving instruction) have not changed greatly in the last 30 years (Brock et al. 2001).

The literature suggests that drivers are generally positive about the "master driver" training model (in which novices learn by riding along — and eventually driving — with a "master driver"), and most driver training schools believe that this is the best approach.

Nevertheless, computer-based training (CBT) is gaining increasing support. Although it will probably never supplant BTW training entirely, it may reduce the amount of time required for BTW training and help ensure a more consistent knowledge base. Simulator-based training is one form of CBT, and can itself involve a range of approaches with varying levels of sophistication. "Simulation is an instructional method that requires students to interact with specific instructional events based on real-world scenarios. Students must see and experience the consequences of their interaction" (Brock et al. 2001, p. 8).

Simulator-Based Driver Training

Driving simulators have been widely used for human factors research and automobile driver training and retraining for more than 30 years (Linck, Richter, and Schmidt 1973, as cited in Reed and Green 1999). "Operator-in-the-loop" simulators were first developed to train military pilots (Wiener and Nagel 1988), but have since been used to train locomotive engineers, and ship helmsmen (Emery et al. 1999, p. 4). In recent years, driving simulators have been used for a wide variety of vehicle applications, including cars, large trucks (Hoskins et al. 2002), buses (Brock et al. 2001), off-road equipment ("Painless Haul-Truck Crashes," 2000), and cranes (Angelo 2001), among others. Recently, as they have become more affordable, driving simulators have been used to train snowplow operators in Pennsylvania (Vance et al. 2002), Utah (Strayer et al. 2004), Minnesota, Michigan (Ross-Flanigan 2002), Iowa, and Arizona (Kihl et al. 2006).

Simulator-Based Training within ADOT

The Arizona Department of Transportation (ADOT) first invested in simulator-based snowplow training in the 2004-05 snow season when ADOT's Intermodal Transportation Division (ITD) contracted with the MRI-Ship Analytics unit of L-3 Communications. Four L-3 TransSim VS III simulators, mounted in a mobile classroom, visited five rural ADOT districts (Globe, Flagstaff, Holbrook, Kingman, and Safford). Training was given by L-3 trainers to 149 ADOT drivers.

In late 2005, ADOT commissioned an L-3 simulator of its own, located in the Globe Maintenance District, initiating a far more extensive pilot training program there for some 61 snowplow drivers. In-house volunteer trainers — each of whom is an experienced snowplow operator — were selected, and went through L-3's "Train the Trainer" program. All drivers in the Globe District participated in a four-hour driver awareness and space management course made up of lectures and a series of three simulator-based scenarios that the drivers used to practice applying the concepts they had learned in the classroom. The relative success of that course and the enthusiasm of participants (especially the newly hired drivers) was reported extensively in Arizona Transportation Research Center (ATRC) Report 585 (Kihl et al. 2006).

ADOT's simulator training during 2005 focused on a defensive driving model called SIPDE (Search, Identify, Predict, Decide, and Execute). During the "stand-up" portion of the training, instructors explained each element of SIPDE in some detail, and examples were used to illustrate each point. Several simulator scenarios were used to reinforce the elements of the curriculum. For example, during an "in-town" scenario, trainees were required to *search* for pedestrians (behind parked cars, in some cases), *identify* and *predict* the most significant hazards in a particular situation (a school bus in front vs. a motorist speeding past on the left), and so forth.

In addition to teaching the SIPDE model, the classroom presentations included material related to space management, speed management and stopping distance, and crew communications. To add greater realism, the trainers had the option of adding whiteout and/or nighttime conditions. Among the simulator scenarios used were snow-covered freeways, a mountain pass and tunnel, high country driving, and in-town driving.

Two additional L-3 simulators have since been purchased for the Holbrook and Flagstaff districts, further expanding the training program for 2006-07. A fourth simulator has been purchased, and will be installed in the Safford District during 2008. The Holbrook and Flagstaff districts adapted the original simulator-based driver awareness course from Globe's first winter of the program to train their own snowplow operators before the 2007-08 snow season (Figure 1). Eight new operators hired in Globe during late 2006 and early 2007 were also trained using this snowplow driver awareness course.

Figure 1. Holbrook Simulator Training — SIPDE Course

As simulator training has expanded within ADOT, it has become critical to maintain consistency across the state while at the same time recognizing and accommodating valid local issues (e.g., terrain, traffic volume, etc.). This was the impetus behind the Simulator Working Group, formed in early 2006. District partners include Globe, Holbrook, Flagstaff, and Safford. The recent accomplishments and ongoing challenges of the SWG are discussed in detail in Appendixes A and B of this report.

The Simulator and FMDT Training

In the spring of 2006, Fuel Management Driving Techniques (FMDT) training was conducted in the Globe District. The same drivers who had been trained on safety awareness in the fall were given instruction on proper gear shifting techniques for better fuel economy, using the FMDT module of the simulator's package. For this training, the focus was purely on shifting gears more smoothly and efficiently (using the gear shift, clutch, and accelerator), rather than on the overall driving experience (as was the case with all previous simulator training sessions). The FMDT course is explained in detail in Chapter II.

II. RESEARCH APPROACH

The objective of Project 635 was to assess the benefits of simulator-based FMDT training in terms of fuel economy and reduced costs of routine repairs for ADOT's heavy vehicle fleet. The study is focused on the Globe Maintenance District, where the first simulator purchased by ADOT was installed in the fall of 2005. An FMDT course was offered to the entire group of drivers based in the Globe District in the spring of 2006, and the same course was given to the District's new drivers hired in late 2006 and through mid-2007. Although the full benefits of the simulator-based training will emerge only over time, the present study offers an opportunity for an initial assessment. The focus of the assessment, indicated above, is on:

1. Potential improvements to fuel economy, as documented in the simulator training session.
2. Driver performance in the real-world environment, as measured in terms of fuel economy.
3. Changes in the aggregate fuel economy and repair costs (for those items relating directly to proper driving/gear shifting techniques) for the Globe District.

ADOT'S FUEL MANAGEMENT DRIVING TECHNIQUES COURSE

Beginning in the spring of 2006, FMDT training was conducted in the Globe District. For this training, the focus was purely on shifting gears more smoothly and efficiently (using the gear shift, clutch, and accelerator), rather than on the overall plow truck driving experience (as was the case with all previous simulator training sessions). The course was typically three hours in length, and involved two trainers instructing two to four students.

Trainees received a combination of "stand-up" lecture training, CBT sessions, and simulator "seat time." The stand-up training covered the basic principles of shifting for fuel economy, and also emphasized the benefits of proper shifting techniques in reducing repair costs associated with the clutch brake and the transmission. The trainers added their own personal observations to the sessions, initiating discussions that helped to engage the interest of all participants. Each driver then had the opportunity to use the simulator for 15 or 20 minutes to practice the shifting techniques presented in class. A trainer coached them as they moved through the gears to the point where they could "cruise" along a highway with maximum fuel efficiency. Other driver trainees worked with the CBT program while waiting for their turn on the simulator.

The CBT reinforced the points covered in the stand-up lectures by offering "one-on-one" modules in which the trainees received instruction (via computer screen and headphones) and answered questions related to the training via on-screen testing.

The main points of the curriculum included:

- Knowing the relevant shift pattern.
- Starting the vehicle in lowest gear.
- Using the progressive shifting technique.
- Downshifting at the proper time.
- Using the tachometer and speedometer as shifting cues.
- Avoiding the lugging or over-revving of the engine.

The CBT covered techniques for reducing fuel consumption, including factors such as vehicle speed, engine idling, horsepower and torque, aerodynamics, and route planning. It also taught drivers how to accurately calculate their fuel economy, and explained how a driver's attitude and performance will affect fuel economy. It also covered using moderate speed, using the air conditioner only when necessary, using smooth starts and progressive shifting, maintaining a constant speed, keeping consistent space ahead of the vehicle to avoid excessive acceleration and deceleration, limiting stop-and-go driving, inspecting trucks frequently, and maintaining proper tire pressures. With the exception of the materials related specifically to shifting gears and using the clutch properly, this curriculum applies to drivers of A/T vehicles as well as M/T vehicles.

At the start of the course, each driver participant was asked to use the simulator to "drive" approximately half a mile, working his/her way through the gears to 60 mph, as a type of "pre-test." The trainer noted both the time and miles logged by the driver, as well as the fuel usage. Then at the end of the course, after each driver had participated in the classroom and the CBT and had the opportunity to apply what he or she had learned on the simulator, the driver took a "post-test" on the simulator. The post-test involved "driving" the 0-60 run through the gears as in the pre-test. The trainer noted the fuel consumed in the post-test, and compared that with the fuel used in the pre-test (these results are summarized in Table 2 on Page 18).

EVALUATING EFFECTIVENESS

With the recent investment in simulators, the obvious question is whether they are effective in training drivers for the real-world challenges they routinely face. The answer largely depends on the objective of the course and the corresponding focus of the training. The relative success of a simulator-based driver awareness course, for example, would be assessed in a manner quite different from that used to evaluate a course designed to teach drivers techniques for saving fuel and reducing drivetrain wear and tear.

In 1994, D.L. Kirkpatrick proposed a four-level evaluation model that could be used to measure simulator training effectiveness (Kirkpatrick, 1994). Table 1, below, is based on that model and highlights each of the four levels of evaluation:

Table 1. Kirkpatrick's Four-Level Evaluation Model

Level	Evaluation	Description and Characteristics	Evaluation Tools and Methods	Ease of Measurement
1	Reaction	How students feel about instruction	Survey, interviews, and focus groups	Quick, inexpensive
2	Learning	Measures increases in skills and knowledge	Pre- and post-test observation	Related to learning objective, may require complex test
3	Performance	Measures on the job performance	Observation, interviews, and supervisor ratings	Need cooperation and participation by supervisors
4	Results	Measures organizational benefits from training	Productivity increases	Estimates, data assessment

Evaluation approach to the ADOT FMDT program

The current project offers evaluations of the simulator-based FMDT course at all four levels. The Level 1 evaluation (Reaction) was conducted via surveys; the Level 2 evaluation (Learning) was based on measurement of learning as reported on the simulator; the Level 3 evaluation (Performance) measured fuel economy in a real-world driving environment; and finally, the Level 4 evaluation (Results) examined fuel and repair cost savings in the Globe District.

Each level of evaluation, and its corresponding results, is described in detail in Chapter III.

