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16. Abstract

Increasingly, and especially over the last decade, U.S. trucking operations are favoring automatic truck transmissions over manual transmissions. Such growth has been the result of the various benefits that are associated with automatic transmissions, including reduced cost, better maintenance, and improved safety. With approximately 2,600 dump trucks in its vehicle fleet, the Texas Department of Transportation could potentially benefit from converting the current manual transmissions of these vehicles to automatic transmissions. Thus, this report (1) identifies, through a life-cycle cost analysis, the financial impact represented by the conversion to, and maintenance of, an automatic dump truck fleet (as against a manual-transmission fleet) and (2) analyzes the operational benefits of an automatic transmission dump truck fleet. The benefits described and discussed were identified from a literature review, from a survey of current practices in other states, and through interviews with selected fleet managers and vehicle operators.

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CONVERSION OF THE TEXAS DEPARTMENT OF TRANSPORTATION 6- AND 10-YARD DUMP TRUCK FLEET FROM STANDARD TO AUTOMATIC TRANSMISSIONS

by

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Rob Harrison
Mark Euritt

Research Report 979-1F

Research Project 3-4-90/0-979
Conversion of the Texas DOT 6- and 10-Yard Dump Truck Fleet
from Standard to Automatic Transmissions

conducted for the

Texas Department of Transportation

by the

CENTER FOR TRANSPORTATION RESEARCH

Bureau of Engineering Research
THE UNIVERSITY OF TEXAS AT AUSTIN

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PREFACE

This is the first and final report for Research Project 979, "Conversion of the Texas Department of Transportation 6- and 10-Yard Dump Truck Fleet from Standard to Automatic Transmissions." This research project was conducted by the Center for Transportation Research (CTR), The University of Texas at Austin, for the Division of Equipment and Procurement (D-4) of Texas Department of Transportation.

Specifically, this report identifies and discusses, with respect to current TxDOT operations, the costs and benefits associated with the purchase and operation of automatic truck transmissions. Using a life-cycle cost methodology, the costs of TxDOT conversion are first estimated. Next, a literature review, a survey of other state practices, and consultations with fleet managers and vehicle operators were thoroughly analyzed in the report's attempt to verify benefits such as might be available to TxDOT in their conversion from manual to automatic truck transmissions.

We would like to thank, first, the Texas Department of Transportation for their sponsorship of this project and, more specifically, several of the Division of Equipment and Procurement (D-4) staff members who assisted in various ways. We are particularly grateful to Glenn Hagler for his support and useful comments, Kirby Moore for his contributions to the development of the TxDOT equipment cost database, and Joe Howard for his help in carrying out the driver and use surveys.

Various CTR staff members also contributed to different aspects of the research. We are particularly grateful to Research Assistants Stephanie Ottis, Brad Sebranski, and Joel Tompkins for their contributions; System Analyst Terry Dossey for writing parts of the ANCOS program; and Ray Donley for his careful editing of the text.

José Weissmann
Rob Harrison
Mark Euritt

LIST OF REPORTS

Report 979-1F, "Conversion of the Texas Department of Transportation 6- and 10-Yard Dump Truck Fleet from Standard to Automatic Transmissions," by José Weissmann, Rob Harrison, and Mark Euritt, compares current manual transmission operational costs with the costs and benefits that might be obtained in converting the truck fleet to automatic-transmission operation.

ABSTRACT

Increasingly, and especially over the last decade, U.S. trucking operations are favoring automatic truck transmissions over manual transmissions. Such growth has been the result of the various benefits that are associated with automatic transmissions, including reduced cost, better maintenance, and improved safety. With approximately 2,600 dump trucks in its vehicle fleet, the Texas Department of Transportation could potentially benefit from converting the current manual transmissions of these vehicles to automatic transmissions. Thus, this report (1) identifies, through a life-cycle cost analysis, the financial impact represented by the conversion to, and maintenance of, an automatic dump truck fleet (as against a manual-transmission fleet) and (2) analyzes the operational benefits of an automatic transmission dump truck fleet. The benefits described and discussed were identified from a literature review, from a survey of current practices in other states, and through interviews with selected fleet managers and vehicle operators.

KEY WORDS: Automatic truck transmissions, Allison transmissions, truck safety, truck fuel costs, life-cycle cost/benefit analysis, driver fatigue, driver stress, driver attitude.

DEFINITIONS: *Workshop* - Repair facilities or district shops.
Gearbox - Transmission.

SUMMARY

This report identifies both the costs and the benefits associated with the conversion of TxDOT's dump truck fleet from manual to automatic transmissions. In estimating costs, a life-cycle cost methodology was used to analyze fuel and maintenance costs, vehicle service life, and comparative resale values at the end of truck service life. Benefits, on the other hand, were identified through a literature survey, a survey of other states' experiences with automatic transmissions, and interviews with fleet managers and vehicle operators.

On a purely financial basis, where the benefits are not quantified by monetary values, current repair and downtime annual rates of increase with vehicle age for manual transmissions need to be reduced by more than 22 percent for 6-cubic-yard automatic trucks and by more than 33 percent for 10-cubic-yard automatic trucks for these to outperform the manuals on an annualized cost basis. However, combining the quantitative analysis with the qualitative features of safety, driver morale, and driver recruiting and training significantly supports the case for adopting automatic transmissions in future purchases. The downtime and repair costs for the existing automatic dump trucks should be carefully tracked in order to allow comparisons with the calculated desired reductions of 22 percent for 6-cubic-yard automatic trucks and 33 percent for 10-cubic-yard automatic trucks.

It is also recommended that the financial model developed in this report be used for supporting any future equipment purchasing decisions in which two or more alternative vehicles are being considered.

IMPLEMENTATION STATEMENT

As this report will show, converting the Department's dump truck fleet from manual to automatic transmissions will provide several benefits. First, the Department will benefit from the potentially lower operating costs provided by automatic transmissions: current literature on maintenance expenditures suggests that automatic transmissions cost less per mile over the full service life of the vehicle. And because maintenance requirements are fewer for automatic transmissions, the vehicle is available for longer and more frequent service. Second, there are safety benefits associated with the operation of automatic transmissions. Automatics are less likely to induce driver fatigue and stress, thus promoting driver alertness (with a potential reduction in the number of accidents). Moreover, automatic transmissions allow drivers to concentrate more fully on driving and on operating ancillary equipment from the cab, thus increasing productivity. And while the conversion from manual to automatic transmissions is costly, a life-cycle cost analysis provided in this report will demonstrate that, over the service life of the vehicle, the additional cost of conversion could be justified if measured against the benefits gained.

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CHAPTER 1. INTRODUCTION

BACKGROUND

Increasingly over the last decade, U.S. urban trucking operations are favoring automatic over standard-shift transmissions, particularly in trucks involved in utility services. Several factors have led to the increase in popularity of automatic transmissions. First and foremost, automatics lead to reduced costs. Current literature on maintenance expenditures suggests that automatic transmissions cost less per mile over the full service life of the vehicle. Additionally, many sources report that manual shifting, particularly in multi-driver applications, gives rise to early replacement of other parts of the transmission system, i.e., drive shafts, bearings, back axles, and oil seals. Moreover, because automatic transmissions require less maintenance, the vehicle is available for service more frequently; commitment time, therefore, is higher. There are also safety benefits associated with the operation of automatic transmissions. Research suggests that automatics are less likely to induce driver fatigue and stress, thus promoting driver alertness and fewer accidents. Automatic transmissions also allow drivers to concentrate more fully on both driving duties and operating ancillary equipment from the cab. Consequently, automatic transmissions should, in theory, yield significant improvements over manual shifts.

The Texas Department of Transportation (TxDOT) currently operates approximately 2,600 6- and 10-yard dump trucks in its fleet of vehicles. Typically, these units are diesel powered, equipped with standard shift gearboxes (six-speed in the smaller vehicles and nine-speed in the larger trucks), and operate between 15,000 and 20,000 miles annually. Their service lives are about 10 years, equating to a lifetime mileage of 150,000 to 200,000 miles, depending on vehicle size. At the end of their useful service life, the vehicles are auctioned, with proceeds credited to the State Highway Fund.

In view of the possible benefits that could accrue to TxDOT, the Department is investigating conversion of current manual transmission vehicles to automatic transmissions on a large scale (currently TxDOT operates a reduced number of dump trucks equipped with automatic transmissions). The change to automatic transmissions, however, requires an increase in initial outlays: TxDOT staff estimates that it adds an additional $3,000 and $8,000 (in 1990 prices) to the purchase price of a 6- or 10-yard truck, respectively.

This study attempts to identify the costs and benefits associated with the utilization of automatic transmissions in TxDOT operations. A central feature of the study is the development of a life-cycle model to determine the change in truck service life that would justify the increase in initial capital expenditure.

OBJECTIVES

The TxDOT Division of Equipment and Procurement contracted in 1990 with the Center for Transportation Research, The University of Texas at Austin, to conduct a study evaluating the costs and benefits of converting Department trucks from manual to automatic transmissions. The research was guided by two basic objectives:

(1) Identify the financial costs of converting to, operating, and maintaining an automatic dump truck fleet in comparison with a manual transmission dump truck fleet.

(2) Identify operational benefits of an automatic transmission dump truck fleet.

Completion of the first objective required an analysis of the time value of money, operator training costs, fuel and maintenance costs, engine life expectancy, vehicle service life, accident rates, and comparative resale values at the end of the service life. Data were collected from TxDOT maintenance records and supplemented with data from manufacturers, other operators, and scientific literature. Accomplishment of the second objective required a thorough analysis of the literature on truck transmission operations, a survey of the experiences of other states using automatics, and consultation with fleet managers and vehicle operators on fleet operations.

SCOPE OF REPORT

This report is organized into seven chapters. Chapter 1 has provided an overview of the study and its objectives. Chapter 2 discusses the various benefits associated with the use of automatic transmissions. Most of the described benefits are based on information collected from an extensive literature review and through interviews with transmission manufacturer's agents. Generally, these benefits can be classified as operational, production, driver-related, and general safety-related. Chapter 3 briefly reviews the issue of truck safety, particularly as it relates to areas where automatic transmissions may be beneficial, including driver fatigue, boredom, stress and health, and cost implications. Chapter 4 reports on the driver attitude and use surveys conducted for the study. The utilization survey reports on four workshops where automatic-transmission trucks are currently employed. A second survey reports on driver's attitudes concerning truck design features, use of automatic and manual transmissions, and other issues. Chapter 5 introduces the life-cycle methodology used in the financial analysis. Data from the TxDOT maintenance files are used and, where possible, supplemented with information obtained from other sources. Chapter 6 presents the results of the financial analysis of the life-cycle costs. In addition to the financial analysis,. other benefits that are difficult to quantify economically are also described. Finally, conclusions and recommendations are presented in Chapter 7.

CHAPTER 2. OVERVIEW OF AUTOMATIC TRANSMISSIONS

BACKGROUND

A literature survey was first conducted to determine the impacts of specifying automatic transmissions for the Texas Department of Transportation (TxDOT) dump truck fleet. In that survey, four distinct subject areas emerged. The first area relates to available transmissions, developing technologies, and perceived needs of the truck transmission industry. The second subject area evaluates documentation of the Allison manufacturers' product line. The third area contains TxDOT and other highway agency documentation of experiences with automatic transmissions, as well as comparisons of automatic designs and other transmission types. Finally, in the fourth area, new developments in gearbox design (some of which use computer engine management systems to provide full vehicle electronic transmission control) are presented.

TRANSMISSIONS AND TECHNOLOGY

Within the trucking market, the three most popular types of transmissions are the manual, semi-automatic, and automatic. In 1978, it was estimated that the manual transmission controlled 97 percent of the medium- and heavy-duty truck market (Ref 1). Although transmission technology is continually advancing, the share of semi-automatic and automatic transmissions in the medium- and heavy-duty truck market is growing to the point that it is slowly overtaking the manual transmission market. According to Allison Transmission Division, U.S.A., total purchases of state government vehicles with Allison automatic transmissions have grown from 450 vehicles in 1985 (14.86 percent of the total government market) to 1,439 vehicles in 1988 (23.57 percent) (Ref 2).

The type of transmission being used in medium- to heavy-duty trucks has been shifting because of trucking-market demands for operating ease and efficiency. More specifically, the current issues in the trucking industry prompting this shift result from stricter engine-emissions standards, a shortage of skilled drivers, new electronic control packages, greater specialization among carriers, and fleet pressure to lower operating costs while extending component life (Ref 3). The chief reasons the automatic transmission has not been more widely used in the past in medium- to heavy-duty trucks are increased costs and technical difficulties. Yet as the intensity of the above demands has increased, and as automatic transmission technology has developed, automatics have come to the point where their increased cost counterbalances the human limitations in driving a truck fitted with a manual transmission. And with this shift, semi-automatic and automatic transmissions have emerged as the optimal response to market demands.

With advancements in vehicle electronics, control and monitoring of vehicle performance (with respect to loads, terrain, speeds, climates, and road conditions) have greatly increased. To achieve the advantages of the modern technology, though, it is necessary to integrate the vehicle engine, transmission, and rear axle so as to provide optimum performance (Ref 5). (The potential impact of electronic gearboxes is covered more thoroughly in Appendix A.)

The semi-automatic transmission is a manual transmission with mechanized gearing. Once the driver preselects the desired gear, the transmission automatically shifts itself. There are many companies which produce different versions of semi-automatic transmissions, including G.K.N.-S.R.M. in Europe (Ref 6) and Hino Motors in Japan (Ref 7). Various U.S. manufacturers include M.A.N. (Ref 8), Spicer Transmission Division of Dana Corporation (Refs 3, 9), Volvo GM Heavy Duty Truck Corporation (Ref 3), Rockwell International Corporation (Ref 3) and Eaton Corporation (Refs 1, 3, 10, 11). While each transmission-type differs slightly in specific features, they all use the same basic design concept. Of these companies, Eaton is the largest, producing 60 to 70 percent of the semi-automatic transmissions.

The automatic transmission, on the other hand, as its name implies, shifts gears automatically. Allison Transmissions division of General Motors, the manufacturer most often associated with automatic transmissions (Refs 1, 3), has been developing and producing truck automatic transmissions since the 1950's. The next two sections will more fully describe the workings and comparative performance of Allison products.

ALLISON TRANSMISSION UNITS

Brochures and articles on Allison products identified three commercial truck transmissions in the Allison family—the AT, MT, and HT. The AT transmission was designed for use in both medium-duty gasoline and midrange diesel engines up to 235 horsepower. Suitable vehicles include pickup and delivery trucks, small commercial buses and school buses, construction vehicles, and vehicles used in applications up to 30,000 pounds gross vehicle weight (GVW). The MT transmission was designed for use in heavier vehicles, including buses, rear dump trucks, transit mixers, refuse packers, and other severe service vehicles. It, too, is used with both gasoline and diesel engines, but can handle up to 250 horsepower, with a governed engine speed ranging from 2,400 to 4,000 revolutions per minute (rpm) and 73,000 pounds GVW. The HT transmission was designed for use in larger vehicles ranging in size from buses to line haul vehicles. It is primarily used with diesel engines of up to 445 horsepower and with a governed speed ranging from 1,900 to 3,000 rpm. Within each of the three categories of transmissions, there are several models providing different features.