III. FINDINGS

This study employed Kirkpatrick's (1994) four-level evaluation model to assess the effectiveness with regard to fuel efficiency of ADOT's FMDT simulator training program. The findings of the study, noted below, are therefore framed within the four levels proposed in Kirkpatrick's model.

LEVEL 1: REACTION

As reported extensively in ATRC Report 585 (Kihl et al. 2006), much of the approach to evaluating ADOT's driving simulator training program has reflected a Level 1 evaluation. Obviously, the reaction of the drivers is extremely important when evaluating any training program, and that reaction has largely been positive (again, ATRC Report 585 includes detailed results). Most of the survey and focus group data is related to the driving awareness portion of the simulator training, though, and not the FMDT training specifically.

However, a focus group with drivers who had recently taken the June 2006 Globe FMDT simulator training revealed that they were very much aware of the fuel economy of their trucks after they had completed the course. Many reported that they applied the shifting techniques learned in class, and had demonstrated improved fuel economy — apparent evidence of positive transfer of training. Some had gone so far as to have informal competitions to see who can get the most mileage out of a tank of fuel.

In terms of this Level 1 evaluation, then, the driving simulator training for ADOT's snowplow operators was a success. The drivers were optimistic about the prospects for applying their training to the real world. There was, however, no way to follow up and see whether the drivers actually *did* apply their new knowledge while driving a snowplow.

Figure 2. Raw Fuel Economy Data Indicated on FMDT Trainer's Screen

LEVEL 2: LEARNING

This form of evaluation was first performed in 2006, with data from Globe's inaugural FMDT simulator training course, using the simulator to estimate fuel consumption for a specific driving task. As described in Chapter II, the trainees initially "drove" from a standstill to 60 mph, then stopped, as their "pre-test" run. They then took the FMDT class, with a focus on proper gear shifting. After the training, drivers again "drove" the zero-to-sixty run as a "post-test." In each case, the trainee's mileage per gallon was displayed, but only on the trainer's screen (see Figure 2, Page 17). Simulated fuel economy was expected to improve in the post-test driving scenario.

The results of ATRC Project 585 suggested some promising results in this area, although further work was recommended. For the present study, therefore, driver experience level was recorded for each driver — the thought being that perhaps new drivers might benefit more from the FMDT training than would veteran drivers. In fact, the results do not support this assumption. More curious, however, is the unexpectedly large variation seen in the results, as indicated in Table 2. (Indeed, it may be that this large variation, as discussed below, is obscuring any pattern that might exist in the novice/veteran data.)

Table 2. Post-Test Results of FMDT Training

District and Year	No. of Participants	Simulator Fuel Economy Measures			
		Average Post-Test Fuel Economy (MPG)	Average Fuel Economy Improvement * (%)	Minimum Fuel Economy Improvement* (%)	Maximum Fuel Economy Improvement* (%)
Globe 2006	50	2.3	9.6	-52	100
Holbrook 2007	18	3.6	44.3	-85	306
Flagstaff 2007	32	1.5	9.4	-42	190
Globe 2007	5	1.5	-14.4	-51	-2

* Negative values indicate that the fuel economy result decreased from pre-test to post-test.

The data compiled in Table 2 raise several questions. First of all, why is there such variation in the average post-test fuel economy numbers? For these trucks — making a single acceleration run from zero to 60 MPH — an average of 1.5 MPG (as was seen in the Globe and Flagstaff numbers from 2007) seems quite reasonable. Averages of 2.3 MPG (Globe 2006) and 3.6 MPG (Holbrook 2007) seem unrealistic.

Another question that the data raise has to do with improvement observed during the simulator training. The 44.3% average improvement recorded by the Holbrook drivers seems suspicious given the dubious average post-test numbers. Again, this seems to be related to a software issue, in which the fuel economy numbers continued to change well after the testing was completed.

The Globe 2006 and Flagstaff 2007 numbers, each just under 10%, would seem more reasonable, especially in light of the real-world testing conducted as part of this study, and described in detail in the next section.

Most curious are the Globe 2007 numbers, which would seem to indicate that the five newly-hired drivers' performance was actually *worse* after the FMDT training than before it. On the surface, this would seem to suggest a failure of the training, and yet the real-world fuel economy numbers from these same drivers suggest just the opposite, as discussed in the following section.

A closer review of the 2007 training activity points to some problems with the FMDT software updates, as well as possible training inconsistencies among the three active districts. These are precisely the kinds of issues that the ADOT Simulator Working Group (SWG) was formed to address (and will continue to do as the simulator training expands across the state).

It may be that the simulator software was the culprit in this case. In addition to the issue previously described (in which the fuel display's MPG numbers continue to accumulate after the test is completed), trainers also struggled during 2007 with an intermittent problem with the actual shifting of the simulator. It is also possible that the cause of these unexpected numbers is something as simple as not having adequate practice time in the simulator. Again, these are among the issues that are addressed in the recommendations of this report, and will continue to be addressed in the future by the SWG.

LEVEL 3: PERFORMANCE

This form of evaluation involves an assessment of the relative success in "transfer of training." That is, how well did lessons learned in the simulator-based training course transfer to the real-world driving environment? There is little in the literature documenting quantifiable transfer of training for driving simulators, although that is the stated objective of simulator-based driver training.

Some studies rely on the observations of supervisors, for example, but perceptions are difficult to measure. In 2006, Globe District supervisors enthusiastically reported that they had observed behavior changes in drivers who had completed the snowplow awareness course, but again, performance improvements were not measured.

Globe to Show Low Fuel Test Runs

The current project, by contrast, attempted to measure performance in a real-world driving environment. ADOT field staff and the ASU research team established a demanding real-world test route: a trip from the Globe maintenance yard to the Show Low maintenance yard and back (a four-hour round-trip of approximately168 miles). The route was through the Salt River Canyon, with a number of relatively steep grades and sections of winding road, as Figures 11-14 in Appendix D illustrate (pages 52-54). The same two snowplow trucks, a 1999 M/T Mack and a 2005 A/T Mack, were used throughout this part of the study. These two trucks were chosen because they had GPS telemetry and engine computers capable of recording key parameters including elapsed time, distance traveled, and fuel consumption.

Figure 3. Fuel Test Run on US 60 Near the Salt River Canyon

Each truck was "fully dressed" for the road test with ADOT's auxiliary salt bed liner and rear spreader, and, as Figure 3 shows, with the standard plow blade used by ADOT. Each truck was then loaded with 8,000 pounds of sand to represent the load of de-icer material typically carried during plowing, so that the truck's total gross weight was roughly 44,000 lbs.

Each of the five drivers[1] involved in this element of the study made four roundtrip runs. The first two trips were made prior to FMDT training (one trip in the M/T truck and one in the A/T truck) in the spring of 2007. The trips were then repeated (again, one trip in the M/T truck and one in the A/T truck) after the drivers had taken the FMDT training (described in Chapter II) in the fall of 2007. The expectation was that "real-world" fuel economy would improve after exposure to the FMDT training course. For comparison, two of Globe's experienced driver-trainers also made the initial test runs. Results of their performance, as a baseline, are included for reference.

Real-World Challenges

This study was plagued with the challenges often faced by such real-world research. The manual transmission trucks, for example, overheated, which forced the drivers to substantially alter their driving behaviors (either reducing their speed or pulling to the side of the roadway). During the "pre-training" trips, drivers of the automatic transmission trucks changed their behavior too, as they slowed to wait for their colleagues struggling in the trucks with manual shifts. During the "post-training" trips, however, this was not done, making a rigorous before-after comparison impossible.

[1] Six drivers took the training, but one left ADOT during the summer and was unable to complete the study.

In addition, the pre- and post-test runs were conducted over the course of several months (the pre-testing during March, July, and August of 2007; the post-testing during September of 2007). As such, ambient temperatures were not consistent (and in most cases, were not typical working temperatures for a fully dressed snowplow — a factor that likely contributed to the overheating of the manual-shift truck). Due to these challenges, and the small sample size, any conclusions must be considered somewhat speculative.

Fuel Economy Results

Despite these real-world challenges, however, this evaluation revealed some promising trends. Drivers of the M/T trucks, for example, demonstrated an average 4.5% improvement in fuel economy following their FMDT training, as can be seen in Figure 4 below. It should be noted, however, that these drivers were also receiving BTW training and driving trucks as part of the regular work for ADOT during the period between the pre- and post-testing. As a result, some of this fuel economy improvement may have been a result of on-the-road experience apart from the simulator training (although the extent is unclear).

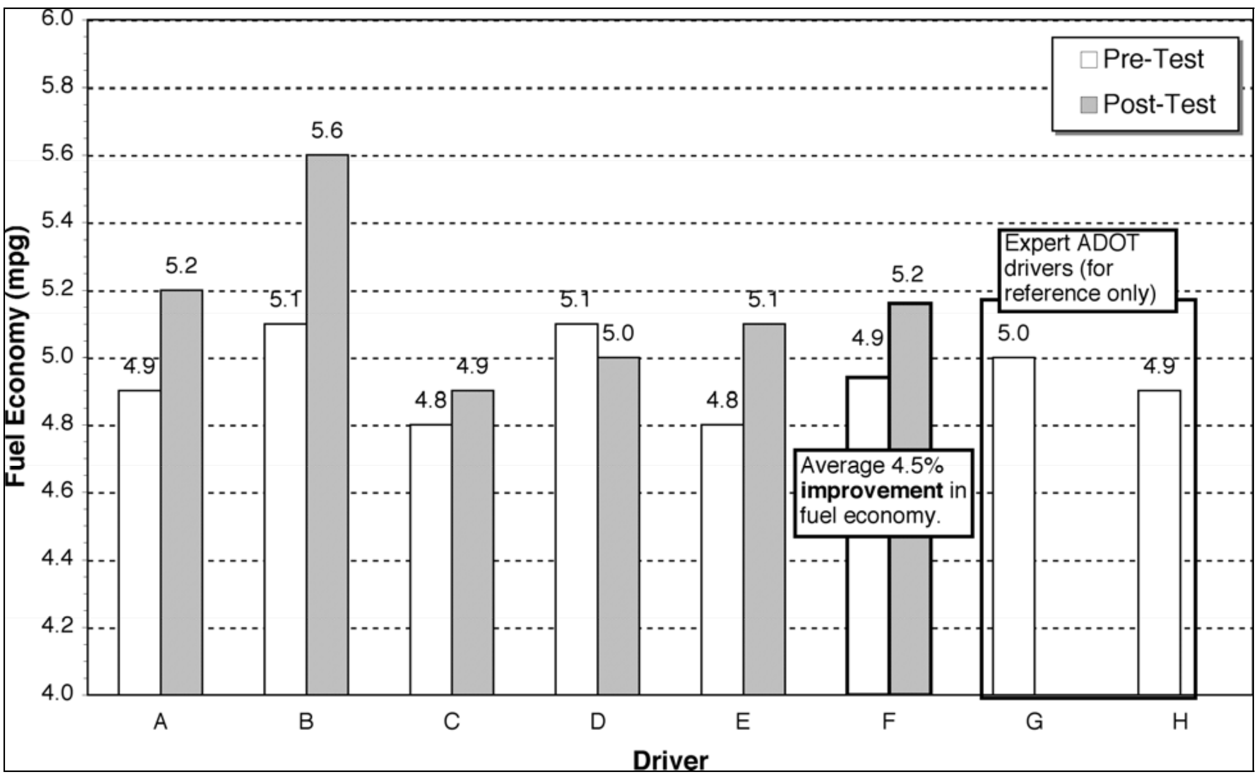


Figure 4. Globe-to-Show Low Evaluation Route — Fuel Economy (Manual Transmission Trucks)

Results for A/T trucks, on the other hand, (see Figure 5, page 22) indicate a 6.1% *decrease* in fuel economy following their FMDT training (it is interesting to note that in pre-training runs, some of the novices achieved greater fuel economy than the expert drivers). There are a number of factors that likely contributed to this unexpected result, as are described further below.