In addition to offering over 28 transmission models, Allison also offers ancillary services to enhance motor performance and operation. The Allison Transmission Electronic Control (ATEC) is one such service. ATEC is a microcomputer that monitors transmission speed, throttle position and output speed, and selects the gear ratio and torque converter mode that provides the most effective vehicle operation. ATEC checks continuously for proper operation, notifying the operator if a problem is detected. Also available are several models of the Allison retarder, a powerful auxiliary braking device that helps keep vehicle operation under close speed control, especially on downhill runs and in heavy stop-and-go traffic situations. Allison also offers several models of Power Take-offs (PTO), which, according to the company, allow automatics to operate at vehicle speeds lower than is possible with manual transmissions, a benefit in many vocations.

Besides these optional features, Allison Transmission Division literature claims their transmissions will reduce driver training and stress (by simplifying the driving process), reduce maintenance costs (by eliminating clutch repairs), reduce shock damage to the drivetrain (thereby reducing downtime), and provide greater reliability and greater safety (by increasing traction and driver control).

TEST COMPARISONS

Several studies compared Allison automatic transmissions with other transmissions, as well as users' responses to the performance of Allison automatic transmissions. The earliest study, performed in 1975, was a 2-year Fleet Evaluation Program undertaken by Allison (Ref 12). This study was initiated to establish product acceptance, product durability, and cost comparisons with manual-equipped units. Initially, a survey was made of 17 line-haul fleets covering a broad range of vehicle duty cycles (varying climates, terrain, road conditions, and loads) and vehicle and engine makes. The survey found that there was high interest in the automatic transmission as a solution to manual transmission-related problems of electrical and engine component maintenance, high driver turnover, training difficulties, driver morale, and intentional driver-abuse of equipment. Some of the vehicles in these fleets were then fitted with Allison transmissions, for comparison with different makes of manual transmissions. Data collected included fuel consumed, monthly mileage, and operating and maintenance costs. Because the Allison transmissions were new to the trucking transmission field, the testing identified areas needing further development. Besides those needed changes, the data led to findings in four areas: operating experiences, maintenance, fuel economy, and durability.

Operating experience showed that the transmission was applicable for line-haul trucking by successfully negotiating and automatically shifting smoothly through the grades, braking on downhill conditions, and out-accelerating comparable manually equipped tractors. Operating experience also showed that automatic transmission prevents driver abuse of the clutch, excessive slippage or early engagement, engine over-speeding or lugging due to wrong gear selection, and excessive shock loading due to shifting. With regards to maintenance, it was found that automatic transmission maintenance costs were significantly less than those for the manual transmission for both engine and electrical components. But because the initial cost of an automatic transmission is higher than a manual transmission, the maintenance costs must be evaluated over the life of the vehicle to realize the full savings.

Fuel economy proved to be slightly better for the manual transmission. This led designers at Allison to make attempts at reducing the frictional horsepower losses in their automatic transmission, thereby reducing fuel consumption. Because the study was not over the life of the transmissions, transmission durability was not fully investigated. The transmissions that were examined, though, proved to be operating properly.

Overall, the results of the study were reported as being very positive, even influencing some fleet owners to include the Allison automatic transmission in their next purchase of line-haul tractors. Fleet owners and drivers alike were impressed with the performance of the fairly new automatic transmission.

A second reference was located describing the results of a test comparing an Allison AT 540 with a 5-speed manual transmission in similar vehicles (Ref 13). This testing was performed by the U.S. Auto Club (USAC) in 1977 on infield roads at the Indianapolis Motor Speedway. The test route, designed to simulate city delivery conditions, was run for 8 hours. With respect to fuel consumption, the results showed that the truck with the AT 540 transmission operated at 4.115 miles per gallon (mpg), while the truck with the manual transmission got 3.950 mpg. The truck with the AT 540 transmission traveled 189.88 miles in 8 hours, while the truck with the manual transmission traveled 187.71 miles. Significantly, the driver of the truck with the AT 540 transmission only shifted 8 times, while the driver of the truck with the manual transmission shifted 2,345 times. Calculating these savings over 5 years, it was reported that, even when accounting for the additional cost of an automatic transmission, the automatic transmission saved $349. These savings did not take into account increased productivity, freedom from excessive downtime, better driver performance, or safer handling.

The two vehicles were also tested for their responses to adverse situations. On hills, the truck with the AT 540 transmission started out much smoother (without rolling backwards or bucking). The shock on the drive line, also measured in this situation, was found to be 200 percent greater for the truck with the manual transmission than for the truck with the AT 540 transmission. In mud, the truck with the AT 540 transmission was also found to move much more easily than the truck with the manual transmission. Overall, this test showed that the AT 540 transmission outperformed a comparable manual transmission with respect to economy, productivity, and protection of the drive train.

In 1977, J. C. Penney performed an in-house study (Ref 14) to evaluate the practical and economic justification for introducing the Allison AT 540 automatic transmissions into their delivery fleets, and to recommend a proposed course of action to the non-resale purchasing department. In their study, they determined that the quantitative data gathered and analyzed for the economic justification of the Allison AT 540 transmission over a manual transmission were inconclusive, although the qualitative data heavily favored the automatic transmission. Overall, the recommendation was to implement the Allison AT 540 transmission for the delivery fleet.

The quantitative issues included gasoline usage (in miles per gallon) and maintenance costs. It was found that trucks using the AT 540 transmission operated at 0.6 miles per gallon less than the trucks with manual transmissions. On the other hand, the Allison AT 540 maintenance costs (0.39 cents per mile) were less than the manual transmissions maintenance costs (3.5 cents per mile). It was also noted that the truck with the manual transmission was down 58 to 60 percent (approximately 8 days) more than the truck with the automatic transmission.

The qualitative issues that arose came from companies that converted to Allison AT 540 transmissions. First, mechanics noted that when repairing the drivetrain (drive lines, U-joints, clutches, axle shafts, pinion bearings, transmission bearings, and gears), the parts in trucks with manual transmissions often showed signs of excessive strain. This is because in a manual transmission the driver controls all functions; consequently, the risk of component overloading increases. The automatic transmission, on the other hand, acts as a safety valve and will not overload the components. By converting to the Allison AT 540 transmission, the responding companies noted three benefits: There was a reduction in drivetrain component costs, an increase in productivity, and an increase in driver ability to cope with the varying speeds on city streets and freeways.

Another test performed by Detroit Diesel Allison evaluated the fuel economy of an AT 545 (with the new TC 290 torque converter) against a 5-speed manual transmission. Each vehicle was given an equal work load and equal tasks (Ref 15). The first half of this test took place on the GM Proving Grounds in Milford, Michigan. Each truck was driven 390 miles, 60 percent under city conditions calling for acceleration to 20 mph and stops every 0.10 miles, and 40 percent at a constant speed of 35 mph. It was found that the truck with the AT 545 transmission got an average of

8.83 mpg, while the truck with the manual transmission averaged 8.36 mpg.

Further testing took place at the GM Desert Proving Grounds in Mesa, Arizona. Each truck, fitted with a pre-weighted auxiliary fuel tank, ran a 4-hour, 100-mile duty cycle on 4 consecutive days. In the first part of this test, the trucks accelerated over 300 times from 0 to 20 mph at 0.10 mile intervals, then were accelerated to a constant speed of 40 mph for the remainder of the test. Upon completion, the auxiliary tanks were again weighed and the results calculated. Table 2.1, providing a summary of the results, shows that the AT 545 transmission had better fuel consumption than the manual transmission.

Table 2.1 Arizona tests fuel economy summary

	5-Speed Manual		AT 545 Automatic		
Day	Fuel Consumption	Fuel Economy	Fuel Consumption	Fuel Economy	% Improved
1	12.2 Gal	8.2 MPG	11.3 Gal	8.8 MPG	7.3
2	12.3 Gal	8.1 MPG	11.5 Gal	8.7 MPG	7.4
3	12.3 Gal	8.1 MPH	11.7 Gal	8.6 MPG	4.9
4	12.5 Gal	8.0 MPG	11.8 Gal	8.5 MPG	6.3

Although not specifically about transmissions, another article discussed pick-up and delivery vehicle maintenance costs (Ref 16), making several relevant points regarding automatic and manual transmissions. In the range of 25,000 to 50,000 miles, the manual transmission is the second highest cost component, at 0.028 cents per mile. In the range of 50,000 to 125,000 miles, the automatic transmission is the second highest cost component, at 0.021 cents per mile. When observing the frequency of repair, the manual transmission dropped to sixth place, in the 25,000- to 50,000-mile range, making up 6.9 percent of the repair costs. The frequency of automatic transmission repairs did not represent a significant portion.

Although none of the above articles was directed specifically at the use of automatic transmissions in dump trucks, their results paralleled the conclusions drawn by the Equipment and Procurement Section of TxDOT when they compared Allison transmissions with manual transmissions in identical dump trucks (Ref 17). A total of 30 trucks were looked at in four districts (Wichita Falls, Lubbock, San Angelo, and Austin). Four were 1981-model, 10-yard dump trucks with a 6V-92 DDC engine, averaging 115,538 miles of use (one automatic, three manual). Nine were 1986-model, 6-yard trucks equipped with the 8.2T DDC engines, averaging 46,575 miles of use (three automatic, six manual). Seventeen were 1987-model, 6-yard trucks equipped with 8.2T DDC engines, averaging 25,093 miles of use (five automatic, twelve manual).

Comparing records on these vehicles, it was found that the one 1981 10-yard truck equipped with an automatic had a maintenance savings of 5.87 cents per mile and a fuel cost of 0.11 cents per mile, resulting in an overall savings of 5.76 cents per mile over the three manual transmission models. The three 1986 automatic models had a maintenance savings of 2.34 cents per mile and a fuel cost of 1.15 cents per mile, yielding an overall savings of 1.19 cents per mile over the six manual transmission models. The five 1987 automatic models had a maintenance cost of 2.05 cents per mile and a fuel cost of 1.84 cents per mile, giving an overall cost of 3.89 cents per mile over the twelve manual transmission models. These numbers suggest that as the trucks' usage increases, the maintenance costs for the automatic models, though starting off higher, become the more economical of the two transmissions.

The District Equipment Supervisor for each district also made comments concerning equipment utilization. Each District Equipment Supervisor indicated a strong preference for the automatic transmission because of its versatility, all-around performance, economy, and safety. Superior performance was especially indicated when used in slow-moving operations (e.g., crack pouring, snow-ice removal, and herbicide application), when working in rough off-road terrain, and also when using inexperienced drivers.

Even though trucks with automatic transmissions are favored in adverse circumstances that increase fuel and maintenance costs, the trucks with the automatic transmissions actually showed lower maintenance costs. The supervisors also felt that low-speed use of the trucks with automatic transmissions explained the higher fuel consumption. There were also inferences that two recent accidents might have been caused by gear-shifting problems. Overall, it was felt that automatic transmissions in diesel dump trucks represent a satisfactory, practical, and economical option.

The literature search confirmed the growing preference for automatic transmissions in both state DOTs and federal agencies: all Pennsylvania Department of Transportation vehicle purchases for the last 3 years have been for automatics; Illinois department purchases have been 100 percent automatic for 15 years; Florida and South Carolina department purchases have been 100 percent automatic for the last 3 to 4 years; departments in New York, New Jersey, Kansas, Indiana, and Michigan are all large users of Allison transmissions; and all federal government and military vehicles have been 100 percent automatic for the last 8 to 10 years (Ref 18).

Ron Evert, former Wisconsin Highway and Transportation Department Shop and Equipment Superintendent, said that although the initial costs were higher, over the long run the economics are more favorable for automatic transmissions. He also noted the following attributes of automatic transmissions: (1) fewer drive line repairs, because the automatic transmissions apply torque smoothly and prevent shock; (2) less downtime, since there are no clutch maintenance problems, adjustments, and replacements; (3) longer engine life, because the engine does not lug or overspeed, thereby protecting all components; (4) more efficient use of engine power and fuel; (5) reduced driver fatigue and increased safety, because the driver is able to concentrate on driving and not on shifting; and (6) increased driver and vehicle productivity (Ref 19).

Willis Howe, Manager of Equipment Services in Mobile, Alabama, expressed similar support for automatics. Mobile has used Allison automatic transmissions for 12 years, citing in particular their good performance and maintenance record (Ref 19).

Winfred Thomas, Service Manager for Greensboro, North Carolina, has also found that automatic transmissions withstand strenuous loads longer, while reducing driver work, downtime and maintenance costs. The city of Greensboro, having used Allison automatic transmissions with good success for 10 years, now equip all new vehicles with automatic transmissions (Refs 19, 20).

Automatic transmissions are also proving adequate for use in school buses. South Carolina is the first state to have a 100 percent automatic transmission-equipped school bus fleet. According to South Carolina transportation officials, buses with automatic transmissions were popular with drivers, provided easier driver recruitment and training, contributed to safer vehicle operation, required fewer spare buses, involved much less downtime, and reduced damage to other drive line components. South Carolina's experience demonstrated that, with a manual transmission, a minimum of one clutch and pressure plate can be expected to be replaced each year, while a bus with an automatic transmission will average 60,000 miles or approximately 6 years of service before needing a comparable repair (Ref 21).

In evaluating the ATEC system, Allison engineers conducted a Type II Fuel/Performance Test in which the performance of ATEC was compared with Manual Electrics control (Ref 22). The off-road test was performed at Lone Star Industries, a plant and quarry which produces cement products in Greencastle, Indiana. The test route was 1.9 miles long, with three major grades ranging from 9 to 12 percent. Each test run consisted of four complete laps of the test route, including an idle time (to simulate loading) and a running time. At the end of a test run, the fuel was weighed to determine fuel consumption. Results showed that with ATEC fuel economy was 12.2 percent better than the Manual Electrics, and cycle time was improved by 2.4 percent.

Today, there is strong employer emphasis on reducing stress in the workplace. One reason for this is that mental disabilities related to stress currently amount to 11 percent of all workers' compensation claims. Recently, Allison Transmission Division has been involved in studies examining truck driver stress and fatigue as an economic, safety, and legal issue in the trucking industry (Ref 23). Stress resulting from truck operation has been determined to be a product of several factors, including the size of the truck, its lower degree of maneuverability, and its more complex operation. The sources of stress in trucking include dense traffic, freeways and expressways, difficult environments, tight maneuvering, and limited driver experience. In each of these situations, an automatic transmission greatly reduces the demands on the driver by eliminating shifting and clutch operations.

The stress test conducted by USAC in conjunction with Allison Transmission Division compared the measured stress involved in driving a manual versus Allison automatic medium-duty truck in real-world, day-to-day driving conditions. Three hour-long courses were laid out to simulate a typical cycle for a number of different vocations; challenging terrain and demanding driving conditions were also included. The trucks used were identical except for transmissions, and identical twins were used to drive the two trucks. The courses were driven three times a day over a period of 8 days, switching drivers on alternating runs so as to eliminate possible errors. Electronic equipment was used to monitor the drivers' reactions and heart rate; diastolic and systolic blood pressure were checked every 5 minutes. By sending the trucks out together, along the same route repeatedly during various times of the day, USAC was able to get a statistically reliable measure of the stress produced within a wide range of situations. Following the test, the driver of the manual transmission truck showed an average of 16.49 percent higher systolic pressure, an average of 13.79 percent higher diastolic pressure, and an average heart rate 10.98 percent higher than the driver of the truck with the Allison automatic transmission. It was also found that after an initial orientation period with the trucks, the stress levels of the driver of the truck with the Allison automatic transmission continually fell, while the stress levels of the driver of the truck with the manual transmission continued to increase. The researchers concluded that there was a relationship between the type of transmission and the level of stress experienced by the driver.

ELECTRONIC GEARBOX

A recent evaluation of automatic transmissions in long-haul trucking (Ref 24) has been reported using data from a group at the University of Michigan (Ref 25). TxDOT trucking needs do not extend to long-haul trucking, but the Michigan report details some valuable information concerning, first, the technical differences between a range of automatic designs, and, second, the potential benefits from a specific type—the electronically controlled manual transmission. Based on this report, four observations can be made:

1. There seems to be an established market for automatic transmissions that has been well documented for at least 20 years. Research in the 1970's of companies with 2 years of use with the Allison HT 750-CRD showed that, compared with manual units, automatic transmissions:
   - allowed better acceleration from rest,
   - provided uninterrupted power flow while shifting,
   - prevented over-speeding or the lugging of the engine,
   - reduced engine maintenance,
   - controlled driver errors more effectively, and
   - improved safety by allowing the driver to keep both hands on the wheel at all times.

   Some of the deterrents to the adoption of automatic units included:
   - high initial cost (at least $7,000 per unit compared with conventional 13-speed),
   - higher maintenance costs from: (1) engine/transmission linkage adjustments, (2) transmission cooling problems, (3) frequency of oil changes (56,248 manual vs 36,035 auto), and (4) lower fuel efficiency (3.93 versus 4 mpg),
   - product complexity and mechanic unfamiliarity, and
   - low engine power.

2. Current use of automatic transmissions is negligible because of high initial cost and apparent expensive maintenance. A major reason restricting the adoption of automatic gearboxes is cost: Current hydraulic automatic transmissions cost at least $7,000 more than conventional manual transmissions. Therefore, whereas a typical 13-speed manual transmission costs approximately $1,600, almost $9,000 is required for an automatic hydraulic 5-speed. In addition to these reported costs, the recent bid for TxDOT 10-year dump trucks resulted in even higher costs (approximately $10,000). Manual transmissions are extremely rugged, having an expected life of 500,000 miles. Truck clutch life depends on use and terrain, and the cost for a clutch is approximately $350 for parts and almost $400 for labor. The small number of automatic transmissions in actual operation makes comparative analyses very difficult.

3. Electronically controlled "automatic" transmissions appear to solve both these cost and maintenance problems. Conceptually, this transmission is a manual gearbox and clutch unit controlled by a microchip and other circuits, rather than by a driver. It requires a fairly complex control system to determine the proper gear match of truck speed and engine/torque characteristics. This matching is performed using various sensors that send information to a microcomputer, which analyzes the data and instructs a shifting mechanism of electronic solenoids connected to air or hydraulic cylinders that activate the gearchange. It has all the benefits of the hydraulic system: less engine wear, more precise shifting, and greater safety. Overall fuel economy is predicted to be about 2 percent better than the manual transmission on long-haul routes, with benefits even greater in difficult terrain or in urban driving. Electronically controlled transmissions cost approximately $2,000 more than manual transmissions, and approximately $5,000 less than the current price of hydraulic transmissions. The impact of this cost is shown in Figure 2.1, which shows that it would be extremely competitive on a cost basis, as long as it delivers the promised performance. The mechanical portion of the trans-

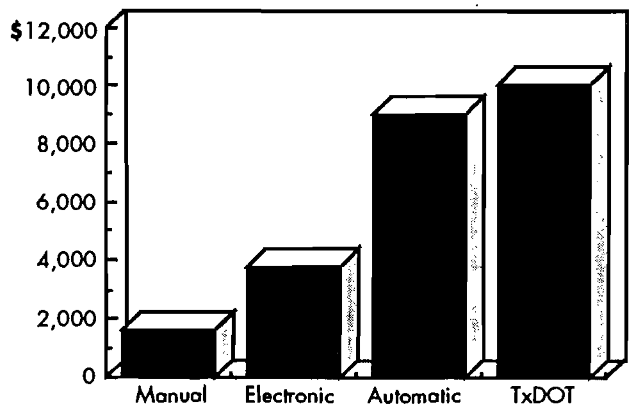


Figure 2.1 Transmission costs: manual, electronic and automatic transmissions

mission, substantially identical to current systems, should impose few new maintenance costs or mechanic re-training. While electronic systems are more complicated, this is now less of a problem, as electronic management systems become more routinely specified in truck engines. Moreover, as these electronic systems become more sophisticated, they can be designed to self-diagnose problems or to be monitored carefully by modern diagnostic equipment (such as that currently being evaluated for D-4 by CTR staff).

4. Widespread use of such transmissions would enlarge the driver pool and offer potential operational savings. Trucking companies face rapid driver turnover and a restricted driver pool. Companies have increased real driver wages and have instituted incentive programs to cut turnover. In addition, many unions are now trying to improve the drivers' environment, stressing such things as air conditioning and automatic transmissions. If newly hired truck drivers did not have to master difficult manual transmissions, the available driver pool would expand. This expansion could include an increase in the recruitment of female drivers, who presently make up only 2 percent of long-haul truck work force. The virtual universal adoption of power steering has made driving less physically demanding; the introduction of automatic transmissions would continue that process. Less skilled drivers may also be less costly to trucking firms since their shifting mistakes would be greatly reduced, resulting in less maintenance and fuel consumption.

The electronic gearbox promises to be an important breakthrough in truck specifications, one that will have important consequences within the trucking sector. Indeed, it may generate the kind of acceptance that ensures that automatic transmissions in trucks will attain to the current popularity of automatic transmission in automobiles.

CONCLUSIONS

Based on the review of the literature, the following conclusions can be made:

1. Automatics decrease maintenance costs by monitoring engine and transmission control. Lower maintenance implies less downtime, longer engine life, and lower service costs.
2. Automatics decrease wear on trucks by eliminating shock and under- or over-revving.
3. Automatics decrease fuel consumption by monitoring and controlling the drivetrain according to the driving conditions, providing maximum use of engine power.
4. Automatics are much easier to drive; accordingly, they open up new potential driver pools, increase safety, and decrease stress.
5. Automatics increase productivity.
6. While the initial cost of automatics is higher than other types of transmissions, they could more than pay for themselves over their extended life-cycle.
7. Advances in gearbox design, particularly the electronic gearbox, could radically alter the market by offering the benefits of automatic transmission at a much reduced price.

The literature seems to offer a compelling argument for adoption of automatic transmissions in many TxDOT operations. However, one area of operations—safety—seemed worthy of further review prior to evaluating the equipment on financial and economic grounds. This topic is examined in more detail in the following chapter.

CHAPTER 3. SAFETY ISSUES

BACKGROUND

Safety is, of course, a major concern in most U.S. transportation operations. Because the costs directly and indirectly associated with accidents can be enormous (and impossible to quantify in the case of fatalities), the transportation industry has made great efforts to improve working conditions. This chapter reviews the issue of safety, focusing in particular on those physical and mental conditions—fatigue and boredom—that individually or in combination tend to undermine safety efforts.

FATIGUE

While fatigue is most commonly associated with the condition of tiredness resulting from a lack of sleep, the term can be more specifically defined as a generalized response to stress over time (Ref 26). Beyond that, the definition becomes rather elusive. Early research concluded that there was no observable criteria for fatigue testing, its causes being too complex (Ref 27). Nevertheless, Bills (Ref 28), in 1934, categorized fatigue into three classes: subjective, objective, and physiological. Bartley and Chute (Ref 29), in accepting Bills' classification system, suggested that fatigue represents a form of conflict between the demands of the task and the person's aversion to effort. In other words, subjective and objective fatigue states represent internal and external conflicts, respectively, while physiological fatigue is simply physical fatigue. Types of objective fatigue include conflicts arising out of a result of outside pressure (e.g., time constraints, job performance requirements); subjective fatigue, on the other hand, includes the pressure that a person puts on him/herself (e.g., personal goals, self-control); finally, physical fatigue relates primarily to both muscle exhaustion and sensory (e.g., touch, sight) over-stimulation.

PHYSICAL FATIGUE

One aspect of physical fatigue refers to the physiological changes taking place at the muscle level, usually brought about through repetitive actions. One study (Ref 30) showed that when army trainees pulled repeatedly on a dynamometer handle (an instrument for measuring torque or hand grip), their strength decreased continually. Factors affecting the number of successive contractions were motivation, pain tolerance, and number (and length) of rest periods.

Somewhat analogous to the above exercise is the handling of truck gear shifts. Because their jobs often require that they shift gears several hundred times daily, manual transmission truck drivers can experience a decrease in strength. With less strength and hand stability, drivers of fully loaded dump trucks tend to find it considerably harder to downshift to keep the truck going; consequently, drivers trying to make a "fast shift" end up grinding gears (Ref 31), risking in the process damage to the clutch. And when manual transmission clutches are improperly handled, the vehicle power train can break down, creating sometimes dangerous situations on railroad crossings or steep slopes.

Fatigue of the senses—another form of physical fatigue—usually occurs when one or more of the senses have been desensitized to stimuli by continual exposure. For instance, a person exposed to a certain fragrance over long periods of time will, through habituation, lose the ability to smell that fragrance. The sensitivity to that fragrance returns when the odor is intensified, changed, or when the person rests (interrupts exposure). Turning to particular research, visual sensory input as a contributor to fatigue has been researched by Hockey (Ref 32), while Parasuraman and Davies (Ref 33) have shown that visual and auditory tasks having high event rates diminish detection of abnormalities. The findings of this last study correlate with (though not specifically cited) actual truck operation experience: the manual transmission of a dump truck adds strain on the driver through over-stimulation of the hands, eyes, feet, and nervous system (Ref 31). Continual visual concentration thus desensitizes the eyes to detect changes in traffic conditions.

OBJECTIVE AND SUBJECTIVE FATIGUE

Objective and subjective fatigue states play a lesser role in our discussion of trucking safety for two reasons: (1) they are both secondary to physical fatigue, and (2) they have not been universally accepted as categories of fatigue. Accordingly, this discussion will necessarily be brief.

Both objective and subjective fatigue are said to result from pressures in the work environment. Measuring this fatigue during skilled performance has been a difficult task, again because of the difficulty in defining fatigue. Yet one of the earliest and most comprehensive studies of objective and subjective fatigue was the Cambridge cockpit studies (Ref 34), which took place in the early 1940s. Subjects in these studies, sitting for long periods of time responding to aircraft controls, showed consistent deterioration of skill over time. Moreover, there occurred anomalies in the group's subjective observations: there was decreasing reliability in operator reports; increasing use of violent language; a tendency to blame errors on the apparatus; and an increased awareness of physical discomfort (Ref 32).

From this and other studies, it has been determined that fatigue is manifested not as a slowdown in pace, but, rather, as a breakdown in organization skill. In other words, in decreasing both reaction time and accuracy, fatigue affects an individual's ability to assess situations accurately and to organize appropriate responses (Ref 32). The Cambridge studies clearly showed that the operators' decreasing performance was associated with the number of control components in the cockpit; and operator frustration brought about through attempts to perform the tasks accurately led to a deterioration of attitudes. Hockey (Ref 32) adds that attitudinal changes generated through fatigue promote the practice of "cutting corners," as well as a willingness to take chances.

BOREDOM

The outward symptoms of boredom in individuals sometimes resemble the condition of fatigue, but it is not the same condition. Boredom occurs not when tasks are stressful to the sensory apparatus, but when they are tedious, meaningless, and not challenging to the individual. As with fatigue, people who are bored tend to operate less efficiently and thus less safely (Ref 35).

A study on long-distance truck drivers (Ref 36) found that the number of errors made on repetitive tasks (particularly errors made at the end of the task when boredom was greatest) was a good predictor of the accident rates of the drivers. Drivers who reported that they were less susceptible to boredom tended to be experienced drivers. Contrary to expectation, these experienced drivers were less consistent in response times and more inconsistent in engine speeds. Apparently, these inconsistencies made their jobs more varied and, therefore, less monotonous. The drivers learned these behaviors to overcome the boredom that reduces efficiency.

This study demonstrated two important and opposing issues. First, the inconsistencies in response times and engine speed can be harmful to manual transmissions, as it is necessary to have consistent and timely shifting (this behavior would not affect automatics). Second, it is possible that experienced drivers feel that manual transmissions keep them more attentive than they would otherwise be with automatic transmissions. In this case, boredom can turn into subjective fatigue: the drivers are unable to resolve the internal conflict arising from their not being able to keep themselves as occupied as they would like to be.

USAC STUDY: STRESS AND HEALTH

A report that showed the differences in stress levels between drivers of trucks with automatic or manual transmission was illustrated in an 8-minute film produced by the United States Auto Club (USAC). The automatic transmission featured in this film was the Allison transmission.

This study utilized two identical, medium-duty trucks—one using an Allison AT 545 four-speed automatic transmission, the other employing a six-speed manual transmission; in addition, a set of identical male twins were used to drive the trucks. Both drivers completed 24 test runs through a variety of difficult terrains: steep mountains, steep curves, urban roads, construction areas, freeways, and market streets.

The USAC medical director states that there are two types of conflicts: external and internal. An example of external conflict is the negotiation of arriving at a destination within a time frame, and an example of internal conflict is the lack of confidence in an individual. If these conflicts are unresolved by the individual, they cause a reduction in physical ability and an increase in psychological dysfunctions. This stress contributes to fatigue, leading to an increased likelihood of mistakes.

Throughout the trip, blood pressure, pulse, and heartbeat were monitored. The results showed that the systolic, diastolic, and pulse rate of the individual using the manual transmission truck was 16.49, 13.79, and 10.98 percent higher, respectively. At the beginning of the trip, both drivers had a similar number of heartbeats. As time progressed, the heart rate of the truck driver operating the automatic transmission decreased, indicating that he became more confident handling the truck, while the heart rate of the truck driver with manual transmission increased and leveled off, indicating that the opposite response had occurred.

This study then goes on to state that the benefits of automatic transmissions include: (1) fewer accidents, (2) lower insurance claims, (3) greater safety, (4) fewer worker compensation claims, and (5) reduced repair costs and downtime. Additional benefits of automatic transmissions include: (1) durability, (2) reliability, (3) increased productivity, and (4) reduced driveline damage. Finally, the study states that the National Institute for Occupational Safety and Health estimated that for 1984, stress-related incidents cost American industry approximately $150 billion. These incidents include absenteeism, lost productivity, health claims, and insurance costs. Of all compensation claims, 11 percent are occupational claims for mental disorders resulting from stress.

A criticism of this study is that, with only one set of drivers, it is difficult to project what differences in stress levels there may be with drivers of different ages, experiences, and physical and mental well-being, and on terrains that are non-demanding (i.e., flat, straight highway with low traffic volumes).

SUMMARY

There are other benefits associated with safer working environments. First, fewer new driver judgment errors were encountered with automatics (Ref 37). Also, drivers paid more attention to driving instead of to shifting. Other significant benefits include better image, better morale, and lower insurance costs.

One possible drawback is the need to change the perception, on the part of many drivers, that manual transmissions allow greater control of the environment. (This issue is discussed in the next chapter.)

All in all, it is less expensive to provide safer working environments. Accident costs can be enormous, even when no fatalities are involved. Table 3.1 shows the direct and indirect costs of accidents using the Maximum Abbreviated Injury Scale (MAIS) (Ref 38).

These figures are in 1980 dollars; when current legal and medical costs are taken into account, these figures dramatically understate the accident costs per victim.

Finally, all recent literature sources report an increase in safety and decrease in stress and fatigue in those operations that switched from manual to automatic transmissions. One company, Magnetic Springs Water Company of Columbus, Ohio, reported a 20 percent increase in safety since the adoption of automatic transmissions 12 years ago.

The next chapter continues the discussion of driver safety by reporting the results of a survey of driver attitudes.