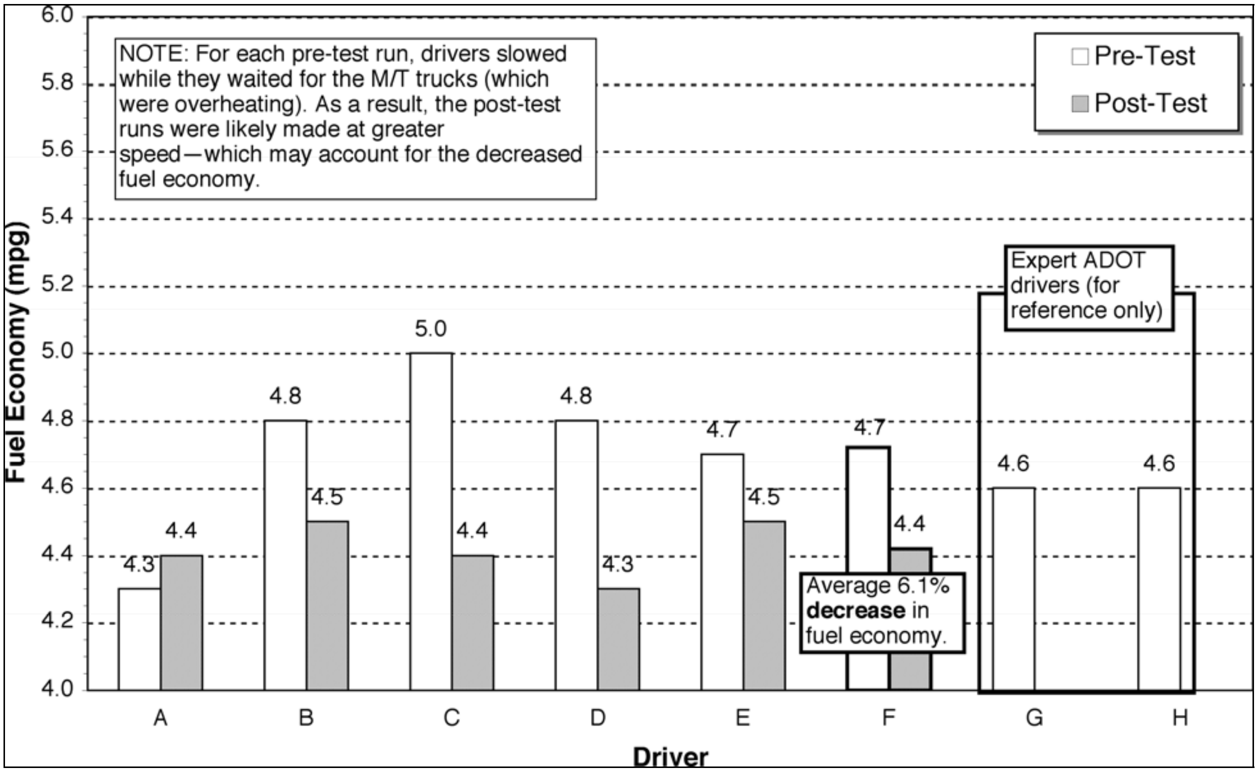


Figure 5. Globe-to-Show Low Evaluation Route — Fuel Economy (Automatic Transmission Trucks)

The decreased fuel economy measured in post-test runs for the A/T trucks is likely the result of increased vehicle speed, as opposed to any exposure to training (which, in any event, largely emphasizes proper gear shifting of *manual* transmission vehicles). Drivers of the A/T trucks agreed during the post-test runs to drive as they normally would, regardless of the overheating (and resultant slower pace) of the M/T trucks, and therefore were able to drive at a greater average speed.

LEVEL 4: RESULTS

Much of the driving simulator training literature relates to Level 4 evaluations. Studies that demonstrate successful training often point to bottom line expectations, the objective being to identify quantifiable findings that indicate benefits to the organization. For example, in the context of driver safety and awareness training, the benefits might be a reduction in the number, severity, and/or costs of vehicle accidents. It is possible for commercial trucking companies to gage benefits in terms of a reduced number of accidents and other types of quantifiable metrics. One agency using a mid-level simulator, for example, decreased trainee dropout rates by 35% (Brock et al. 2001). In another example, training time for bus operators enrolled in a simulator-based training program was reduced from 19 days to 17 days. Yet another transit agency with a driving simulator reported that 90 days after training, only 18% of the simulator-trained bus drivers had experienced a crash, as compared to 32% of conventionally- trained drivers (Brock et al. 2001). Bison Transport, a commercial transport company based in Winnipeg, Manitoba, reported that since 2002, when it began using simulators in its training effort, the annual accumulated safe driving miles for this fleet of 800 trucks has increased by nearly 30% (MPRI 2006).

Departments of transportation, however, rarely have similar quantifiable data available to demonstrate the benefits of simulator-based training, and the number of crashes involving heavy equipment is typically very low. For example, the number of crashes involving snowplows for a maintenance district in Arizona is in the range of only six to nine per year. Obviously, a single costly accident can dramatically affect repair costs for that year. This makes “bottom line” evaluations extremely challenging, as was reported in ATRC Project 585 (Kihl et al. 2006).

Aggregate Fuel Economy

Monitoring the bottom line associated with a FMDT course should, however, be more straightforward than with a defensive driving course. It was anticipated, for example, that fuel economy would, generally speaking, improve after drivers took the course. Monitoring fuel records is, however, more complex in a state DOT than it is in a commercial shipping company, as DOT drivers typically engage in a wide variety of tasks and use multiple types of equipment — all of which can change with the seasons and specific projects. These complexities (explained in greater detail below) made it difficult to parse the data in such a way that real differences might be seen in the pre- and post-training fuel economy numbers.

Study Period

The 61 drivers in the Globe District took the course in four-person groups over the period February to April 2006, with the majority of the drivers completing the course by the end of the first quarter, in March. Potential changes in fuel economy as a result of drivers putting their training into practice, would, therefore, have been apparent during April, May, and June of 2006 (Q2 2006), and in the following winter months of January, February and March 2007 (Q1 2007).

Table 3. Study Periods

Year	Pre-Training	Post-Training
2005	April-Jun (Q2)	---
2006	Jan-Mar (Q1)	Apr-Jun (Q2)
2007	---	Jan-Mar (Q1)

Obviously, the impact of the FMDT training ought to be evident year-round, but these quarters were studied most carefully because they represent consistent, intense working periods for these trucks (and also are the most recent for which data could be tabulated for this report). Table 3 illustrates the study periods used in the pre- and post-training analysis.

Truck Selection

The first step in this portion of the investigation was to select a number of trucks that would be studied in great detail with regard to their fuel economy. Initially, Globe District performance records were collected for each of the 53 M/T trucks assigned to the district during the 2005 to

2007 period. The data for 2005 reflected the performance of these trucks before the training course in March/April 2006. The data for the spring, summer, and fall of 2006 and the winter and spring of 2007 represent the period following the training course.

Over the 2005-07 period, a number of trucks were added to the Globe fleet, while others were transferred or withdrawn. Some trucks were heavily used in one year and had only limited use in another. As it was essential for this study to focus on trucks that saw consistent heavy use during 2005-07, a subset of the 20 trucks was selected for further study. The expectation was that because these trucks were used extensively for winter as well as summer activities, they would reflect an accurate snapshot of fleet fuel economy. ADOT provided detailed fueling and associated mileage data for each of these 20 trucks.

The subset of 20 trucks was further reduced — finally to ten trucks — during the process of trying to reconcile the two different data sets (one containing data for miles performed daily, the other, data for daily refueling). Complexities in matching the data files led to dropping out of anomalies. For example, some trucks were reported as generating a considerable number of miles, but lacked fueling data; others were fueled, but mileage data were not recorded. Nine truck records were considered outliers, and only those trucks with consistent fueling records over the two-year period were retained. That left 10 trucks for further analysis: F243, F294, F302, F313, F316, F334, F341, F344, F346, and F362.

Once these 10 trucks were selected for the study, the ASU researchers attempted to match miles travelled with the daily fueling reports. However, differences in data collection methods made it very difficult to match the daily fueling records with the monthly fuel and mileage reports. Of the 81 monthly fueling records reviewed (10 trucks over nine months, with some trucks having the occasional idle month) daily and monthly mileage totals matched in only seven cases.

The daily fueling meter records reported *more* mileage than did the monthly report for 25 of the "mismatches," and for 49 of the "mismatches," the daily fuel records reported *less* mileage than the monthly report. Although some detailed analysis was conducted (as described below), the level of detail was somewhat limited by these discrepancies between fuel records. Recommendations related to this issue are given in Chapter IV.

Aggregate Fuel Economy Results

Although the expectation was that an improvement in fleet fuel economy could be observed for the 10 study trucks, described previously after the FMDT training in Globe, this is not the case. For both Q1 and Q2 comparisons, the post-training mean fuel economy was actually less than the pre-training mean, although not at a statistically significant level.