Table 3.1 Costs by MAIS categories (1980 dollars) (Miller et al., 1984)

MAIS category	(PDO) 0	1	2	3	4	5	(Fatality) 6
Direct	$716	$1,601	$3,442	$8,089	$18,467	$138,684	$18,294
Indirect	$132	$690	$1,165	$2,217	$32,564	$122,897	$724,227
Total	$848	$2,291	$4,607	$10,306	$51,031	$261,581	$742,521

a - Costs per vehicle in reported property-damage-only (PDO) accidents.

b - Direct costs include property damage, medical, legal, and funeral costs.

c - Indirect costs include administrative costs, human capital costs (lost productivity) for injuries, and for a fatality, human capital costs adjusted for individuals' willingness-to-pay to reduce their risk of death or injury.

CHAPTER 4. DRIVER ATTITUDES AND USE SURVEYS

BACKGROUND

Two surveys were conducted as a part of this research project. The first survey concerned driver attitudes towards truck operations. As indicated in the preceding chapter on safety, the occupation-related internal conflicts of truck drivers are difficult to describe because of the infinite number of behavioral and psychological responses possible. In examining the issue of driver attitudes (considered part of the larger issue of safety), the first part of this chapter presents the results of a survey of TxDOT truck drivers. Of interest here are the responses of drivers experienced with automatic transmission dump trucks.

The second survey analyzed the use of dump trucks by TxDOT. One of the tasks of the project was to identify the nature of truck use and to identify applications more appropriate to an automatic or manual transmission operation. Additionally, it was necessary to evaluate the hourly use of vehicles in order to analyze fuel consumption differences fairly.

DRIVER ATTITUDE SURVEY

The driver attitude survey, shown in Figure 4.1, was distributed to 10 TxDOT sections (including Special Jobs in District 7) and produced 94 responses with 99 percent of the respondents having some driving experience with automatic dump truck transmissions. Overall, as indicated in question 11 (see Table 4.1), 56 percent of the drivers favored (the strongly agree and agree responses) automatic transmissions for the trucks, 34 percent preferred manuals, and 10 percent had no preference. The survey questions can be categorized according to the following four areas:

- truck performance (questions 1, 3, 4, 6),
- safety (questions 2, 5, 7, 9, 10),
- general preference (questions 8, 11, 12), and
- driving experience (questions 13, 14, 15, 16).

Truck Performance

The following survey questions relate to truck performance:

- Manuals perform better on rough or off-road areas (question 1).
- Automatics have inadequate power for hauling heavy loads (question 3).
- Manuals are more reliable than automatics (question 4).
- Most of the time, manuals have smooth and easy gear transition (question 6).

Based on these questions there is not a significant difference in performance between automatics and manuals. The largest difference in opinion is with respect to performance on rough and off-road areas, where 44 percent believed manuals performed better, as opposedto 38 percent who disagreed with this statement (18 percent did not know). There was very little difference for question 3 relating to power and question 4 on reliability. A majority of the respondents did believe that there was not smooth and easy gear transition for manuals. When including only respondents with frequent automatic driving experience, 40 percent agree and disagree on rough and off-road performance and on reliability. Fifty percent disagree with question 3 on inadequate power from automatics and 62 percent disagree with the smooth and easy gear transition for manuals.

Safety

The following questions related to safety:

- Automatics are easier to use on congested roads (question 2).
- I prefer the manuals when driving in rainy or wet weather (question 5).
- Automatics allow the driver to concentrate more on road conditions and traffic than manuals (question 7).

SDHPT Study 979: Driver Survey
August 1991

This survey is about using automatic and manual transmissions in the dump trucks you drive. For each statement below, indicate your preference by circling one of the responses for each question.

	Strongly Agree	Agree	I don't know	Disagree	Strongly Disagree
1. Manuals perform better on rough or off-road areas.	1	2	3	4	5
2. Automatics are easier to use on congested roads.	1	2	3	4	5
3. Automatics have inadequate power in comparison to manuals, for hauling heavy loads.	1	2	3	4	5
4. Manuals are more reliable than automatics.	1	2	3	4	5
5. I prefer the manuals when driving in rainy or wet weather.	1	2	3	4	5
6. Most of the time, manuals have smooth and easy gear transition.	1	2	3	4	5
7. Automatics allow the driver to concentrate more on road conditions and traffic than manuals.	1	2	3	4	5
8. Manuals are more rewarding to drive.	1	2	3	4	5
9. I am more tired after driving an automatic.	1	2	3	4	5
10. Automatics are safer.	1	2	3	4	5
11. Overall, I prefer automatic transmission in our trucks.	1	2	3	4	5
12. Given a choice, I prefer an automatic transmission over air conditioning.	1	2	3	4	5
13. Are you assigned to an automatic?	Yes		No		
14. Have you driven an automatic?	Yes		No		
15. If you are not assigned to an automatic, how often do you get the chance to drive one?	Frequently	Seldom	Not At All		
16. How many years have you been driving a truck?	________				

Other Comments:

Figure 4.1 Driver attitude survey

Table 4.1 Driver attitude survey responses

	Strongly Agree	Agree	Disagree	Strongly Disagree	Do Not Know
Question 1	19	25	26	12	18
Question 2	49	35	9	2	4
Question 3	20	27	30	16	7
Question 4	23	14	21	18	23
Question 5	18	23	28	17	14
Question 6	12	30	35	17	6
Question 7	38	38	14	4	6
Question 8	13	18	31	20	17
Question 9	7	6	43	34	10
Question 10	17	18	24	9	32
Question 11	34	22	23	12	10
Question 12	14	10	26	37	14
	Yes	No			
Question 13	30	70			
Question 14	99	1			
	Frequently		Seldom	Not at All	
Question 15	40		59	1	

- I am more tired after driving an automatic (question 9).
- Automatics are safer (question 10).

The responses from the safety questions are mixed. Overall, only 35 percent agreed that automatics are safer than manuals, with 32 percent disagreeing and 32 percent not knowing. However, 75 percent of the respondents believed that automatics allowed the driver to concentrate more on traffic and road conditions than manuals, and 85 percent agreed that automatics are easier to use on congested roads. With respect to weather, slightly fewer respondents preferred manuals over automatics. Because of poor wording on question 9 it is difficult to draw any conclusions other than automatic drivers are not more tired.

When including only frequent automatic drivers the results are more positive. Forty-three percent agree that automatics are safer than manuals and only 24 percent disagree. For question 7, the percentage agreeing increases to 86 percent and for question 2, the percent agreeing is 89 percent. Interestingly, safety responses are tempered when you compare it with the responses on question 12—"Given a choice, I prefer an automatic transmission over air conditioning." In this case, despite the claims of those who agreed that automatics conduce to greater concentration on traffic and road conditions, it was evenly divided between preferring air conditioning or an automatic. However, for those frequent drivers who believed automatics are safer, 50 percent still preferred automatics over air conditioning, while only 25 percent disagreed with this statement. Generally, this indicates that the safety advantages of an automatic are not as important to drivers as general comfort.

General Preference

As noted at the beginning of this chapter, 56 percent of the survey respondents preferred automatics. However, about 74 percent of the drivers who frequently drove automatics preferred automatics to manuals, while only 44 percent of the drivers who seldom drove automatics preferred them over manuals. However, in this latter group, the 44 percent was higher than the 41 percent who preferred manuals, the remaining 15 percent not having a preference. Question 8 attempted to address the image of driving a manual or transmission truck. Generally, it is hypothesized that manuals foster stronger images for a truck driver. However, the survey findings indicate that 52 percent disagreed with question 8, "Manuals are more rewarding to drive." Surprisingly, when including only those drivers who seldom drive an automatic or who have never driven an automatic, the results change very little, with nearly 50 percent still disagreeing with question 8.

Driving Experience

Another important result of the driver survey was the determination of the age profile of the TxDOT dump truck driver population. This age profile was determined by tabulating the results for item number 16 of the survey form, which asked the respondent to furnish the number of years of experience. The responses for item 16, years of experience, serves as a surrogate for the age of the drivers and allows for the calculation of the dump truck driver's age frequency distribution for the TxDOT population of dump truck drivers. The cumulative frequency distribution for the years of experience for the sample is depicted in Figure 4.2 and shows that 30 percent of the dump truck drivers surveyed have more than 22 years of experience. This important finding suggests that a few years from now TxDOT will be involved in an intensive recruiting effort to replace this group of drivers nearing retirement. This is an argument in favor of the automatic trucks, since they facilitate recruiting and training of prospective drivers.

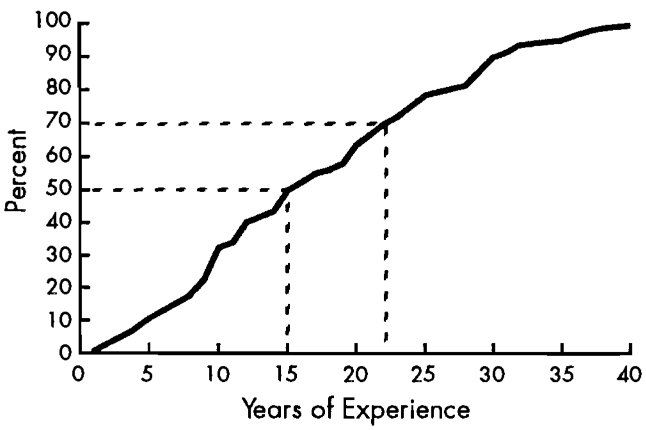


Figure 4.2 Cumulative frequency distribution of the years of experience driving trucks

TRUCK UTILIZATION SURVEY

The truck utilization survey (see Figure 4.3, page 17) was carried out at four TxDOT locations with 10 dump trucks equipped with automatic transmissions and 22 dump trucks equipped with standard transmissions. The survey generated more than 700 data points, one for each day of truck operation. This data is summarized in Figure 4.4. Surprisingly, there is little difference in truck use for automatics and manuals. Given the nature of the trucks, automatics lend themselves more to stop/go operations and manuals more to steady haul operations. However, based on this survey manuals logged more stop/go use as a percent of total time than automatics. The survey also revealed that automatics get fewer miles per hour of operation than manuals.

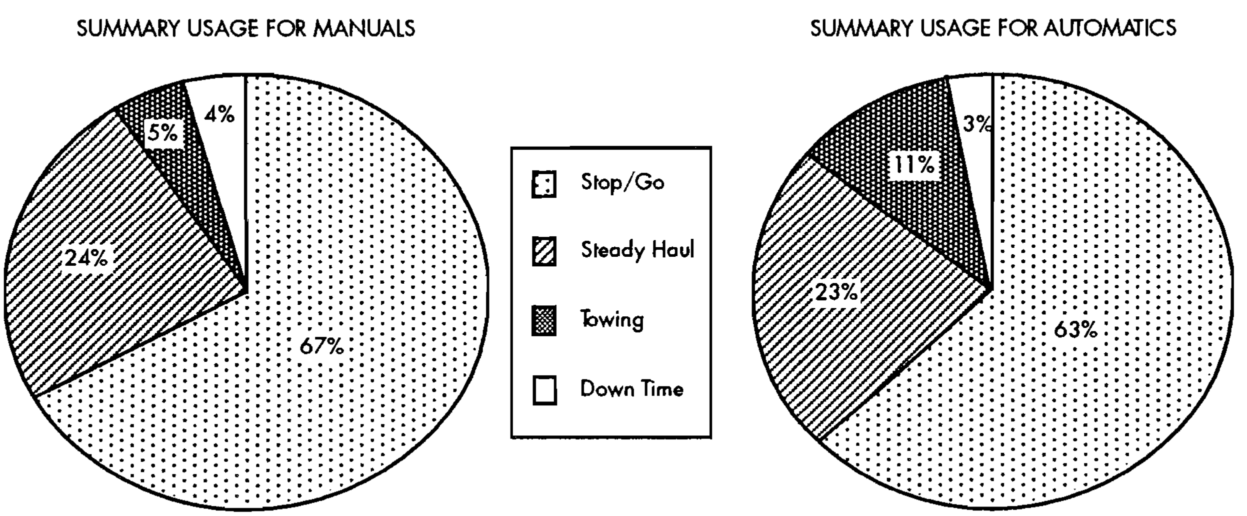


Figure 4.4 Summary usage for manual and automatic dump trucks

Truck Utilization Data: Study 979

Please fill this in at the end of each workday. Select a category that best describes the truck's use for that day and place an " X " in the appropriate " category " box. Then place an " X " in the " hours " box that is closest to the number of hours the truck was in operation.

Work Category Codes
1 Steady haul
2 Stop/go haul, long idle times
3 Towing equipment
4 Down time [repair, cleaning]

Vehicle #: ____________

Week beginning: ______ / ______ / ______

Beginning odometer reading: ____________

Beginning hour meter reading: ____________

Day	Use	Category					Hours in Use				
Monday	Primary Use	1	2	3	4	Hours	2	4	6	8	8+
	Secondary Use	1	2	3	4	Hours	2	4	6	8	8+
Tuesday	Primary Use	1	2	3	4	Hours	2	4	6	8	8+
	Secondary Use	1	2	3	4	Hours	2	4	6	8	8+
Wednesday	Primary Use	1	2	3	4	Hours	2	4	6	8	8+
	Secondary Use	1	2	3	4	Hours	2	4	6	8	8+
Thursday	Primary Use	1	2	3	4	Hours	2	4	6	8	8+
	Secondary Use	1	2	3	4	Hours	2	4	6	8	8+
Friday	Primary Use	1	2	3	4	Hours	2	4	6	8	8+
	Secondary Use	1	2	3	4	Hours	2	4	6	8	8+
Saturday	Primary Use	1	2	3	4	Hours	2	4	6	8	8+
	Secondary Use	1	2	3	4	Hours	2	4	6	8	8+
Sunday	Primary Use	1	2	3	4	Hours	2	4	6	8	8+
	Secondary Use	1	2	3	4	Hours	2	4	6	8	8+

Figure 4.3 Truck utilization survey

CHAPTER 5. LIFE-CYCLE COSTING ANALYSIS

INTRODUCTION

In calculating the potential economic benefits to be obtained by introducing automatic gear boxes into the TxDOT dump truck fleet, the study team employed a life-cycle costing analysis (Ref 41). Such analyses, relying as they do on real costs over time, more accurately depict the cost of an item. For example, a dump truck purchased at the lowest initial cost may not necessarily be the vehicle that also costs the least in the long run. The costs involved in the ownership of the equipment (e.g., operations and maintenance costs over the truck's life cycle) are significant and could be many times the purchase price. Thus, the data analysis included in this chapter, used along with the financial analysis techniques discussed in Chapter 6, is designed to measure the life-cycle costs of introducing automatic gear boxes into the TxDOT dump truck fleet. The quantifiable benefits of the adoption of automatic transmissions include the reduction of downtime, reduced maintenance costs, extended life, and greater productivity. These potential savings are compared against the additional initial investment required in purchasing the automatic gear box, typically 10 percent of the initial cost. Other objectives of this and the following chapter include: (1) identifying the economic life of a truck; (2) presenting a sensitivity analysis of the results to the different inputs; and (3) comparing manual dump trucks, for which extensive life-cycle data are available, with automatic dump trucks on a financial basis. Figure 5.1 illustrates the basic functioning of a life-cycle costing exercise.