Table 4 on the following page summarizes the mean fuel economy for the periods prior to and following the FMDT training.

Table 4. Aggregate Fuel Economy Results

StudyPeriod	Mean Fuel Economy and Standard Deviation (mpg)	
	Pre-Training	Post-Training
Q1	5.00 (1.69)	4.53 (1.39)
Q2	5.39 (1.66)	5.31 (1.18)

Of course, a number of factors may have contributed to this unexpected result. Despite efforts to minimize the influence of a number of external factors (e.g., road type, activity type, etc.), it should be noted that these numbers represent *aggregate* fuel economy. Included in them — and virtually impossible to parse out — are a range of weather conditions, road surfaces and inclines, activities, and so forth.

The actual loads on the trucks — and resultant fuel consumption — can vary considerably over the broad range of activities for which these trucks are employed. Finally, the source and quality of diesel fuel, which can also vary, may be a contributing factor. As such, it is nearly impossible to tease out "localized" improvements in fuel economy.

Nevertheless, a closer look at the aggregate fuel economy data, broken down by activities, reveals some additional — and potentially useful — information. Table 5 on Page 26 breaks this data down into five of the "high-mile" task activity categories, based on ADOT's Performance Controlled System (PECOS) work-effort database, and compares pre- and post-training quarters.

Again, the results are mixed (indicating increased post-training fuel economy for some task categories, and decreased performance for other categories), which may reflect the various external factors described previously. However, examining the data this way, it becomes apparent that activities often vary greatly by season. While this is hardly news to anybody involved in performing these activities, it quantifies the extent of these differences.

For future studies, these differences should be kept in mind. For example, although "routine maintenance" such as support of major highway reconstruction projects may account for many thousands of miles driven in some quarters of the year (making it an attractive category for studying fuel economy performance) that is not always the case, especially during the Winter months.

Table 5. Aggregate Fuel Economy by Work Activity Category

Activity Category (from PECOS)	**Before** FMDT Training		**After** FMDT Training	
	Q1 2006 Miles (MPG)	Q2 2005 Miles (MPG)	Q1 2007 Miles (MPG)	Q2 2006 Miles (MPG)
Non-Routine Maintenance	0 (N/A)	1,128 (4.9)	0 (N/A)	17,028 (5.5)
Support	6,390 (5.7)	7,484 (5.5)	276 (5.0)	4,149 (5.5)
Material Handling	203 (6.0)	1,398 (6.2)	1,417 (5.6)	1,911 (6.1)
Shoulders	6,973 (5.3)	1,835 (5.6)	487 (5.7)	3,218 (4.8)
Snow & Ice Control	20,852 (4.2)	107 (4.7)	27,527 (4.2)	815 (4.7)

Repair Costs Related to Driving Techniques

The FMDT training course emphasizes shifting for fuel economy, but also the benefits of proper shifting techniques in reducing repair costs associated with the clutch brake and the transmission. The instructor-led portion of the course, for example, includes tips on how to avoid premature wear-out of the clutch brake (a broken one is passed around the class, to reinforce this point). In a training session in Globe in early April 2006, participants shared stories of their struggles with the proper use of the clutch brake (several participants admitted to having broken one shortly after joining ADOT, in fact).

Simulator course trainees were informed how much they had improved in terms of shifting and fuel conservation, as was shown previously in Table 2. However, the simulator-generated reports that include data about brake and clutch usage have not yet been incorporated into the training sessions. Especially in light of the driver turnover rate, and the resultant large number of novice drivers in these training sessions, it may be worthwhile to use this data as immediate feedback for drivers. In fact, parameters could be set within the simulator software that would require a certain level of performance in order to "pass" particular portions of the simulator training.

Since all drivers in the Globe district took the FMDT course by the end of March 2006, it should be possible to assess the benefits to the district not merely in terms of fuel usage, but also in terms of repairs associated with the clutch brake and the transmission, although to what extent is unknown, as fuel economy was the primary focus of the training.

Repair records (2005, 2006, and January-June 2007) for the Globe District fleet were provided by ADOT Equipment Services. This allowed a comparison of the aggregate repair costs for two three-month intervals corresponding to periods both before and after the implementation of FMDT training. As was done with the fuel costs, it seemed logical to distinguish winter from spring driving for an assessment of repair costs, since the driving activities vary considerably by season. In the Globe District, for example, winter driving generally includes lots of plowing, while spring introduces a range of activity, often involving road maintenance and repair.

Specific driving techniques are, of course, only one of the many factors related to the frequency and extent of equipment repairs. The age, quality, and exposure of the vehicles themselves are also important factors. The trucks in the Globe fleet are relatively new and — due to the relatively light winters since they were purchased — have not, generally speaking, experienced severe usage yet. This made it quite difficult to assess “normal” wear and tear. In many cases, repairs to these trucks — especially if the repairs are substantial — are postponed until late summer, when the trucks are prepared for the upcoming winter season. In such cases, it is unlikely that any repairs would show up in records for the first and second quarters.

The data provided from ADOT Equipment Services (as shown in Table 6) suggest no reduction in transmission- and brake-related repairs in the three-month winter driving period from 2005 to 2007. In fact, there was a striking increase in repair costs in 2007, the year after the FMDT course was implemented. However, a closer look at specific repairs reveals that much of the increase in repair costs in 2007 can be attributed to transmission work totalling $3,267 for parts and labor on a single 1997-model truck. This unit had only recently been acquired from another district, and may have joined the Globe fleet on the verge of major problems; the technician that overhauled the transmission felt that improper shifting techniques caused the failure. Excluding that one substantial repair, the repair costs for 2007 would have been $2,286, a substantial reduction when compared the same period in the prior two years.

The costs of shop repairs in the spring months — April, May, and June — were consistently much lower than those associated with repairs made in the winter to maintain fleet readiness. There was, however, no reduction in repair costs either in spring 2006 (which followed the initial FMDT training) or in spring 2007. In fact, the spring 2007 repair costs exceeded those of the previous years, although still relatively low.

Table 6. Repair Costs Related to Driving Techniques: Winter and Spring Months, 2005-2007, Globe District

Driving Season	Repair Costs (Parts and Labor)		
	2005	2006	2007
Winter	$3,059	$3,107	$5,554*
Spring	$141	$627	$852

* Includes a transmission repair of $3,267.

Simulator Feedback

Again, at this time, the driving techniques feedback generated by the simulator (e.g., clutch usage, engine speed, etc.) is not being incorporated into the training sessions. This seems to be a missed opportunity. If a more integrated FMDT training program can assist in reducing costs for brake, clutch, and transmission repairs, then that would be a valuable contribution. In the calendar year 2006 alone, brake, clutch, and transmission repairs totaled approximately $17,319. As indicated above, the cost of one transmission replacement ($3,267) has a major impact on repair budgets.

There is an additional cost of repairs, too: the time when trucks are out of service. The one major transmission rebuild described above kept that truck in the shop for six critical weeks of winter - from February 5 to March 16. That is a significant opportunity cost. In the winter months, when it is essential that as many snowplows as possible are in proper working condition, an equipment repair could interfere with ADOT's commitment to keep roadways clear.

SUMMARY

The current study applied Kirkpatrick's four-level evaluation model to determine whether the FMDT training improved fuel economy in the Globe District. The results were mixed, as previously described.

At the Reaction level, the results look positive. ADOT drivers and supervisors in the Globe District report that the FMDT training has increased awareness and changed driving behaviors related to fuel consumption. At the Learning level, the results are similar to those reported in SPR 585 (Kihl et al. 2006), that is, some drivers improved while others actually performed worse in their post-test simulator scenarios.

At the Performance level, the results were promising, with drivers of the M/T trucks achieving, on average, a 4.5% improvement in fuel economy. And finally, at the Results level, the aggregate fuel economy for the 10 study trucks indicates no discernable difference between pre-training and post-training fuel economy.

IV. CONCLUSIONS AND RECOMMENDATIONS

The premise of the current study was that any post-training improvements to fuel economy would be evident in a review of the full fleet of trucks operating year-round in the Globe District. The results, however, suggest the fuel consumption picture is even more complex than was anticipated. Any potential reduction in fuel usage will vary — perhaps greatly — with a large number of external factors, including transmission type, age and condition of the truck, activities in which the truck is engaged, terrain, and road conditions, as well as the driving techniques of the driver.

The simulator is intended to address only one of these factors: driving technique. Although the literature does underscore the importance of driving technique, these external factors also play a role — a role larger, perhaps, in departments of transportation than in over-the-road trucking operations (the focus of many fuel economy studies). Unlike commercial vehicle operators, who drive largely along interstate highways with a standard vehicle carrying a regulated weight of goods, DOT operators drive a mix of vehicles, perform a variety of activities, and travel over roadways with a range of qualities. Accurate changes in fuel economy are, therefore, difficult to anticipate. Nevertheless, focusing specifically on the fleet of vehicles operating in the Globe District, and on operations in that district, did help, at least to some degree, to isolate the role that the drivers play in fuel efficiency and snowplow truck driveline repairs.

It also must be noted that fuel economy, however important, is secondary to public safety in terms of ADOT's mission. As was suggested in the Project 585 report (Kihl et al. 2006), the simulator is a promising tool for improving public safety by way of exposing drivers to risky real-world situations in the safety of the classroom. Obviously, there is no way to quantify the accidents avoided, but anecdotes from ADOT drivers and supervisors show that these drivers are putting into practice the safe driving behaviors they have learned during their simulator training.

POTENTIAL FUEL SAVINGS

Ideally, this study would have demonstrated clear fuel economy improvements at the Learning, Performance, and Results levels of evaluation. Although the results did not fully meet expectations, they do suggest areas of promise.

Level 2: Learning

The estimated fuel economy numbers documented during the FMDT training sessions indicate improvements for some trainees, and decreased performance for other trainees. This is similar to the results reported from Project 585. The large variation observed reveals the importance of consistent training equipment (hardware and software) and curriculum (training materials and the trainers themselves). This is one of the key issues to be addressed by the SWG.

Level 3: Performance

The improvement achieved in fuel runs by the drivers of the M/T trucks — an average of 4.5% — is substantial. If this were applied to all manual transmisson trucks in the Globe District, the potential savings become substantial. These savings would be even greater, of course, when all M/T trucks are considered across all of ADOT. In fiscal year 2006, ADOT purchased 1,079,068 gallons of diesel fuel, at a cost of nearly $2.8 million. Although these numbers are fleet-wide — and include all types of vehicles using diesel, including many A/T vehicles — it is clear that even a modest improvement in fuel economy has the potential to yield significant dividends, especially as fuel costs continue to rise.

Level 4: Results

Due to a number of factors that mask any improvements in post-training fuel economy (as were previously described), the results of the aggregate fuel study are largely inconclusive. Still, the approach taken has revealed some useful insights, as described in the following section.

RECOMMENDATIONS

Project 585, which considered the effectiveness of driving simulators for training ADOT's snowplow operators, distinguished between tactical training (training for large concepts, such as safety awareness) and operational training (training for more focused skills, such as improved driving techniques). That study concluded that simulators could be effective in training for both types of skill set, but that measures of effectiveness for each of these types of training would necessarily be quite different. Tactical training would best be measured qualitatively, while operational training could be effectively measured in quantitative terms. The current study supports this assertion, while at the same time highlighting some of the challenges involved in such quantitative assessments. Future related studies should therefore take into consideration the following recommendations.

Data Reporting

It became clear over the course of the aggregate fleet study that the ADOT systems used for recording fuel usage, job activity codes, etc., do not lend themselves to performing such analysis. Having separate systems (fuel numbers coming from one system and driver or vehicle information from another, for example), results in separate data sets, which are often difficult to integrate. A single, comprehensive — and user-friendly — system for reporting this important data would make it easier for all levels of ADOT to monitor fleet performance. Indeed, if the system were made user-friendly at the driver level (providing feedback on a daily basis, for example), vehicle operators would have a very real sense of their fuel consumption. The research suggests that improvements to fuel economy are more likely to occur when immediate feedback is provided.

Improved Gear Shifting

It was noted in the Project 585 report that drivers were not given enough practice time during the FMDT training, that "additional training is required to achieve over-learning." This factor almost certainly contributed to the rather uneven results for the current study. While veteran drivers may be able to improve their fuel economy with a quick refresher course, novices may struggle while they are attempting to master multiple new tasks, and they may be setting aside some bad habits at the same time. That is, they may very well get worse before they get better. Additional training time for those who need it would likely result in estimated fuel economy data with less variation.

The way the fuel economy numbers are "reported" by the simulator has been a source of confusion (at least with the latest software update from L-3). In the future, this issue should be addressed so that estimated fuel economy is a measure only of the trainee's performance, free from the influence of the trainer, software, etc. (indeed, the SWG is already aware of this issue and is pushing for its resolution). It may be desirable to have a single MPG number appear in large type on the computer screen at the end of each test run. This would not only eliminate any confusion about the performance of the trainee, but also has the potential to create some friendly competition (similar to what is accomplished with driving "rodeos") among the trainees, as each attempts to beat the "high score."

Obviously, there are numerous pressures on the drivers (and the field ORGs in general) to be productive; training requires the allocation of resources that might otherwise be applied to ADOT's core mission. Nevertheless, the investment in driving simulators has been substantial, and mistakes made by drivers in the real world can obviously be quite costly (with a single transmission rebuild in excess of $3,000). To reap the benefits of this investment, drivers must be allowed (perhaps *required*) to take the time necessary to develop real expertise in gear shifting technique. This is among the issues being addressed by the ADOT's Simulator Working Group (as discussed in Appendix B).

Expansion of A/T Training

Researchers observed that some of the experienced drivers engaged in the small-sample driver study used the transmission controls to override the programming of the automatic transmission (generally shifting into a lower gear than the one "selected" by the automatic unit). This raises a number of questions. For example, is this really "best practice," or does it reflect some lingering "urban myth" from earlier truck models about driving trucks with automatic transmissions? These units are becoming an increasingly large percentage of the ADOT truck fleet. And, where are these drivers getting their information about "best practices?"

With automatic-transmission trucks becoming more common within ADOT, it is worthwhile to consider how transmission override controls can be integrated into the simulator's FMDT program. At this time, the simulator acts as a three-speed transmission during the FMDT training (as opposed to the five- and six-speed A/T Macks in the ADOT fleet), as shown in Figure 6 on Page 32. Again, this training realism issue is among those being addressed by the ADOT's Simulator Working Group (as discussed in Appendix B).

Simulator Down Time

It was noted during the research that the simulator in Globe was frequently in need of technical support (similar problems were noted in Flagstaff and Holbrook). Screens were inoperable in some cases, as was the simulator's gear shifting software, an obvious impediment to FMDT training. Keeping multiple simulators running properly poses challenges for ADOT in general and individual districts in particular. This recent experience may support the argument for having fewer simulators that travel around the state (presumably all in proper working order), rather than many simulators located in each district across the state, although there are tradeoffs with either approach. A 24-foot self-contained simulator training trailer was purchased (at a commissioned cost of roughly $50,000) by the Flagstaff District in 2007, as an alternate concept for evaluation (see Appendix C); this issue is also discussed in some detail in Appendix A.

Figure 6. Simulator Display — Automatic Transmission

SUMMARY

Although none of the results reported to date provide clear evidence that the implementation of FMDT training in the Globe District has improved overall fuel economy for its fleet of large trucks, the study conducted *does* provide some valuable insights for making such improvements in the future. As was suggested in the Project 585 report, the greatest benefits will come from carefully integrating the simulator training programs into the larger ADOT training program.

Much of this integration has already taken place at the district level; future improvements will require greater accommodation at the management level. Among the key initiatives needed are:

- A state-level champion for simulator training.
- A completely new fuel usage reporting system.
- Formal recognition and incentives for the training Working Group.

Many of the recommendations from the 585 report have been or are being addressed, due in no small part to the efforts of the Simulator Working Group members. As they continue to address those issues, they will in addition be faced with implementing the recommendations of this study. Their progress to date suggests that ADOT’s simulator training program will continue to improve and yield a positive return (whether in quantitative or qualitative terms, or some combination thereof) on its investment. The activities of the SWG are discussed in detail in Appendixes A and B.

APPENDIXES

APPENDIX A
SIMULATOR WORKING GROUP & JOINT TRAINING

PROGRAM GROWTH: 2006-07

One of the most critical accomplishments of the ADOT Technical Training Group and their three current Maintenance District partners was to establish a Simulator Working Group (SWG) in early 2006, involving Globe, Holbrook, and Flagstaff training forces. Most recently, Safford has also joined the SWG, but they have not yet commissioned their new TranSim VS III simulator.

As was emphasized in recommendations by ASU for the earlier Project 585, it was imperative from the outset for ADOT management to coordinate a joint effort to standardize key elements of the simulator training program. Due to local factors specific to some districts only (e.g., terrain, traffic, weather conditions, etc.), each district would naturally have some individual issues, policies, and practices for winter maintenance.

However, as this simulator program was expanded, the Department also had a requirement to maintain certain core elements of the key training courses. There is a clear and obvious need for basic consistency of training across the state in both safety topics and good winter driving practices, and also in ADOT's fundamental principles of winter maintenance.

Training consistency is a key issue for ADOT. As it relates to winter operations, this consistency has a direct impact on the effective clearing and maintenance of roadways statewide (thereby reducing state liability and the risk of injury to persons or property along the highway system). Effective, consistent driver training is also a key factor in reducing engine and drivetrain repair costs to the truck fleet, and reducing fuel costs – both crucial issues for ADOT.

The Simulator Training Working Group

One of the most fundamental concepts of ADOT's 2005-06 simulator deployment was that the driver training was given by experienced snowplow operators from across the Globe District. These volunteer trainers were able to communicate their real-world experiences, from years of winter operations around the district, to the student drivers. Their enthusiasm and willingness to share their techniques and lessons learned made the program much more meaningful for the other Globe trainees.

This successful staffing approach was critical for the program's expansion in 2006-07. As two new L-3 simulators were deployed in 2006 to ADOT's Holbrook and Flagstaff Districts, a number of questions about direction had to be answered at the outset. Management from each district had to define their key goals and areas of concern, while at the same time recognizing ADOT's critical goal of consistency in the core training materials and content.

The Working Group concept also was crucial for the existing Technical Training program staff in each district. For these individuals, the simulator deployment, commissioning, curriculum development, and scheduling were a new responsibility, and at times a full-time activity.

The local training coordinators in each district were initially responsible for:

- Coordinating a suitable facility.
- The L-3 installation and train-the-trainer activity.
- The training material packages.
- The initial recruitment of volunteer trainers.

It was therefore urgent that in each district acquiring a simulator, the local and regional training staff would work together in each of these areas, following the Globe District model established in the previous winter. Their key challenges were to gain the skills and knowledge to organize the program, troubleshoot hardware and software, and create new course material (with occasional remote support from the L-3 technical team in Utah).

To some extent, each of the District training coordinators also had to educate their supervisors, managers, and the workforce on the program plans and anticipated benefits of this new training resource. They also required significant support from the maintenance managers in their districts to begin the process of recruiting volunteer trainers, with the attendant issues of scheduling group meetings, train-the-trainer sessions, and "homework" for these volunteers to learn and practice their new avocation — as simulator trainers for their peers.

Considering the many challenges noted, the makeup of the SWG required the prompt recruitment of volunteer trainers at the ORG level, to perform the day-to-day training of the workforce and thus to help share the greatly increased workload of the district training coordinators.

The Globe District program had recruited a group of five volunteer trainers in their first winter. With their local training coordinator, these trainers developed additional course material for the simulator training curriculum. This core group was drawn from the ADOT maintenance ORGs at Springerville, St. Johns, Show Low, and Globe. They served as hosts and mentors to the new Simulator Working Group, which met for the first time in Globe in August 2006.

Representatives from the Holbrook and Flagstaff Districts also attended the kickoff meeting. The initial group of 2006 volunteer trainers represented ADOT ORGs from Flagstaff, Williams, Page, Gray Mountain, Chambers, Holbrook, Ganado, and Keams Canyon. Since then, the group size has been generally steady, at about 16 to 18 (including both driver volunteers and district staff). Trainer turnover has been about 40 percent overall in roughly 15 months, due to factors discussed further in Appendix B. The Safford District also acquired ADOT's fourth simulator in 2007 and has joined the SWG, although their unit awaits completion of a permanent facility before trainers are recruited.

The SWG members normally meet every other month, with meetings rotating among the several district offices. These meetings involve progress reports on training performed, demonstrations and reviews of draft new training materials, and discussions of issues with hardware or software. Other topics include training progress, trainer status, peer-training challenges, and issues of management support. The meetings may also include internal training for L-3's Scenario Builder software, and discussion of possible new training topics relevant to the simulator, e.g., defensive driving. Management requests in this area are not unusual.