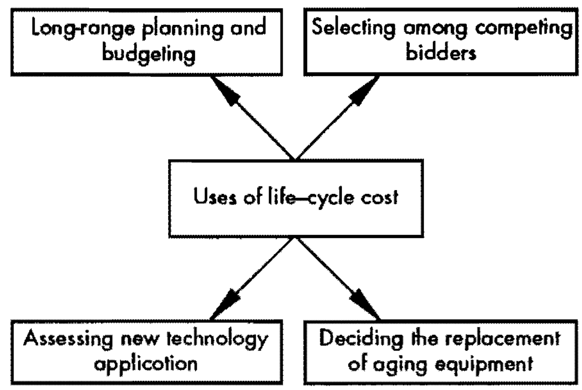


Figure 5.1 Basic uses of life-cycle costing techniques

INFORMATION NEEDED FOR LIFE-CYCLE COSTING

Most of the information required to conduct a life-cycle cost analysis is available from the extensive data base maintained by the TxDOT Division of Equipment and Procurement. This data base includes:

(1) operational life of the item in years,
(2) inflation rates,
(3) annual maintenance costs,
(4) salvage value,
(5) acquisition cost,
(6) annual operating costs (energy costs, supplies, labor, parts), and
(7) downtime.

Equation 5.1 below presents the mathematical model that combines these costs to give the total cost over the economic life of the truck. The time value of money and associated modeling, not reflected in Equation 5.1, is discussed in the following chapter, where a financial analysis comparing automatics with manuals is performed. Again, the main goal in this chapter is to reconstruct the life-cycle costs of the 6- and 10-cubic-yard dump trucks operated by TxDOT. Equation 5.1 includes the cost elements of the financial model that need to be retrieved from the TxDOT Division of Equipment and Procurement data base.

$$L_{cc} = AC + \left[\sum_{i=1}^{n} \left(SMC_i + OC_i + URC_i + DT_i \right) \right] + DC \qquad \text{(Eq 5.1)}$$

where

L_{cc} = the life-cycle cost of the truck,
AC = the acquisition cost of the dump truck,
SMC_i = the scheduled maintenance cost (tune-up, lubrication, etc.) of the dump truck for year i,
OC_i = the operating cost (tires, gas, oil, etc.) of the truck for year i,
URC_i = the unscheduled repair cost (dependent on the failure rate of the truck) for year i,
DT_i = the cost for the down time for year i, and
DC = the disposal cost (positive or negative if there is a salvage value).

The different life-cycle costs accrued during the operational life of a dump truck (and for almost any type of equipment) are illustrated in Figure 5.2. The operating costs are generally constant throughout the operational life of the truck, with the costs for repairs and associated downtime increasing with age.

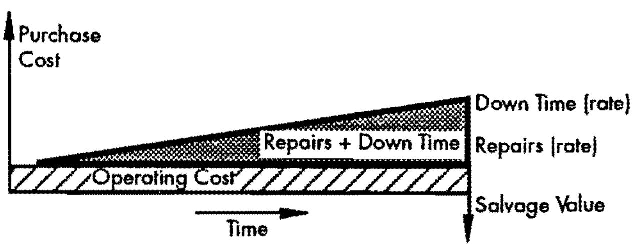


Figure 5.2 Life-cycle costs of a dump truck

THE TxDOT DATA BASE

For the purposes of this study, the Division of Equipment and Procurement specifically forwarded a set of master record tapes for fiscal years 1985 through 1990, which included much information on the life-cycle costs of the equipment fleet. The approximately 180 fields recorded in these tapes are costs accumulated during a fiscal year, making it possible to reconstruct the life-cycle costs for each piece of equipment. The information in the tapes was organized to include only the data for 6- and 10-cubic-yard dump trucks (Class codes 540010 and 540020), for both manual and automatics. The resulting data base consisted of 2,103 observations (1,836 for 6-cubic-yard trucks and 267 for 10-cubic-yard trucks): one observation for each dump truck, and 149 variables summarizing the data available from computer tapes for fiscal years 1985 through 1990. For each fiscal year, the elements retrieved from the tapes are described in Table 5.1 (though not all elements listed in Table 5.1 were used in the analysis). These 2,103 observations generated over 6,300 life-cycle observations (5,854 for 6-cubic-yard trucks and 448 for 10-cubic-yard trucks), one for each age of a vehicle, reporting the repair costs, downtime and operating costs at different ages and as depicted in Figure 5.2. These 6- and 10-cubic-yard dump trucks—all powered by diesel engines—reflect a TxDOT purchasing trend. Several automatic gasoline units purchased between 1979 and 1981 were basically 5-cubic-yard dump trucks (class code 520020; most of these units

Table 5.1 Fields retrieved from end-of-fiscal-year summary tapes

Field #	Description
1	Equipment number
2	Class code
5	Equip status
12	Receipt date
21	Purchase cost
23	Salvage percentage
24	Current depreciation
25	Depreciation months remaining
30	Total depreciation to date
38	Purchase date
47	Retirement date
48	Retirement code
49	Resale trade value
71	Engine fuel type
81	Transmission type
113	Air conditioning flag
136	Previous fiscal repair expenses
139	Previous fiscal diesel expenses
140	Previous fiscal diesel quantity
141	Previous fiscal oil expense
142	Previous fiscal oil quantity
145	Previous fiscal hydraulic fluids expenses
146	Previous fiscal hydraulic fluids quantity
147	Previous fiscal rental expense
148	Previous fiscal indirect expenses
149	Previous fiscal usage miles or hours
150	Previous fiscal hours of commitment time
151	Previous fiscal down time
168	Total repair expenses
170	Total gas quantity
171	Total diesel expenses
172	Total diesel quantity
173	Total oil expense
174	Total oil quantity
177	Total hydraulic fluids expenses
178	Total hydraulic fluids quantity
180	Total indirect expenses
181	Total usage miles or hours
182	Total hours of commitment time
183	Total downtime

Table 5.2 Six- (class code 540010) and ten-cubic-yard (class code 540020) dump trucks with automatic transmissions in the TxDOT fleet

Equipment Number	Class Code	Purchase Date	Fuel	Purchase Cost (Uncorrected)
03608D	540010	16-Mar-87	Diesel	$21,279
03609D	540010	16-Mar-87	Diesel	$21,279
03611D	540010	16-Mar-87	Diesel	$21,279
03612D	540010	16-Mar-87	Diesel	$21,279
05260C	540010	2-Jan-86	Diesel	$25,989
05261C	540010	2-Jan-86	Diesel	$25,989
05262C	540010	2-Jan-86	Diesel	$25,989
05445D	540010	3-Aug-88	Diesel	$31,600
04567E	540010	10-Apr-90	Diesel	$29,536
04734E	540020	2-Aug-90	Diesel	$61,944
04735E	540020	2-Aug-90	Diesel	$61,944
04736E	540020	2-Aug-90	Diesel	$59,344
04737E	540020	2-Aug-90	Diesel	$59,344
04738E	540020	2-Aug-90	Diesel	$63,998
04739E	540020	2-Aug-90	Diesel	$63,998
04740E	540020	2-Aug-90	Diesel	$63,998
04741E	540020	2-Aug-90	Diesel	$63,998
04742E	540020	2-Aug-90	Diesel	$63,998
04743E	540020	2-Aug-90	Diesel	$63,998
04744E	540020	2-Aug-90	Diesel	$59,498
04745E	540020	2-Aug-90	Diesel	$59,498
04757E	540020	2-Aug-90	Diesel	$59,198
04761E	540020	2-Aug-90	Diesel	$59,598
04762E	540020	2-Aug-90	Diesel	$59,598
04763E	540020	2-Aug-90	Diesel	$59,598
04764E	540020	2-Aug-90	Diesel	$59,598
04766E	540020	2-Aug-90	Diesel	$59,448

have been disposed of). The TxDOT data are used in the financial analysis chapter (Chapter 6) to compare life-cycle-costs of manual and automatic 6-cubic-yard dump trucks. However, there are only eight 6-cubic-yard automatic units for which historical data are available (see Table 5.2). While TxDOT has recently purchased eighteen 10-cubic-yard dump trucks and one 6-cubic-yard truck equipped with automatic transmissions, not enough usage has accrued to develop significant historical data.

Inflation Rates

Inflation should be taken into account in any analysis of historical cost data. However, it is fairly difficult to find the ideal index that would be best suited for correcting all components of the historical data available at TxDOT for deriving the life-cycle costs of the average dump truck. Moreover, the index needed to correct the historical acquisition costs of the trucks would probably differ from the index needed to correct the annual maintenance costs.

Nevertheless, *Highway Statistics* (Ref 42), an annual publication of the FHWA, publishes an index on highway maintenance and operation costs that gives an idea of the cost trends. The variation of the index associated with equipment is of particular interest for this chapter; this is depicted in Figure 5.3, using 1977 as the base year.

It is observed that the tendency is for the average equipment costs to increase at a rate of $11 per year for each $100 spent in 1970, whereas for the labor costs there is an increase of $8.5 per

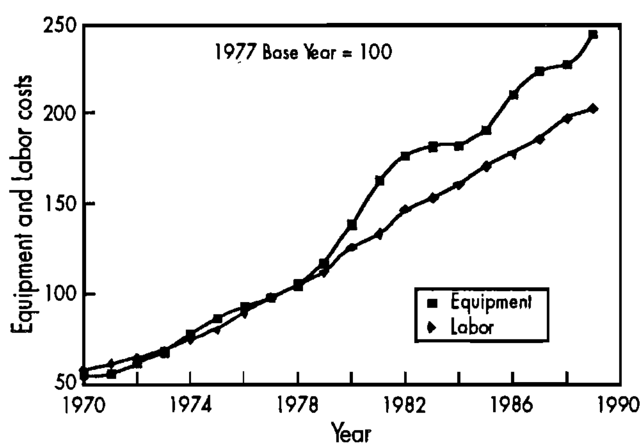


Figure 5.3 Cost index trends for labor and equipment (FHWA 1990)

Table 5.3 Inflation correction factors used for TxDOT cost data

Year	Equipment Index	Correction Factor	Variation from Year to Year
1985	188.64	1.3488	-
1986	197.13	1.2907	4.50%
1987	218.14	1.1664	10.66%
1988	232.36	1.0950	6.52%
1989	235.79	1.0791	1.48%
1990	254.43	1.0000	7.91%

year, reinforcing the need to correct the different components of cost with different indices. The values presented in Figure 5.3 are based on unit cost information submitted each year by state highway departments throughout the nation. The values included in Table 5.3, based on the values reported in Figure 5.3, were used to correct the cost data obtained from TxDOT.

The prospect of inflation can either accelerate or retard replacement of equipment, depending on how it affects acquisition costs or wage costs. Increases in wage levels make the replacement equipment that requires fewer operating and maintenance hours a more competitive option. This may be the case for automatic-transmission-equipped dump trucks, where increases in acquisition costs make a slowdown in replacing existing equipment more advisable.

Acquisition Costs

Tables 5.4 and 5.6 present the average purchase cost for manual 6-cubic-yard and 10-cubic-yard dump trucks by year. Comparing average purchase cost for manual dump trucks by year with the purchase costs for automatics presented in Table 5.2, it is observed that for the 6-cubic-yard dump trucks purchased in 1987 there was no significant difference. For 1986, the difference between the purchase cost of automatics as compared with the mean purchase price for manuals is 21 percent, making the purchase cost significant for the life-cycle cost financial analysis of automatics. For 1988, the only automatic-transmission-equipped dump truck that was purchased cost $31,600; this value translates into a 42.5 percent increase over the $22,175 purchase cost paid for a manual-transmission-equipped dump truck in the same year—a price difference highly significant for a life-cycle cost analysis. Comparing Tables 5.2 and 5.6 for 10-cubic-yard dump trucks, the purchase of an automatic-transmission-equipped dump truck added approximately 20 percent to the initial truck cost.

The purchase cost presented in Table 5.4 for 6-cubic-yard dump trucks does not include the cost of the truck body, which is added by the Texas Department of Criminal Justice (TDCJ) under contract with TxDOT. As shown in Table 5.5, the mean costs of the body, by year of receipt for the 6-cubic-yard truck, were calculated by utilizing the net adjustments to capital field from the TxDOT database. Because the 10-cubic-yard models, in contrast, are purchased from the suppliers complete with body, their purchase cost does not require correction. The body costs, for the 6-cubic-yard trucks, will be added to the chassis costs for the financial analysis presented in the next chapter.

Operational Life and Salvage Value

There are 33 manual 6-cubic-yard dump trucks recorded in the TxDOT data base for which retirement history is available and for which the retirement code is sold in auction or through a negotiated sale. There are four other trucks that the retirement codes indicate were either dismantled or sold at an earlier age; these were disregarded in the statistical calculations. The 33 remaining trucks, retired during the years 1989 and 1990, had an

Table 5.4 Values for the mean purchase cost by year of 6-cubic-yard dump trucks equipped with manual transmissions (uncorrected for inflation)

Year	Units	Mean	Std Dev	Minimum	Maximum	Range
1978	13	$10,817.46	$0.00	$10,817.46	$10,817.46	$0.00
1980	4	$25,915.00	$0.00	$25,915.00	$25,915.00	$0.00
1981	198	$22,018.22	$1,379.05	$20,216.00	$26,568.00	$6,352.00
1982	192	$20,495.54	$889.25	$19,061.00	$23,823.27	$4,762.27
1983	79	$21,260.14	$602.38	$20,286.00	$21,888.00	$1,602.00
1984	67	$21,772.00	$0.00	$21,772.00	$21,772.00	$0.00
1985	195	$21,697.92	$196.00	$21,341.00	$21,805.00	$464.00
1986	250	$21,479.60	$55.96	$21,434.00	$21,548.00	$114.00
1987	225	$21,083.30	$225.03	$20,846.00	$22,693.00	$1,847.00
1988	260	$22,175.00	$0.00	$22,175.00	$22,175.00	$0.00
1989	233	$25,485.68	$2,881.24	$23,829.00	$30,961.00	$7,132.00
1990	110	$26,274.36	$149.88	$26,183.00	$26,518.00	$335.00

Table 5.5 Values for the mean body cost by receipt year of 6-cubic-yard dump trucks equipped with manual transmissions (uncorrected for inflation)

Year	Units	Mean	Std Dev	Minimum	Maximum	Range
1981	1	$1,206.21	0	$1,206.21	$1,206.21	$0.00
1982	124	$3,307.74	$1,237.47	$1,389.12	$8,143.65	$6,754.53
1983	85	$3,470.73	$615.11	$3,296.55	$8,143.65	$4,847.10
1984	100	$3,517.91	$499.07	$3,289.24	$6,605.10	$3,315.86
1985	123	$3,849.46	$834.08	$3,336.15	$10,569.15	$7,233.00
1986	341	$3,628.50	$397.03	$3,336.15	$8,158.06	$4,821.91
1987	214	$5,150.60	$1,477.37	$1,744.00	$20,661.48	$18,917.48
1988	271	$5,951.28	$307.91	$5,447.76	$7,924.23	$2,476.47
1989	64	$6,208.67	$372.02	$5,680.81	$7,834.50	$2,153.69
1990	128	$6,181.94	$203.88	$6,032.46	$7,233.86	$1,201.40

Table 5.6 Values for the mean purchase cost by year of 10-cubic yard dump trucks equipped with manual transmissions (uncorrected for inflation)

Year	Units	Mean	Std Dev	Minimum	Maximum	Range
1981	3	$48,407	$482	$47,936	$48,900	$964
1982	10	$47,191	$524	$46,491	$47,655	$1,164
1985	18	$50,022	$1,418	$48,814	$52,904	$4,090
1986	36	$45,517	$1,790	$43,491	$48,306	$4,815
1988	65	$44,734	$1,716	$43,360	$47,892	$4,532
1989	46	$47,621	$993	$47,049	$50,498	$3,449
1990	22	$50,029	$1,145	$49,298	$52,079	$2,781

Table 5.7 Statistics for retirement history for manual 6-cubic-yard dump trucks

	Average Age at Retirement (years)	Salvage Value	Mileage at Retirement
Mean	8.27	$6,884.85	146,434
Std Deviation	0.72	$898.39	18,141

Table 5.8 Retirement history for manual 10-cubic-yard dump trucks

Equipment Number	Age	Retirement Value	Retirement Date	Mileage at Retirement
04369A	6.82	$11,250	22-Mar-86	237,510
04370A	6.68	$12,000	2-Feb-86	231,948
04371A	7.23	$2,175	19-Aug-86	228,355
04372A	7.66	$8,000	24-Jan-87	266,100
05007	7.48	$6,220	6-Mar-90	122,632
Means	**7.17**	**$7,929**	**N/A**	**217,309**

average life of 8.3 years and an average salvage value of $6,885, which represents approximately 31 percent of the average purchase cost of the trucks in 1981. The average mileage at retirement for these dump trucks was 146,434 miles. The summary of the statistics for the retirement history for 6-cubic-yard dump trucks is presented in Table 5.7.

For 10-cubic-yard dump trucks, retirement data are available for five units only. As shown in Table 5.8, the mileage at retirement for the 10-cubic-yard dump trucks is significantly higher than that for the 6-cubic-yard dump trucks. The average retirement salvage value is $7,929 and the values are uncorrected for inflation due to the insensitivity of the purchase cost to the year of purchase, as observed in Table 5.6.

Annual Maintenance Costs (Scheduled and Unscheduled)

The average annual maintenance costs (scheduled and unscheduled) corrected for inflation for 6-cubic-yard dump trucks are presented in Table 5.9. A regression analysis of the data shows that the annual costs of scheduled and unscheduled maintenance increase at a rate of $419 per year of usage of the 6-cubic-yard manual dump truck.

As illustrated in Table 5.10, the same procedure was applied to calculate the average annual repair costs as a function of the age for the 10-cubic-yard manual dump trucks. In the subsequent regression analysis performed over the 10-cubic-yard data, the repair costs were found to increase at a rate of $669 per year of usage.

Annual Operating Costs

Annual operating costs are recorded in the TxDOT data base as a summary of the cost of fuel, hydraulic fluids, and lubricants expended during the fiscal year. A summary of the values, corrected for inflation, is presented as a function of the age of the truck in Table 5.11 (observations

Table 5.9 Average annual repair costs for manual 6-cubic-yard dump trucks (scheduled and unscheduled; corrected for inflation)

Age	Trucks	Mean	Std Dev	Minimum	Maximum	Range
1	1195	$112.08	$426.36	$0.00	$8,082.11	$8,082.11
2	1139	$1,478.67	$1,227.85	$18.34	$7,824.91	$7,806.57
3	1023	$1,836.29	$1,552.00	$83.08	$13,145.27	$13,062.19
4	985	$2,268.02	$1,634.37	$77.85	$13,133.82	$13,055.97
5	731	$2,113.09	$1,376.78	$32.46	$14,203.38	$14,170.93
6	540	$2,373.69	$1,567.16	$76.54	$13,764.10	$13,687.56
7	455	$2,674.31	$1,719.32	$255.07	$10,326.95	$10,071.88
8	334	$2,768.02	$1,987.48	$27.05	$12,417.63	$12,390.58
9	180	$2,229.50	$1,482.40	$0.00	$10,038.92	$10,038.92

Table 5.10 Average annual repair costs for manual 10-cubic yard dump trucks (scheduled and unscheduled; corrected for inflation)

Age	Trucks	Mean	Std Dev	Minimum	Maximum	Range
1	164	$1,062.88	$1,210.29	$0.00	$4,779.07	$4,779.07
2	102	$1,570.79	$953.66	$189.04	$4,792.26	$4,603.22
3	63	$2,902.18	$2,319.71	$490.72	$15,540.33	$15,049.61
4	50	$3,073.58	$1,658.38	$408.97	$8,473.36	$8,064.39
5	22	$2,806.19	$1,423.67	$448.91	$4,862.58	$4,413.67
6	13	$3,297.84	$1,956.60	$390.56	$7,518.23	$7,127.67
7	13	$4,136.21	$2,310.58	$1,587.89	$9,725.98	$8,138.09
8	8	$2,787.10	$1,400.96	$1,013.38	$5,274.52	$4,261.14
9	2	$4,211.91	$418.81	$3,915.77	$4,508.05	$592.28

Table 5.11 Average cost per mile of fuel and other fluids by age for 6-cubic-yard manual dump trucks

Truck Age	Trucks	Mean $/mile	Std Dev	Minimum	Maximum	Range
1	139	$0.10	$0.05	$0.02	$0.50	$0.48
2	998	$0.09	$0.04	$0.02	$0.75	$0.73
3	879	$0.09	$0.03	$0.05	$0.36	$0.31
4	801	$0.09	$0.03	$0.05	$0.22	$0.17
5	731	$0.10	$0.03	$0.05	$0.23	$0.18
6	527	$0.09	$0.02	$0.03	$0.16	$0.13
7	455	$0.08	$0.02	$0.00	$0.18	$0.17
8	334	$0.09	$0.10	$0.00	$1.80	$1.80
9	180	$0.11	$0.02	$0.07	$0.26	$0.19

with zero values were removed from the analysis). It is observed that the sensitivity of the values to the age of the truck is insignificant. The average operating cost per mile to operate a 6-cubic-yard manual dump truck is approximately $0.10/mile. Combining the cost per mile with an average usage of 15,000 miles per year, the costs of operating a manual 6-cubic-yard dump truck total $1,500 per year, approximately consistent with the age based on the TxDOT data analysis. The same analysis performed for the 10-cubic-yard manual trucks resulted in an overall average of $0.12/mile for the operating costs. The results of the analysis by age are presented in Table 5.12. The overall average usage of the 10-cubic-yard dump trucks during their operating life at TxDOT is approximately 13,500 miles per year, giving an overall operating cost of $1,620 per year of operation, which is fairly constant with the age.

Cost Associated with Downtime

Reliability of equipment is a major concern for public agencies. When equipment fails, there are two costs associated with its failure: first, there are the tangible costs of labor, materials, and other resources needed to repair the equipment (these costs are included in the maintenance costs discussed previously); second, there are the intangible costs that impact the organization. Intangible

Table 5.12 Average cost per mile of fuel and other fluids by age for 10-cubic-yard manual dump trucks

Truck Age	Trucks	Mean $/mile	Std Dev	Minimum	Maximum	Range
1	85	$0.11	$0.02	$0.06	$0.16	$0.10
2	102	$0.12	$0.02	$0.08	$0.16	$0.08
3	57	$0.12	$0.03	$0.08	$0.21	$0.13
4	48	$0.14	$0.03	$0.08	$0.22	$0.14
5	22	$0.14	$0.03	$0.09	$0.23	$0.14
6	13	$0.12	$0.03	$0.09	$0.17	$0.08
7	13	$0.12	$0.02	$0.09	$0.16	$0.07
8	8	$0.14	$0.02	$0.11	$0.17	$0.06
9	2	$0.16	$0.01	$0.15	$0.17	$0.02

costs, if quantified with reasonable accuracy, can influence equipment decisionmaking in several ways. Intangible costs can be used to measure the impact of less-than-perfect equipment against other equipment in the organization. Intangible costs can also be used to assess the effectiveness of maintenance policies and procedures to ensure a high level of reliability of the equipment operations. Finally, intangible costs combined with tangible costs can be used in an economic replacement model to provide a better assessment of economic life and for the comparison of different alternatives (such as automatic and manual dump trucks). Intangible costs are broken down into four areas:

(1) time loss by crew, equipment, and associated resources,
(2) contract defaults,
(3) safety problems, and
(4) traffic congestion.

Time Loss: The section on time loss by crew, equipment, and associated resources (outlined in a comprehensive model developed by Vorster, Ref 44) is illustrated in Figure 5.4.

Contract Defaults: Contract defaults occur when the quality of work is poor or when the work falls too far behind schedule (often as a result of equipment downtime). The penalty of contract defaults should be assessed according to savings potential, safety hazards, and traffic congestion. While private corporations sometimes penalize late contracts according to a percentage

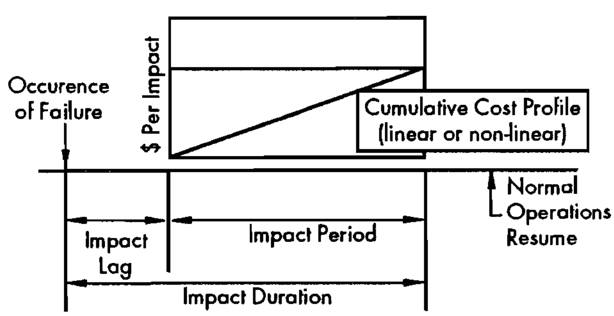


Figure 5.4 Time loss by crew, equipment, and associated resources

of the value of the contract, public agencies, on the other hand, must contend with indirect penalties: since the contract is awarded by the agency itself, which is financed with taxes, the penalty that falls on a public agency is more likely to be in the form of political pressure; that is, politicians sensitive to the concerns of their constituents (who after all can vote them out of office) can pressure a public agency to correct contract defaults that impede public service on public roads.

Safety Problems: Equipment that is down may pose safety problems to its driver and to other drivers, both directly and indirectly. An inoperative truck obstructing a roadway requires that other drivers maneuver around the stranded truck—a sometimes hazardous operation. The indirect consequences of an inoperative dump truck may or may not be at the site of the dump truck. For instance, in icy weather, other drivers are affected if sand is not on the road. Another indirect consequence is the irritation and frustration drivers experience when the safest and clearest route possible is obstructed; these drivers may aggravate the situation by acting on irrational impulses, causing other accidents to occur, as noted in Chapter 3.

Traffic Congestion: Equipment that is down also affects traffic flow. Congestion created by downed equipment results in air pollution, driver frustration, safety problems, and a waste of energy and time. Costs associated with vehicle congestion, though difficult to quantify, can be quite high. For example, if congestion results in 10 minutes lost per vehicle, if idling wastes fuel at approximately $3/hr, and if the average wage (plus overhead) of a driver is $30/hr, then the added congestion would cost at least $550 per hundred vehicles on the roadway. Normally, major highways have tens of thousands of vehicles travelling on them daily; if equipment is stranded for at least an hour during rush hour, then the traffic congestion cost to drivers encountering a stranded vehicle can approach $33,000. The cost in terms of air pollution and driver irritation is even more complex, primarily because both components have long-lasting effects on the driver and on the community. Pollution causes acid rain, poor air quality, noxious fumes, and health problems, while driver irritation can result in physical and mental health problems that may not appear until much later in the driver's life. Such health problems are costly to both the driver and to society.

Unfortunately, while these costs associated with equipment downtime can be cited, the attempt to quantify them is a tremendously complex exercise and outside the scope of this study. Even a survey of the literature reveals few published studies regarding the specific costs of downed equipment. Nonetheless, for the purpose of this project, the estimation of downtime expressed in terms of annual hours of downtime as a function of the age of the equipment and combined with an unit cost for the downtime, will be used as a surrogate for estimating the cost of downtime.

Beyond that, however, there is some controversy regarding how to estimate the unit cost of downtime within the TxDOT administrative structure. For example, there are many questions that arise when determining a hourly rate for downtime: Is the rental rate of equivalent equipment a good surrogate for the hourly cost of the downtime? How should the cost of the affected construction or maintenance crew be taken into account? And finally, what is the effect of back-up equipment available to replace inoperable equipment? In Chapter 6, the financial analysis assumes a unit cost of $20/hour for downtime.

Table 5.13 includes the statistics for the downtime for 6-cubic-yard manual dump trucks by age; a trend revealed by further regression analysis shows the downtime increases at a rate of 22 hours per year of operation of the truck. For 10-cubic-yard trucks, shown in Table 5.14, the same procedure indicated an increase of 25 hours of downtime per year of operation.

Discount Rates

According to Brown and Yanuck (Ref 43), there is no acceptable method for defining the rates for state and local governments. The use of the interest rate on bond issues is not acceptable, since interest on the issues of state and local governments is not subjected to federal income tax (and would thus result in yield rates lower than they would otherwise be). Brown and Yanuck recommend that for life-cycle cost analyses state and local

Table 5.13 Average downtime for 6-cubic-yard manual dump trucks by age

Truck Age (years)	Trucks	Average Down Time Hours	Std Dev	Minimum	Maximum	Range
1	1195	11.6	46.2	0.0	494.0	494.0
2	1139	88.8	100.6	0.0	651.0	651.0
3	1023	62.5	85.0	0.0	692.0	692.0
4	985	70.9	98.7	0.0	964.0	964.0
5	731	110.3	132.0	0.0	1633.0	1633.0
6	540	135.8	147.3	0.0	1222.0	1222.0
7	455	160.7	155.9	4.0	1272.0	1268.0
8	334	186.3	172.4	0.0	902.0	902.0
9	180	162.9	148.7	0.0	889.0	889.0

Table 5.14 Average downtime for 10-cubic-yard manual dump trucks by age

Truck Age (years)	Trucks	Average Down Time Hours	Std Dev	Minimum	Maximum	Range
1	164	93.5	136.1	0.0	613.0	613.0
2	102	70.6	80.5	4.0	408.0	404.0
3	63	68.9	100.1	0.0	728.0	728.0
4	50	81.2	79.0	0.0	340.0	340.0
5	22	76.0	78.0	10.0	249.0	239.0
6	13	122.5	77.4	12.0	286.0	274.0
7	13	153.1	151.2	19.0	538.0	519.0
8	8	116.0	79.4	16.0	231.0	215.0
9	2	476.0	121.6	390.0	562.0	172.0

governments use their long-term borrowing rate adjusted for the tax-exempt status of the interest payments.

THE COST OF THE CHALLENGER (AUTOMATIC GEARBOX)

Limited data are available at TxDOT on the historical costs for automatic gear box, 6-cubic-yard dump trucks. As summarized in Table 5.15, the significant downtime and repair costs for equipment 05260C and 05445D in the second year of operation, well above average for the manuals, may be explained by the preparation for operation. The amount of data available for the different age classes is not sufficient for the calculation of summary statistics (e.g., the mean for the different costs by age). Also unavailable are the life-cycle cost data for the operation of 10-cubic-yard automatic dump trucks (the 18 TxDOT units being too new to be useful for such data analysis).

The literature comparing automatics with manual trucks tends to favor automatics as regards repair and costs resulting from downtime. And automatics, as the literature points out, save money through their extended engine life and by obviating the need for clutch and pressure plate replacement. Yet information comparable to that found for manual trucks is not available for the automatics; nevertheless, the methodology presented in this chapter could be used in the future, when more data are available, to determine the life-cycle costs of automatic dump trucks.

SUMMARY

Figures 5.5 and 5.6 summarize the 6- and 10-cubic-yard manual dump truck life-cycle costs retrieved from the TxDOT data base. In the next chapter, this information will be compared (using financial modeling) with the available life-cycle cost information for automatics.