The 585 project noted that several senior Globe drivers with ten-plus years of experience had become excellent trainers, and their history of winter operations gave them strong credibility with new trainees. Conversely, the expansion of the SWG has shown that a number of younger snowplow operators, with good computer skills, have also become very successful trainers. Another lesson learned is that student response to receiving this training from their local peers — whether very experienced or not — has been very positive overall.

The Working Group Role: Focused Training

The Project 585 report noted that the initial 2005-06 training program in Globe was based upon the course materials furnished by L-3, but the volunteer trainers made changes in the handouts and PowerPoint material to better reflect local content, including policy and procedure topics, and plowing route information. For example, more discussion was added regarding awareness of the local communities' traffic signals and signs, an important issue in the Globe District's many small cities and towns. Trainees were also instructed to be alert to their truck's load weights, and the grades on the narrow, winding mountain roads in the district.

In addition to district-specific issues added to the curriculum, the 2005-06 training also reflected general issues of concern to ADOT. For example, Globe drivers were expected to follow the CDL checklist in inspecting their equipment before operating it. There was also additional discussion of the need for adherence to proper braking techniques, safety testing, and proper communication among drivers plowing in tandem.

With four ADOT districts now participating in the SWG, greater consideration can be given to potential new curriculum content related to local issues. However, the overall goal of core material consistency has been reviewed in each meeting of the SWG. For most SWG meetings, some senior operations staff of the hosting district will usually try to attend, and can provide their perspectives on statewide training goals.

There was some trial and error during the 2006-07 training courses, especially when it came to efficiently delivering all three courses to all operators. In a few cases, the safety (SIPDE), snowplowing, and fuel efficiency courses were combined into one all-day course to reduce the trainees' travel time. This approach had some success, but with a consensus among the trainers that the number of drivers must be reduced in order to deliver really effective training. Among the negative factors with full-day classes are allowing sufficient practice time for all, motion sickness, distractions, overload, retention, and even ventilation.

The SWG's Role in the Research Project

This 2006-07 training evaluation project has remained focused primarily on the first ADOT-owned simulator unit in the Globe District. As described earlier, all of the Globe snowplow operators received a half-day course of simulator training on fuel efficiency management and gear shifting in the spring of 2006. Then, as the 2006-07 winter season progressed, all newly-hired drivers in the Globe District also were given the FMDT training, with a combination of classroom and simulator seat time.

This program ensured that from 2006 to 2007, all Globe District drivers received very similar training. On this basis, the district's fleet of heavy vehicles could be monitored for average fuel consumption over the entire past year, as well as in the longer term against previous yearly averages, before FMDT training was available.

A key aspect of documenting the FMDT training was the recording of each driver's fuel mileage figures for his or her first simulator scenario run (pre-training) and then for a final run at the end of the session. These figures suggest a measure of the training course's effectiveness, as least in terms of *simulated* fuel economy. It is not clear, however, how well this might correlate to real-world fuel economy.

During the 2006-07 winter, the two new partner districts, Flagstaff and Holbrook, gave initial snowplowing and FMDT courses to their maintenance crews as well. Closely coordinating through the SWG, these district trainers also recorded each driver's pre- and post-training fuel figures on the simulator, as a further reference to the Globe District's results. Again, these estimated fuel economy numbers are thus far inconclusive, but it is hoped that with further training experience they can be used as measures of training effectiveness.

Figure 7. CDL Driving Course — Loading Dock Area

Working Group Enhancements to Training

Figure 7 shows a view of a virtual loading dock, part of the first completely new driver training course created by the SWG. This course is a commercial driver's license (CDL) orientation class, developed during summer 2007. One key accomplishment over the 2005-06 winter was the delivery of field training by L-3 for this Scenario Builder program, a powerful resource to create totally new customized courses for vehicle operator training. This enabled trainers to add new relevant situations into scenarios, or change the level of difficulty.

New maintenance workers have a deadline by which they must obtain their CDL in order to drive ADOT heavy vehicles. This new training course serves to orient them to the nature of the test by creating a virtual CDL driving test course, as shown in Figure 7, and all associated training materials. The CDL test involves tight maneuvers, backing to a dock, and working around fixed obstacles; the required lanes are defined by virtual cones.

These simulator scenarios are not replacing the CDL tests, but they allow practice drives without burning fuel or damaging the trucks or infrastructure; the course is given to new hires before they do any practice drives or take the actual test. The outline and simulator scenarios for this course were developed by the Flagstaff District trainers, with extensive peer review and input from the other SWG members over several months. The CDL course is in use by all three districts with currently-operational simulators (Globe, Holbrook, Flagstaff) for new maintenance personnel.

In addition, further work has also been done with elements of the FMDT training course, and to incorporate more useful information into the basic space-awareness and snowplowing training. The content of each course has been enhanced to some extent by SWG trainers. The have, for example, added photographs from actual local plow routes and district-specific topics to the PowerPoint slides and handouts, while still maintaining the core training elements. Review of other members' draft training materials is one of the ongoing roles of the SWG.

Another significant new training course is a half-day refresher course for all snowplow operators. As the pilot district for the program, Globe has taken the lead to develop the new refresher course, to include updated SIPDE, safety, fuel, and snowplowing elements. Project stakeholders agree that all drivers, once initially trained, should have periodic refresher training on the core elements of the basic courses. These courses should involve new material and are also likely to include significant upgrades from L-3. How often the training course should be delivered is still undecided, although a two-year interval has been proposed by the SWG.

The SWG has worked with L-3 to develop upgrades to the simulator's capabilities for more realistic training. For example, L-3 has added on-screen dashboard buttons to represent plow blade controls (up-down, left-right, and wing plow). There also is a button for the snowplow's deicing material spreader (although at this time the driver cannot see any material being applied). A radio microphone allows for radio traffic in the scenarios (e.g., the driver calling in vehicles off the road, calling for road and weather updates, etc.).

Training Facilities — Here, or There?

With snowplow simulators now established in four of ADOT's snow-country districts, the best approach to housing the current and future L-3 simulators is far from resolved. The evolution of thought within ADOT regarding the simulator training facility approach has been gradual, and regional, but the key factors and conclusions are not yet clear. Currently, the Globe, Holbrook, and Safford districts either have, or are waiting for, semi-permanent building accommodations.

The Flagstaff District chose to purchase a 24-foot self-contained, climate-controlled trailer in 2007, to deliver training to the more remote field locations (see Figures 8 and 9 on page 48, in Appendix C). While waiting for delivery, they actually began their training program in a tent, inside the Flagstaff maintenance truck barn (Figure 10, page 49, Appendix C).

The basic cost in the ADOT infrastructure system to prepare a new training building, or just an addition can easily be more than twice the $50,000 cost to commission a 24-foot trailer. Worse, the time to complete a fixed facility may be three or four times the delivery schedule for a trailer.

On the other hand, a training trailer requires a substantial tow vehicle (potentially dedicated to the task) to move it, not to mention the assignment of a driver. There is also the risk of damage or loss in an accident, or from travel vibration, wear and tear, moisture, dust, and temperature extremes. Additionally, other districts may ask to "borrow" the trailer — and the trainers.

Still, a fixed central facility requires significant time and travel for most of a district's trainees, sometimes creating schedule and resource conflicts with the workload at their home ORG. If only the primary trainer has to travel, that saves time and wages. As an additional factor, there is a positive perception that ADOT is committed to each remote rural ORG's workforce, when their district sends a mobile unit out to the field to give them these important training courses.

Because the locations vary so widely for district offices and satellite ORGs, this question may not have a single "one size fits all" answer. Either way, however, ADOT must be sure to provide the needed training resources, as well as strong support for the volunteer trainers.

APPENDIX B
PERSPECTIVES ON ADOT'S SWG CONCEPT

LONGER-TERM PROGRAM ISSUES

It is clear that the volunteer trainers of the SWG are the key to a successful long-term simulator training program, but there are real long-term challenges to this approach. While most trainers have excelled in their new role, there has from the beginning been some attrition from the group for a variety of reasons, not least of which are their overall workload as highway maintenance technicians and a need for recognition of their extra efforts.

Not everyone has the ability or temperament to be a trainer, regardless of his or her experience and talents as a snowplow operator. The challenges of working with the computers, the software programs, and troubleshooting of the L-3 hardware are additional issues for some otherwise very good candidates. Being the only peer trainer in a small local group also can create more stress for some, due to possible interpersonal pressures.

The varied roles of a volunteer trainer all combine to involve a great deal of work, both during the work week and sometimes after hours. Travel times across the district, and time required for preparation and for presentation of the courses, have been issues. Another factor is that the volunteer trainers are generally among the key personnel at their ORG, and are often critical to some highway maintenance activities from which they can't be spared. When a promotion occurs, such as to Leadman in an ORG, then that person may no longer be able to commit time to training. And as always, there is turnover from ADOT to other employment opportunities.

These factors are also real problems for the local training coordinators, for whom the program has created a greatly increased workload and level of responsibility. Additional tasks involve dealing with technical issues for the simulator system, the facility, and equipment (e.g., trainers' laptop computers). They also must balance the scheduling of both trainees and trainers, to ensure that their time is spent effectively.

SWG ASSESSMENT

The Simulator Working Group continues, individually and as a team, to aggressively address the short- and long-term recommendations made by the Arizona State University researchers as the outcome of Project 585. The most significant topics are described below, with perspectives from program stakeholders and sponsors on the progress made to date, and on further actions needed. Items in **bold** below have been acted upon, or are being resolved in 2006-07, by ADOT's SWG team, with support by the L-3 system design team. A few of the original ASU recommendations have been deferred, or deemphasized, or lacked clear sponsorship, and these are noted in *italics*.

<u>Project 585: Short-Term Recommendations</u>

1. **Complete a detailed needs analysis.**
   Needs assessment is a continuous SWG role, to identify specific training and procedural issues, and to refine the program to meet those challenges. The SWG trainer group has already evolved the standalone CDL orientation course in response to input from district management. Other new classes or enhanced training course elements are being planned.

2. **Make full use of capabilities of L-3 simulators.**
   This is an evolving process; some key enhancements have already been made with L-3's Scenario Builder course development tool. The SWG members and L-3 have collaborated on adding operational controls (blade, spreader), and have added two-way radio functions.

3. *Set a consistent (fleet) policy on type of vehicle transmission and potential fuel economy. (Future item?*) This requires more data analysis at ADOT's central level, to effectively and authoritatively compare both fuel usage and repair cost histories over the fleet's life cycle, for both manual and automatic transmissions.

   A related core training issue is to resolve the" best driving practices" for ADOT snowplow trucks, to improve fuel efficiency and to reduce fleet repair costs and downtime. ADOT Equipment Services must provide consistent direction to the SWG training team on *proper shifting of automatic and manual transmissions* in all conditions, with procedures that are integrated and consistent. These must be very specific, *from the vendor sources*, and must be mechanically and technically correct. District-optional policies and procedures should focus on snowplowing operational issues only, not on basic mechanical or technical requirements of the transmission, the engine, or other equipment's performance and operating limits.

4. **Capitalize on ADOT trainers.**
   Peer-level training is a core element of the SWG program; the use of experienced operators is the key to getting all levels of snowplow operators to give credence to the training program.

   A key problem with using local trainers is the time it takes them away from their primary maintenance functions. This is both a blessing and a curse — the success of the training hinges on the credence the trainees give to the trainers. However, the absence of a key resource does adversely affect the maintenance ORGs which depend on the field work of these trainers.

5. **Increase simulator seat time of new trainees; provide independent practice time for less experienced drivers.**
   Available training time is a real issue and with the simulator in one central location, travel is a factor also. Flagstaff and possibly other districts will use a trailer-based approach that may enhance their ability to provide more training opportunities to the field forces. Otherwise, it does not appear practical to give extra practice time outside the class session, due to the need for a trainer to be on hand to enable any practice sessions.

   Several options were tested among the three active districts to optimize the course length relative to the number of trainees. It became fairly clear over 2006-07 that a ratio of one trainer to two students, or four to five in a class with two trainers, was the optimum. Beyond that number, each extra trainee added an hour to the group's training class time.

   It was also found that combining several courses into a day-long class (to reduce driving and lost work time) was not practical. There was too much material and the focus of the training was dissipated; fatigue and occasional motion sickness were noted. The extra time to drive in to the training center also added to make it a very long day, with reduced effectiveness.

6. **Enhance course content to allow more practice on real-world challenges.**
   This is an ongoing effort, with course and scenario refinements by SWG; they have added CDL training for new-hires, and have increased the local content of the new snowplowing refresher course. This will be an ongoing goal to achieve real-world routes and more lifelike visuals. More realistic enhancements are needed to the cab configuration for plow controls, spreader controls, wipers, lights, etc.

7. **Focus the Driving Techniques course on functions related to all participants.**
   This is an ongoing effort, with course and scenario refinements by SWG. With L-3 support, they have added radio-traffic functions to the snowplow scenarios. The Equipment Shops and suppliers are being consulted on this to ensure that proper techniques are being practiced and taught by the class materials. The fuel efficiency figures derived from ASU's automatic transmission test runs show a possible breakdown of training on this very issue.

8. **Offer drivers documented feedback on performance in the Driver Awareness course.**
   This is an ongoing effort; one-on-one peer feedback and reinforcement is given by the SWG trainers. All training needs to be supervised, not only to ensure the consistency and the seriousness of the effort, but to care for the equipment and prevent errors or damage.

9. **Increase use of simulator-generated training-session performance reports.**
   This is an ongoing effort. The SWG made concerted efforts in 2006-07 to capture manual records of the trainees' before/after fuel-run mileage figures. Due to software problems and trainer multitasking issues, the fuel display data and resulting records were not consistent. The simulator also can track some safety or process errors by drivers, but the program does not relate to ADOT task and safety checklists. For both of these issues, ADOT will require formal L-3 support to refine the system to give accurate feedback on performance criteria.

10. ***Offer separate courses for experienced and less experienced drivers; offer an advanced class for experienced drivers.***
    (*Future item?*) Although considered by the SWG and management, there are significant benefits to having the trainee groups mixed. This exposes the new drivers to the experiences of the more seasoned operators, and also challenges the seasoned operators with the basic issues that may need to be remembered at the start of each snow season.

    There is still a need to continue to challenge experienced drivers with tactical situations, especially in the semi-annual refresher training course that is being developed. If ADOT does not continually enhance the features and scenarios, this training resource could become "old hat" for the more experienced operators. For the inexperienced new hires, the benefits will certainly be there, but they too will need a refresher class to retain the lessons learned.

11. **Incorporate references to de-icing in the Driver Awareness course.**
    This is an ongoing effort, with course and scenario refinements added by the SWG trainers. It is a critical statewide training consistency issue that will require management buy-in and direction to maintain efficiency, while always compliant with environmental constraints. ADOT de-icing training focuses on proper work methods within ranges of conditions, based on observed chemical performance, as learned and understood by operators and management. The trained operator is expected to make the right decision based on the conditions in the

field. This is a risk and takes follow-up and effort to teach and hold the operator accountable for his/her performance in the field. This needs to become a clear expectation which the operators understand, and that management buys into.

12. *Provide closer linkage in record keeping (e.g., fuel, PECOS, repairs, etc.)* *(Future item?*) This is a key concern, as demonstrated by the efforts of ASU to effectively relate different databases and software types to measure fuel and repair relationships to the 2006 pilot program of simulator training in the Globe District.

Project 585: Long-Term Recommendations

1. **Maintain state-wide consistency in simulator training.**
   Program and SWG sponsors have continually emphasized this key goal; as the program expands, the quality of the curriculum and the core elements of each course must be held to higher standards, to ensure optimal and equal training for the statewide ADOT workforce.

   Consistency should be a basic goal among all the Districts, just as it is for ADOT's Technical Training Group. Future enhancements should be evaluated by the program sponsors and added across the board if deemed appropriate; if not, they can still be additional or special training not required of all. The base curriculum should be maintained consistently, since sharing of snowplow operators is occurring more and more with today's limited resources.

   In the past, a lack of consistency sometimes led to repetitive or overlapping training. This reduced the attentiveness and willingness of personnel to participate, and to get full benefit out of these training efforts.

2. **Develop scenarios that reflect Arizona roadways.**
   This is an ongoing effort, with course and scenario refinements by the SWG over time. However, the issue of route realism has gradually faded, as the situational nature of the snowplow training courses is presented more clearly to students in advance of the class.

3. **Develop a scenario related to the wing plow.**
   The recent software upgrades by L-3 have added a new wing plow switch / button. The SWG has added emphasis on wing plowing into some lecture and scenario training materials.

4. **Modify simulator to include switches related to controls; add a switch to lift the plow; add a switch to apply deicing chemicals.**
   Recent software upgrades by L-3 have added, among other virtual features, a new spreader switch/button as well as plow-blade buttons/switches for up and down, left and right. Also, L-3 has added a new spreader switch/button, but there is currently no clear visual feedback to the driver of the materials as they are being spread.

Additional Notes - Significant Features

L-3 has recently added button or switch controls into the software of the 'glass dashboard' to enable several desired functions as noted above. However, the SWG further requests that future software show de-icing material being spread on-screen. Another key software realism issue is the obvious need for functional windshield wipers to operate realistically on-screen.

Also as noted above, there is a clear need for the simulator to accurately capture each driver's performance in key training areas, such as fuel efficiency runs and safety-related criteria, so that feedback on their fuel economy gains will become a reliable learning tool.

The SWG has also considered what may be done to improve fuel efficiency by giving immediate accurate feedback to drivers out on the roadway. On the simulator, the ability to show correct fuel consumption figures as direct feedback to the trainees is needed. In the real world, a fuel economy MPG readout would assist drivers of automatics, while having a shift-point light on the dashboard would help drivers of manual trucks.

SWG CONCLUSIONS

The SWG includes district training coordinators and local volunteer equipment operator-trainers. As of mid-2007, this group's work has enabled the successful field deployment of three ADOT simulators, and in 2006-07 the SWG has delivered three distinct core training courses to more than 100 equipment operators, including a large number of new hires. This program is enhanced by utilizing local-area trainers who not only relate well with their peer-trainees, but effectively mentor the newly hired workers, in the process.

The SWG volunteer trainers are the single most critical link in the training program. Their morale, motivation, and commitment to the task are crucial to the success of the program. Their willingness to make the extra time commitments needed — both on and off the job — is a key area of program vulnerability.

ITD management must be strongly committed to championing this program in the long term. They should provide compensation for skills and recognition for commitment, to include:

- A simulator-trainer stipend for training, travel, and preparation time.
- A training-skill upgrade in the overall pay grade.
- Recognition leave or compensatory-time payment.
- Considerations as above for the district training coordinator role, as well.

As for the best approach to staffing and housing the simulator facility, so far there is no clear answer. The Flagstaff trailer experience will be closely monitored as their program continues.

LONG TERM BENEFITS

Some of the key benefits to ADOT of this simulator training program, as regards safety and risk, cannot be effectively measured — they are the accidents, damages, injuries, and deaths that never occurred due to improved training of the snowplow operator workforce. Winter conditions in Arizona are widely variable but in recent years the number of fatalities attributed to snowy and icy roadways in the state has ranged between 7 and 14 annually.

The losses from a single fatality, or from the hundreds of injuries and crashes each year, put the costs of the simulator program and of reasonable incentives for the training force in perspective.

SIMULATOR PROGRAM VISION

In the view of the ADOT deployment sponsors, further attention to consistent training courses and strong program sponsorship absolutely must occur, at the highest levels of the Department, as the program expands from its 2007 level. At this point in the simulator training program's evolution, it is critical that someone with authority and credibility is identified to take command of these exceptional tools and maintain the effort and the focus.

As this ADOT training program has evolved over three years, the process owners at senior levels of ADOT's rural winter maintenance operations have become strong proponents of the snow-plow simulator training concept. Most of these key managers have, over time, given their full support to the local and district trainers of the Simulator Working Group.

As this study was being concluded, the vision of the program was effectively expressed in a memo to the research team by the Globe District Maintenance Superintendent, Joel Miller:

> "I truly believe the system is having a positive effect on our operators, and is reducing equipment neglect and abuse. I believe it is the best way to give exposure to winter conditions without placing the equipment at risk in the field, or exposing the new novice operator to the real dangers until they have some sound knowledge and skills."

> "This improves public safety and reduces our own exposure, even though accidents avoided can't be measured or quantified. How many wrecks have occurred during the simulator training that cost us no down time or injuries? How many lessons were learned without having close calls out on the roadway, rendering that operator less than confident, or even unwilling to do snowplowing operations?"