Table 5.15 Life-cycle cost data available for 6-cubic-yard automatic dump trucks

Equipment Number	Age	Annual Repair Cost	Fiscal Year	Total Mile-age	Operating Cost (Fuel, etc.)	Down Time	Annual Miles	Operating Cost per Mile
03608D	1	$0	88	5,812	$0	0	0	0.000
03609D	1	$0	88	12,533	$0	0	0	0.000
03611D	1	$0	88	9,263	$0	0	0	0.000
03612D	1	$0	88	9,033	$0	0	0	0.000
05260C	1	$10	87	13,278	$0	0	0	0.000
05261C	1	$247	87	14,452	$51	44	0	0.000
05262C	1	$8	87	16,137	$0	0	0	0.000
05445D	1	$0	89	0	$0	0	0	0.000
03608D	2	$539	89	18,951	$681	23	5,812	0.117
03609D	2	$2,395	89	28,300	$1,070	43	12,533	0.085
03611D	2	$2,039	89	28,663	$828	177	9,263	0.089
03612D	2	$2,536	89	23,299	$957	265	9,033	0.106
05260C	2	$2,926	88	32,331	$1,032	465	13,278	0.078
05261C	2	$3,328	88	31,029	$1,153	174	14,452	0.080
05262C	2	$3,006	88	38,405	$1,387	280	16,137	0.086
05445D	2	$2,009	90	12,061	$1,101	319	10,505	0.105
03608D	3	$538	90	27,743	$1,091	27	8,532	0.128
03609D	3	$921	90	43,133	$1,637	24	14,426	0.113
03611D	3	$831	90	46,375	$2,081	28	17,192	0.121
03612D	3	$1,312	90	36,600	$1,612	42	12,454	0.129
05260C	3	$1,428	89	51,924	$1,539	36	19,053	0.081
05261C	3	$827	89	49,891	$1,450	121	16,577	0.087
05262C	3	$1,471	89	51,555	$1,923	27	22,268	0.086
05260C	4	$1,163	90	72,110	$1,864	136	18,103	0.103
05261C	4	$1,759	90	70,007	$1,995	35	19,283	0.103
05262C	4	$1,119	90	60,318	$870	95	7,483	0.116

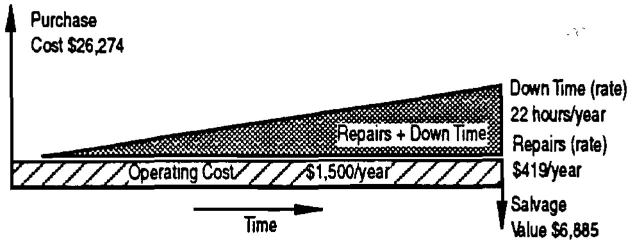


Figure 5.5 Data base analysis results for a 6-cubic-yard manual dump truck

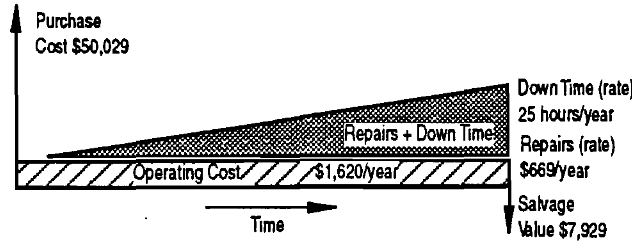


Figure 5.6 Data base analysis results for a 10-cubic-yard manual dump truck

CHAPTER 6. FINANCIAL ANALYSIS

INTRODUCTION

In establishing the life-cycle cost profiles for 6- and 10-cubic-yard dump trucks, the previous chapter analyzed the available historical cost data. Using the results of that analysis, this chapter presents financial models for comparison of automatic and manual dump trucks on a cost-performance basis. As discussed below, there are various techniques for comparing different alternatives on a financial basis (Refs 45, 46, and 47). However, it is important to note that no economic evaluation can replace the judgment of experienced managers, who must balance the quantitative aspects (presented in this chapter) with the non-quantitative aspects (presented in previous chapters) when comparing manual and automatic dump trucks.

ENGINEERING ECONOMICS

The methodologies used to compare alternatives on a financial basis and available in the literature of engineering economic analysis consist in converting cash flows to a single numeric value. Three of the methods include Net Present Value (NPV), The Internal Rate of Return (IRR), and the Equivalent Uniform Annual Cost (EUAC). In reviewing these techniques, the study team determined that the last method, EUAC, was the methodology most appropriate for comparing equipment alternatives and for determining equipment economic life, described in the literature as replacement analysis. The EUAC technique is particularly useful in comparing equipment alternatives when the alternatives in question have unequal economic life spans, such as found in the present case of automatic and manual dump trucks. The EUAC technique converts a series of cash flows, depicted in Figure 5.5 and 5.6 for the 6- and 10-cubic-yard manual trucks, into a series of equivalent annual cash disimbursements, as depicted in Figure 6.1. Using an analogy suggested by Figure 6.1, the process could be viewed as an exercise in translating truck costs assumed in the current TxDOT cost structure to an annual rent (including all maintenance) paid to a hypothetical leasing company for providing the same dump trucks to TxDOT. By using the EUAC technique, it is possible to compare, first, automatic and manual dump trucks on a financial basis and, second, to determine the required cost performance of automatic dump trucks to make them competitive with manuals.

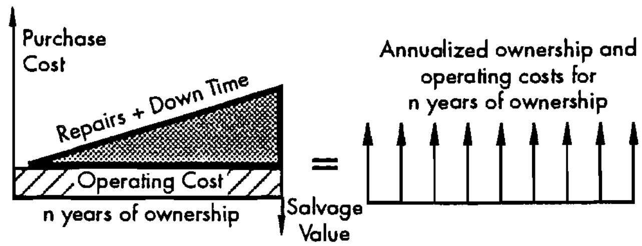


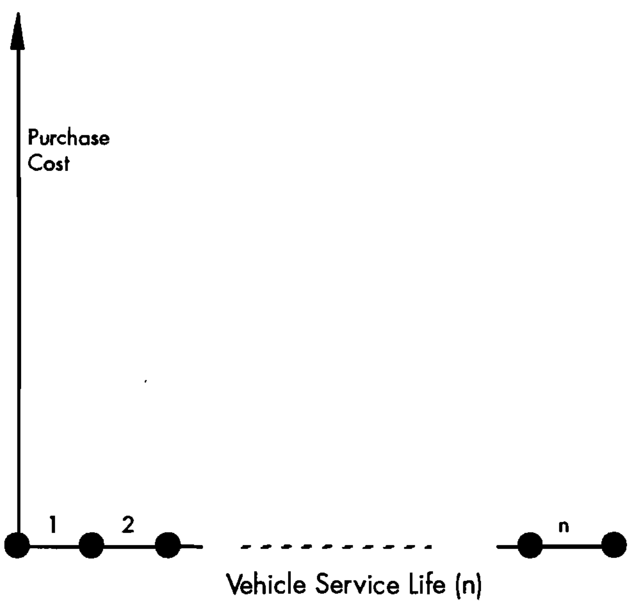
Figure 6.1 Conversion of cash flows to an annual series of costs

ANNUALIZED COSTS

The formulae used to convert the cash flows depicted in Figure 6.1 to annualized costs (extensively covered in the literature of engineering economics analysis) are summarized in Eqs 6.1 through 6.4. Annualized costs for a truck can be calculated for a different number of years for which the equipment is kept in operation. These costs may be divided as follows:

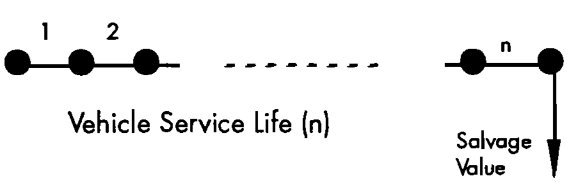
(1) the financial costs of owning the truck, and
(2) the costs of maintaining (scheduled and unscheduled repairs) and operating the truck (fuel, tires, and other fluids), including a charge for downtime to account for time and productivity losses.

Schematically, these costs as a function of the years of ownership are illustrated by Figure 6.2, where each point in the EUAC "Total Costs curve" represents the EUAC for owning and operating the equipment for a given number of years. Figure 6.2 also gives a quantitative description of what is known intuitively by both equipment managers and car owners: For the initial years of operation of a dump truck or a private car, the cost of owning the equipment prevails over all other costs. And because these ownership costs represent the cost of immobilized capital, it would therefore be a poor financial decision to replace a vehicle in the early years of ownership. On the other hand, as the vehicle ages the costs of repairs and associated downtime—represented by the operating cost curve in Figure 6.2—start placing a significant burden on the annualized total costs, making it a wise decision at a given point in the vehicle's economic life to replace it. It is possible through this financial modeling approach to identify the optimum point at which a given vehicle should be replaced. This task is accomplished by identifying the year of ownership of the vehicle for which the total annualized cost is minimum. This minimum can be easily determined by observing the curves illustrated in Figure 6.2.



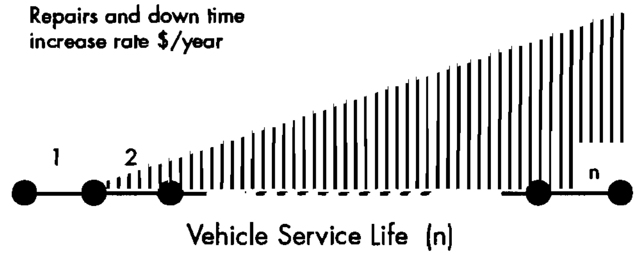
Multiply Purchase Cost by:

$$\frac{i(1+i)^n}{(1+i)^n - 1} \qquad \text{(Eq 6.1)}$$



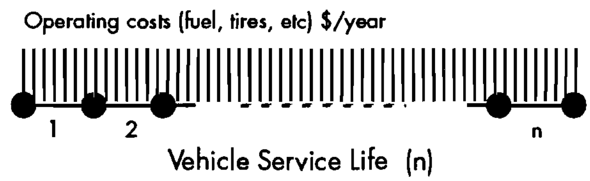
Multiply Salvage Value by:

$$\frac{i}{(1+i)^n - 1} \qquad \text{(Eq 6.2)}$$



Multiply the increase rate of the repairs + the down time by:

$$\frac{(1+i)^n - (1+ni)}{i\left[(1+i)^n - 1\right]} \qquad \text{(Eq 6.3)}$$



Multiply the operating costs by:

$$1 \qquad \text{(Eq 6.4)}$$

where (in all the above equations)

i = the discount rate, and
n = vehicle service life.

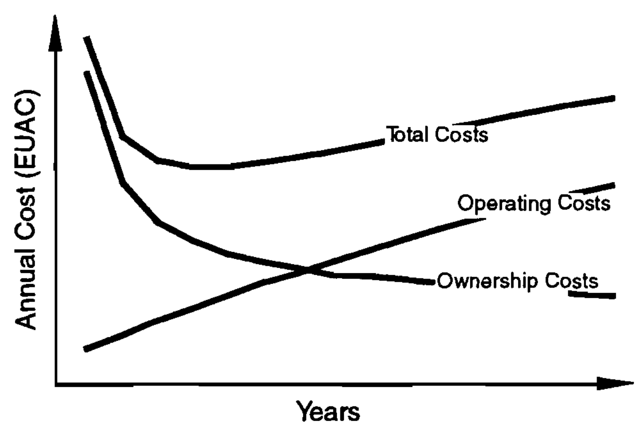


Figure 6.2 Equivalent Uniform Annual Costs (EUAC) of owning and operating equipment

Another feature of this model is the comparison of different vehicles on the basis of the minimum annual costs. With respect to this project, the comparison involves the cost performance of an automatic and manual transmission dump truck. By comparing the two minimums of the total cost curves for the two vehicles, it is possible to identify the most competitive option. It is important to note that the techniques presented here are applicable to similar decisionmaking problems that (1) involve comparing the performance of different vehicle models, or (2) relate to any equipment having a life-cycle pattern similar to that identified for dump trucks.

ANNUALIZED COST COMPONENTS AND THE AVAILABLE TXDOT DATA

Ownership Costs

The financial costs of owning a truck for a given period of time include the initial purchase cost less the salvage value of the truck at the end of its service life. And as discussed in the previous chapter, these two costs are routinely recorded for TxDOT manual 6- and 10-cubic-yard dump trucks. The purchase cost occurs at the beginning of year one of the life-cycle, while the retirement (or salvage) value occurs at an average age determined by statistical analysis of the data base. The historical data available for 6-cubic-yard dump trucks show that these trucks are kept in operation for 8 to 9 years on average. Using this information, the study team next developed a depreciation model for the numerical modeling that follows. This model, included in the routines of the program ANCOS (Annualized Costs of Vehicles) developed for this project (see appendix), describes how the salvage value is affected when ownership periods differ from the retirement history identified in the data. This depreciation model, adjusted and depicted in Figure 6.3, assumes that the salvage value of a vehicle, in a given year, is a constant percentage of the salvage value of the vehicle in the previous year, and that the vehicle loses a significant percentage of its value in its first year of operation. Two points of the depreciation curve need to be determined for the modeling, one from the data base through the salvage value and age of retirement, and a second through the assignment of a salvage value at the end of year one, defined by the decisionmaker. With these two points, it is possible to calculate the constant percentage rate of depreciation after year one through Equation 6.5, and the salvage value by the end of any year by using Equation 6.6.

$$D_{rate} = \left(\frac{V_r}{V_{y1}} \right)^{\frac{1}{(y_r - 1)}} \qquad \text{(Eq 6.5)}$$

$$V_{yn} = V_{y1} \left(D_{rate} \right)^{(y_n - 1)} \qquad \text{(Eq 6.6)}$$

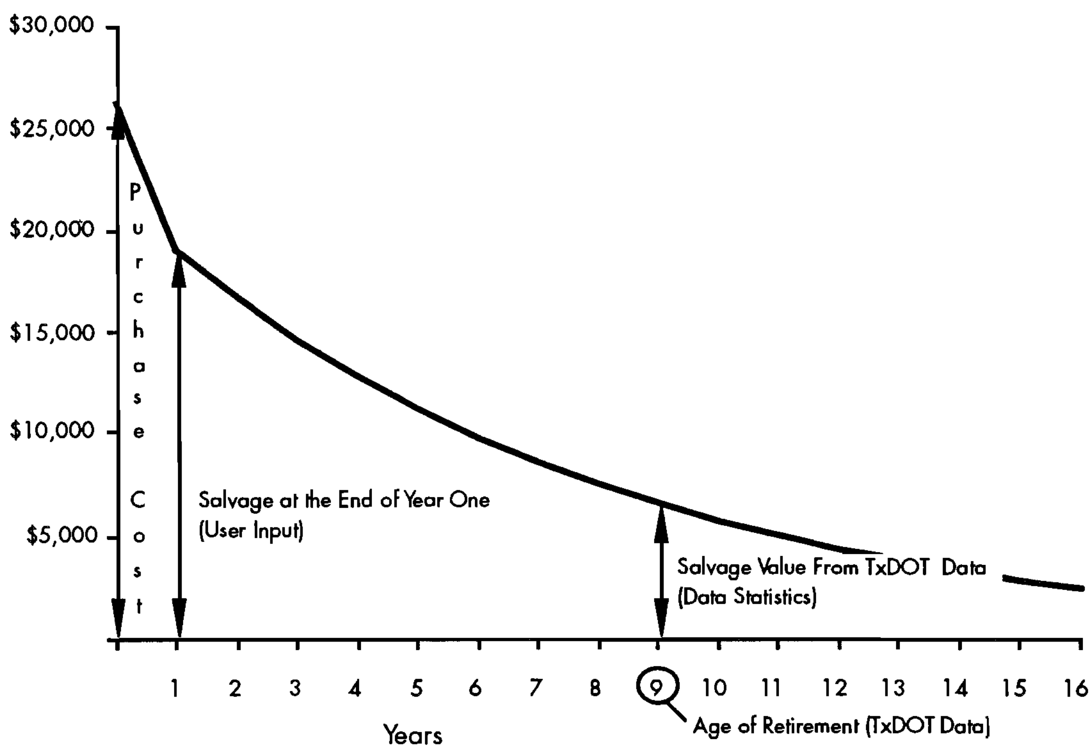


Figure 6.3 Depreciation model for use in the analysis and ANCOS program

where

D_{rate} = the depreciation rate after year one,
V_{y1} = the salvage value by the end of year one,
V_r = the salvage at retirement (from TxDOT data),
y_r = the age at retirement (also from TxDOT data),
V_{yn} = the salvage value at the end of the n^{th} year, and
y_n = the age at the end of the n^{th} year.