> "This is not a cure-all, but the benefits are great when developing the new and reinforcing the right operational practices and real-life possibilities that will be faced sooner or later in the field. The consistent and structured nature of the training helps make sure no points are missed, unlike what can occur with OJT with no outline to follow. ADOT needs a structured and maintained basic instruction program like this."

APPENDIX C

ADOT TRAINING TRAILER PROTOTYPE

Figure 8. Flagstaff Simulator Training Trailer

Figure 9. Flagstaff Simulator Training Trailer, Interior

Figure 10. Simulator Training in Flagstaff — Temporary Tent Facility

APPENDIX D

FUEL ECONOMY TEST ROUTE – US 60

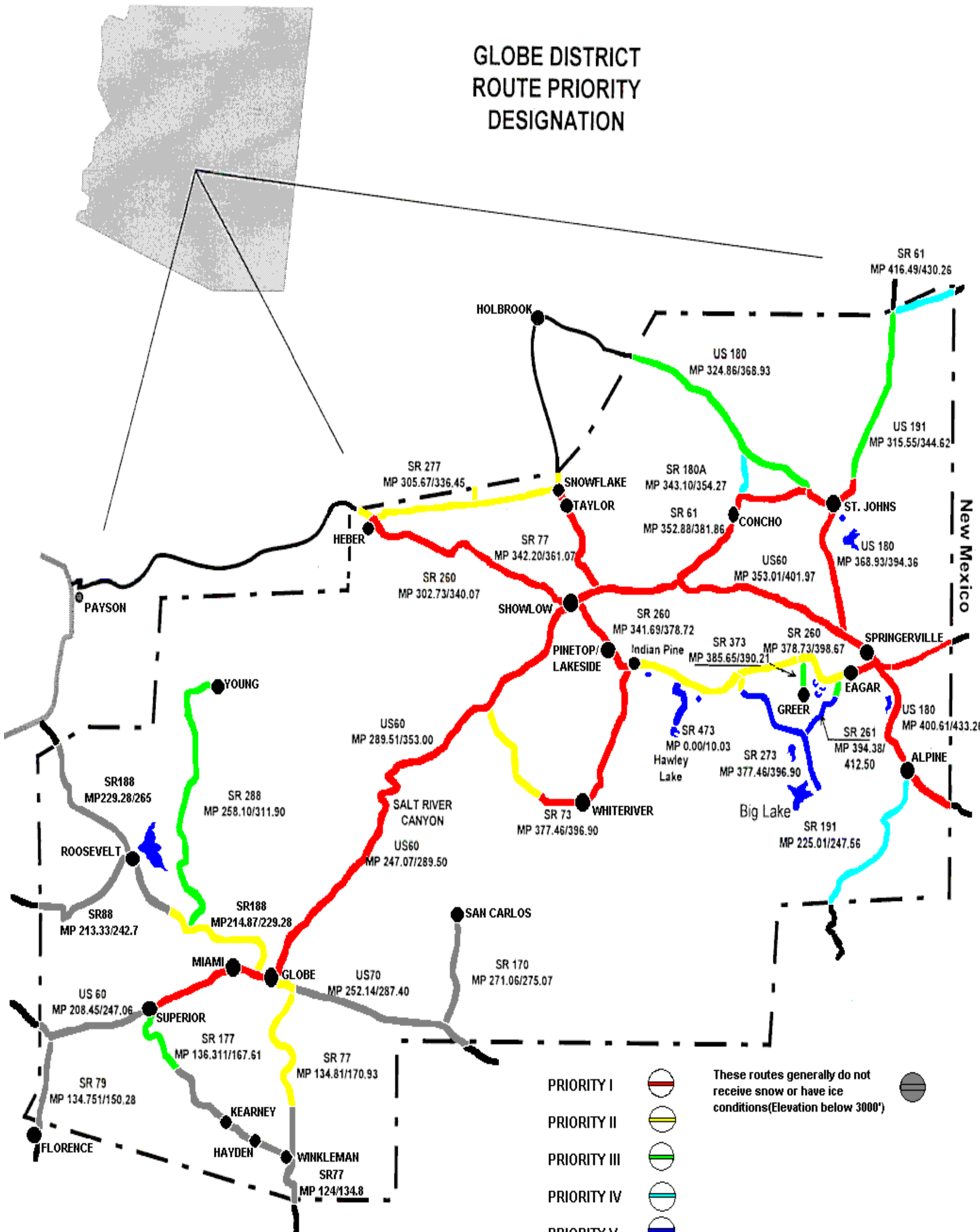


Figure 11. Globe District Snowplow Route Map

Figure 12. Globe Yard – Beginning of Fuel Test Runs

Figure 13. Approaching Show Low – Fuel Test Turnaround Point

Figure 14. Salt River Canyon Views – US 60

REFERENCES

Angelo, W. J. 2001. Training, Technology and Testing Take the Bite Out of Crane Operation. *Engineering News-Record* 247: 24. December 10.

ATA-American Trucking Association. 2006. Statement of Bill Graves, President and CEO, on White House initiatives to ease gasoline and diesel fuel price crisis, from website: http://www.truckline.com/cgi-bin/MsmGo.exe?grab_id=6&page_id=12845824&query=%246+6&hiword=%246+6+ (Oct 07)

Brock, J. F., C. Jacobs, H.van Cott, M. McCauley, and D. M. Norstrom. 2001. *Simulators And Bus Safety: Guidelines For Acquiring And Using Transit Bus Operator Driving Simulators.* Transit Cooperative Research Program Report 72. Washington, D.C.: Transportation Research Board, National Research Council.

Department for Transport (DfT), United Kingdom. 2004. *Review of the Road Haulage Modernisation Fund*. http://www.dft.gov.uk/pgr/freight/archive/rhmf/reviewoftheroadhaulagemodern3179 (retrieved October 2007)

Emery, C., J. Robin, R. Knipling, R. Finn, and S. Fleger. 1999. *Validation of Simulation Technology in the Training, Testing, and Licensing of Tractor-Trailer Drivers*. Washington, D.C.: Federal Motor Carrier Safety Administration. http://www.fmcsa.dot.gov/documents/tb00-007.pdf (retrieved October 2007)

e-Roadstar. 2005. Drive Right to Save Fuel [Electronic Version], from http://www.roadstaronline.com/2005/07/066a0507.asp (retrieved October 2007)

Florida DOT. 2007. Update on Highway Construction Cost Trends in Florida [Electronic Version], 7. From www.dot.state.fl.us/planning/policy/costs/Update-0407.pdf (retrieved December 2007)

Foss, B. 2005.Trucking Industry Embraces Training Simulators. *Boston Globe*, December 28: http://www.boston.com/news/local/connecticut/articles/2005/12/28/trucking_industry_embraces_training_simulators/ (retrieved October 2007)

Hoskins, A., M. El-Gindy, R. Vance, N. Hiller, and C. C. Goodhart. 2002. *Truck Driving Simulator Performance Effectiveness.* Paper presented at the ASME International Mechanical Engineering Congress & Exposition, New Orleans, LA.

Kihl, M., D. Herring, P. Wolf, S. McVey, and V. Kovuru. 2006. *Snowplow Simulator Training Evaluation.* Report No. FHWA-AZ-06-585. Phoenix, AZ: Arizona Department of Transportation.

Kirkpatrick, D. L. 1994. *Evaluating Training Programs: The Four Levels* (1st ed.). San Francisco: Berrett-Koehler.

Linck, W., B. Richter, and R. Schmidt. 1973. *Simulation and Measurement of Driver Vehicle Handing Performance*. SAE Technical Paper No. 730489. Warrendale, PA: Society of Automotive Engineers.

MPRI (2006). "MPRI and Bison Transport Combine Simulation Technology and Driver Training to Deliver Superior Safety Results and Fuel Savings" [Electronic Version], from http://www.mpri.com/main/newsroom/MPRIandBisonTransportCombi.html (retrieved October 2007)

Painless Haul-Truck Crashes. 2000. *Engineering and Mining Journal* 201 (9):130-132, September.

Parkes, A. M., and H. J. Rau, n.d. An Evaluation of Simulation as a Viable Tool for Truck Driver Training. from http://www.trucksim.co.uk/Documents/An%20evaluation%20of%20simulation%20as%20a%20viable%20tool%20for%20truck%20driver%20training.pdf (retrieved October 2007)

Quality Alliance Eco-Drive. 2002. "Eco-Drive Simulator Facts & Figures." [Electronic Version], from http://www.eco-drive.ch/en/02.html (retrieved February 22, 2006)

Roberts, M. 2004. Rising Gas Prices Have State Scrambling For Fuel Alternatives [Electronic Version]. *WRAL.com*., from http://www.wral.com/news/local/story/109343/?print_friendly=1 (retrieved December 2007)

Ross-Flanigan, N. 2002. New Driving Simulator. *Research Review* 33:1-5, April-June.

Smith System (2004). "The Right Foot Fuel Economy" [Electronic Version], from http://www.smith-system.com/driverslog.shtml (retrieved October 2007)

Strayer, D. L., and Drews, F. A. *Simulator Training Improves Driver Efficiency: Transfer from the Simulator to the Real World.* Presented at the Second International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design, 2003, Park City UT.

Strayer, D. L., F. A. Drews, and S. Burns. 2004. *The Development and Evaluation of a High-Fidelity Simulator Training Program for Snowplow Operators*. Report No. UT-04.17. Salt Lake City: Utah Department of Transportation.

Transport Research Laboratory (TRL), United Kingdom. 2005. Benefits of Truck Simulator Fuel Efficiency Training Revealed. http://www.trl.co.uk/press/press_detail.asp?pid=20&aid=94 (retrieved February 22, 2006)

U.S. Department of Energy (DOE). 2007. After Setting Records, Oil Prices are Projected to Decline. *EERE Network News*, from http://www.eere.energy.gov/news/news_detail.cfm/news_id=11413 (retrieved October 2007)

van der Voort, M., M. S. Dougherty, , and M. van. Maarseveen. 2001. A prototype fuel-efficiency support tool. *Transportation Research Part C* 9 (4):279-296, August.

Vance, R. J., M. El-Gindy, A. H. Hoskins, N. J. Hiller, and R. A. Tallon. 2002. *Simulator Training Evaluation Program*. University Park, PA: Pennsylvania Transportation Institute.

Wiener, E. L., and D. C. Nagel. 1988. *Human Factors in Aviation*. San Diego: Academic Press.