In the future, when more data are available for manual and automatic dump trucks, the model depicted in Figure 6.3 may still be used for the financial modeling, with such updated parameters as purchase cost, salvage value, and the age at retirement obtained from analysis of the TxDOT data base. The salvage value at the end of year one, as discussed before, is a parameter to be established by the decisionmaker using the model; it allows that decisionmaker to account for the steep loss in value that occurs during a vehicle's first year of operation. These calculations for depreciation are automatic in the program ANCOS. An example using the parameters depicted in Figure 6.3 is presented in Table 6.1; the constant percentage rate of depreciation after year one calculated for this example by substituting the parameters in Equation 6.5 is 88 percent.

Table 6.1 Numerical example for depreciation

Years Keeping Truck	Salvage Value by End of Year
0	$26,000 *
1	$19,000
2	$16,720
3	$14,714
4	$12,948
5	$11,394
6	$10,027
7	$8,824
8	$7,765
9	$6,833 #
10	$6,013
11	$5,292
12	$4,657
13	$4,098
14	$3,606
15	$3,173
16	$2,793

* Purchase Cost from TxDOT data

\# Salvage Value and Age of Retirement from TxDOT data

For each number of years of ownership, the financial costs of owning the vehicle consist of annualizing the cash flow depicted in Figure 6.4 by using Eqs 6.1 and 6.2. Repeating the process for several ownership periods of the vehicle allows for the plotting of a curve similar to the annualized ownership cost curve depicted in Figure 6.2.

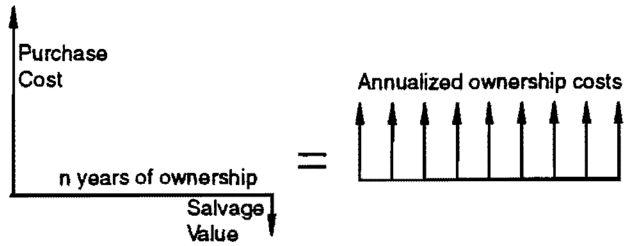


Figure 6.4 Annualized ownership costs

Operating Costs

The costs of maintaining and operating a truck include the costs of fuel, other fluids, and tires (which are fairly constant for a given annual mileage); the costs of unscheduled repairs; and costs associated with equipment downtime. Downtime and unscheduled repairs are likely to increase with the age and usage of the vehicle, while the parameters for the costs of maintaining and operating manual dump trucks were discussed in the previous chapter.

The procedure for calculating the data points for the operating cost curve depicted in Figure 6.2 involves converting the different costs involved into an EUAC, as schematically depicted in Figure 6.5. This task is accomplished by applying Eqs 6.3 and 6.4 to the data, a procedure fully automatized by the ANCOS program.

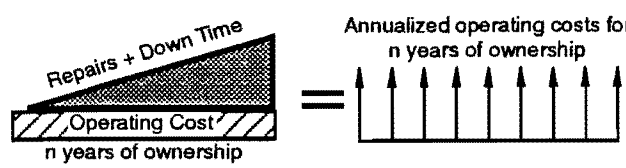


Figure 6.5 Annualized operating costs

THE ANCOS PROGRAM

The program ANCOS, which automatizes all the concepts presented in the previous discussion, uses a data input screen to prompt the user for the parameters that describe the life-cycle costs of the vehicle. As an example, Figure 6.6 illustrates the data screen for the manual 6-cubic-yard dump truck life-cycle cost data calculated in the previous chapter and summarized by Figure 5.5. For a given planning horizon, the program outputs a table, depicted in Figure 6.7, and a chart similar to that depicted in Figure 6.2. The chart highlights the minimum point and reports the value for the minimum, together with the number of years of ownership for the minimum. The minimum point can also be found by reviewing the table depicted in Figure 6.7. This minimum, defining the optimum period of ownership and the associated cost of owning and operating a vehicle, may be used, as discussed before, to compare two alternative vehicles (e.g., manual and automatic dump trucks).

after be referred to as the base case for manual 6-cubic-yard dump trucks. Importantly, the results depicted in Figure 6.7 are extremely sensitive to the discount rate and other parameters, as will be discussed later in the sensitivity analysis section.

The following exercise may be instructive: assume that the life-cycle costs for an automaticdump truck are equivalent to those for the base case (manual truck), the only difference being the higher initial purchase cost of $35,718, including the body added by the Texas Department of Criminal Justice (TDCJ); calling this the base

```
ANCOS                                              Screen 2

                       INPUT SCREEN

Purchase Cost . . . . . . . . . . . . . . . . . . . . .   32456
Salvage Value (first year). . . . . . . . . . . . . . .   23368
Depreciation Life (yrs) . . . . . . . . . . . . . . . .       9
Salvage Value at End of Depreciation Life . . . . . . .    6885
Operating Costs (fuel, tires, etc.) . . . . . . . . . .  1500.0
Increase in Repair Costs ($/yr) . . . . . . . . . . . .   419.0
Increase in Down Time (hr/yr) . . . . . . . . . . . . .   22.00
Downtime Rate ($/hr). . . . . . . . . . . . . . . . . .   20.00
Planning Horizon (yr) . . . . . . . . . . . . . . . . .      16
Discount Rate (%) . . . . . . . . . . . . . . . . . . .   10.00

                       F1 - CONTROL                        1
```

Figure 6.6 Input screen for the program ANCOS (base case)

MANUAL OR AUTOMATIC DUMP TRUCK: THE BASE CASE

A significant amount of data available at TxDOT was used in the previous chapter to calculate the life-cycle costs for a 6- and a 10-cubic-yard manual dump truck. These life-cycle profiles, depicted in Figures 5.5 and 5.6, develop a benchmark for comparing alternative options, such as automatic dump trucks. The optimum solution for the base case is the minimum annualized cost calculated for a 6-cubic-yard manual dump truck in Figure 6.7. For the inputs depicted in Figure 6.6, the minimum annualized cost of owning and operating a 6-cubic-yard manual dump truck would be $9,434, representing the costs for operating the truck for 7 years before replacing it with similar equipment and in an infinite cycle. These results will here-

case for an automatic dump truck, and using the program ANCOS, we arrive at a minimum cost of $10,075 for owning and operating the automatic 6-cubic-yard dump truck for 8 years. Given this scenario, the decisionmaker must determine if the annual difference of $641 is compensated by productivity and safety gains obtained by operating automatics in lieu of manuals.

The modeling can be used to analyze another important question: What percentage decrease in the repair costs and downtime could make the automatic dump trucks competitive with the manuals on an annualized cost basis? The ANCOS program, again, can be used to provide an answer. Using the program with the rate of increase of downtime and the rate of increase of repair costs reduced by 22.14 percent from the base case, and with the purchase cost and body cost of $35,718 for an

```
---------------------------- OUTPUT SCREEN ----------------------------

                    Annual        Annual        Total
         Years     Operating     Ownership      Annual
          Kept       Cost          Cost          Cost
         -----     ---------     ---------      ------
           1         1500         12334         13834
           2         1909          9150         11059
           3         2305          7850         10154
           4         2686          7055          9741
           5         3055          6484          9539
           6         3410          6041          9451
           7         3752          5682          9434
           8         4081          5382          9463
           9         4397          5129          9526
          10         4700          4911          9611
          11         4991          4723          9714
          12         5270          4560          9829
          13         5536          4417          9953
          14         5791          4291         10082
          15         6035          4180         10215
          16         6267          4083         10350

                Press (Almost) Any Key to Continue ...
```

Figure 6.7 Output screen for the program ANCOS

automatic, the annualized cost of owning and operating the automatic dump truck for 10 years is $9,434—a value that matches exactly the amount calculated for the manual base case (the output for this scenario is presented in Figure 6.9 and the inputs in Figure 6.8). This reduction in downtime and repair costs thus defines the breakeven point between automatic and manual 6-cubic-yard dump trucks.

Using the statistics calculated in the previous chapter, the same methodology can be applied to the 10-cubic-yard dump truck models; the results of such an exercise are summarized as follows:

1. The base case for manual 10-cubic-yard (see Figure 5.6) with a depreciation life of 8 years and a salvage value at the end of year one of $38,000 gives a calculated minimum annual cost of $13,783 for 9 years of service life.
2. The base case for automatics (same as in the previous item) with a purchase cost of $61,255, the average purchase price for the 10-cubic-yard automatic trucks purchased in 1990 (from Table 5.2), gives a calculated minimum annual cost of $15,583 over 11 years of service life.
3. The breakeven point for the automatic 10-cubic-yard trucks with the manual 10-cubic-yard trucks is for a reduction of the downtime and the unscheduled repair cost rate of 32.6 percent.

SENSITIVITY

The results obtained by the program ANCOS are extremely sensitive to the inputs, particularly the discount rate. Table 6.2 demonstrates the sensitivity of the base case for 6-cubic-yard manuals for different discount rates. Table 6.2 shows that, as the discount rate increases, the minimum cost of owning and operating the manual 6-cubic-yard truck increases, and that the economic life of the

Table 6.2 Sensitivity of the manual 6-cubic-yard (base case) to the discount rate

Discount Rate	Minimum Total Cost	Year of Minimum
1%	$7,401	5
2%	$7,632	5
3%	$7,865	5
4%	$8,099	6
5%	$8,319	6
6%	$8,541	6
7%	$8,766	6
8%	$8,992	6
9%	$9,216	7
10%	$9,434	(base case) 7
11%	$9,654	7
12%	$9,877	7
13%	$10,099	8
14%	$10,317	8
15%	$10,538	8
16%	$10,761	8
17%	$10,982	9
18%	$11,204	9
19%	$11,429	9
20%	$11,654	10

```
ANCOS                                              Screen  2

                        INPUT SCREEN

Purchase Cost . . . . . . . . . . . . . . . . . . . . .     35718
Salvage Value (first year). . . . . . . . . . . . . . .     23368
Depreciation Life (yrs) . . . . . . . . . . . . . . . .         9
Salvage Value at End of Depreciation Life . . . . . . .      6885
Operating Costs (fuel, tires, etc.) . . . . . . . . . .    1500.0
Increase in Repair Costs ($/yr) . . . . . . . . . . . .    326.23
Increase in Down Time (hr/yr) . . . . . . . . . . . . .     17.13
Downtime Rate ($/hr). . . . . . . . . . . . . . . . . .     20.00
Planning Horizon (yr) . . . . . . . . . . . . . . . . .        16
Discount Rate (%) . . . . . . . . . . . . . . . . . . .     10.00

                        F1 - CONTROL                            1
```

Figure 6.8 Input screen for the program ANCOS for the breakeven point between automatic and manual 6-cubic-yard dump trucks

OUTPUT SCREEN

Years Kept	Annual Operating Cost	Annual Ownership Cost	Total Annual Cost
1	1500	15922	17422
2	1818	11029	12848
3	2126	9161	11288
4	2424	8084	10508
5	2711	7345	10055
6	2987	6790	9777
7	3253	6352	9605
8	3509	5994	9503
9	3756	5695	9451
10	3992	5442	9434
11	4218	5226	9444
12	4435	5038	9474
13	4643	4876	9519
14	4841	4734	9575
15	5031	4609	9640
16	5212	4500	9711

Press (Almost) Any Key to Continue ...

Figure 6.9 Output screen for the program ANCOS for the breakeven point between automatic and manual 6-cubic-yard dump trucks

unit, defined by the minimum total annualized cost, also has to increase. Because the discount rate includes an allowance for inflation, the curves in Figure 6.10 show that when the inflation rate increases the economic life of the truck combined with the annualized costs also increases. The points on Table 6.2 and for all the sensitivity analysis tables that follow are the minimum points of a family of curves, with each curve defined by one value of the sensitivity analysis variable. This family of curves, depicted in Figure 6.10, shows both the discount rate sensitivity analysis and the minimum annualized total cost curve for different levels of the discount rate.

Downtime is another factor that significantly influences the calculations. As expected, as the downtime unit cost increases, the minimum total cost increases and the economic life of the dump truck shortens. Results for the sensitivity analysis on downtime cost are presented in Table 6.3.

Table 6.3 Sensitivity of the manual 6-cubic-yard (base case) to the downtime cost (10 percent discount rate)

Down Time Cost ($/hour)	Minimum Total Cost	Year of Minimum
$0	$7,884	14
$10	$8,784	9
$20	$9,434	(base case) 7
$30	$9,937	5
$40	$10,336	5
$50	$10,653	4
$60	$10,957	4
$70	$11,184	3
$80	$11,390	3
$90	$11,597	3
$100	$11,803	3
$110	$12,001	2
$120	$12,106	2
$130	$12,211	2
$140	$12,316	2
$150	$12,421	2

Sensitivity Analysis for the Automatic Base Case

The sensitivity of the minimum annualized costs for the 6-cubic-yard automatic dump truck (base case) to the decrease in downtime rate and repair cost rate is presented in Table 6.4. As discussed previously, the breakeven point between the automatic and the manual 6-cubic-yard truck is represented by a decrease in the downtime rate and unscheduled repair rate of 22.14 percent. From this point on, the automatic 6-cubic-yard dump trucks become competitive costwise, even without considering such intangibles as gains in productivity and increased safety levels discussed in previous chapters.

INTANGIBLE BENEFITS

The ideal approach to life-cycle cost modeling with EUAC would be to include all the life-cycle costs and benefits derived from the use of manual and automatic dump trucks. As an example, any possible gains in productivity and safety associated with the automatic dump truck should be translated into monetary values and included as positive inputs into the life-cycle cost of the automatic dump truck. Including intangible benefits, discussed in the previous chapters, would lead to a reduction in the annualized costs and would consequently make the automatic dump truck more competitive with the manual. It is, however, very difficult to assign monetary values to gains in productivity and safety; nonetheless, the decision maker should take these factors into account when comparing alternatives. In summary, EUAC comparisons are not the final word on a decision process; consequently, this method should be balanced by a consideration of the intangible advantages each option might conceivably confer.

Table 6.4 Sensitivity of the automatic 6-cubic-yard to decreases on downtime and repair rates (constant 10 percent discount rate)

Decrease or Down Time and Repair Cost Rates	Minimum Total Cost	Year of Minimum
0%	$10,075	8 *
5%	$9,946	8
10%	$9,802	9
15%	$9,657	9
20%	$9,502	10
22.14%	$9,434	10 #
25%	$9,342	10
30%	$9,169	11
35%	$8,989	12
40%	$8,798	13
45%	$8,594	14
50%	$8,377	15
55%	$8,145	16
60%	$7,897	18
65%	$7,630	20
70%	$7,342	22
75%	$7,030	26
80%	$6,692	30
85%	$6,324	38
90%	$5,924	52

* Automatic base case
\# Breakeven with manuals

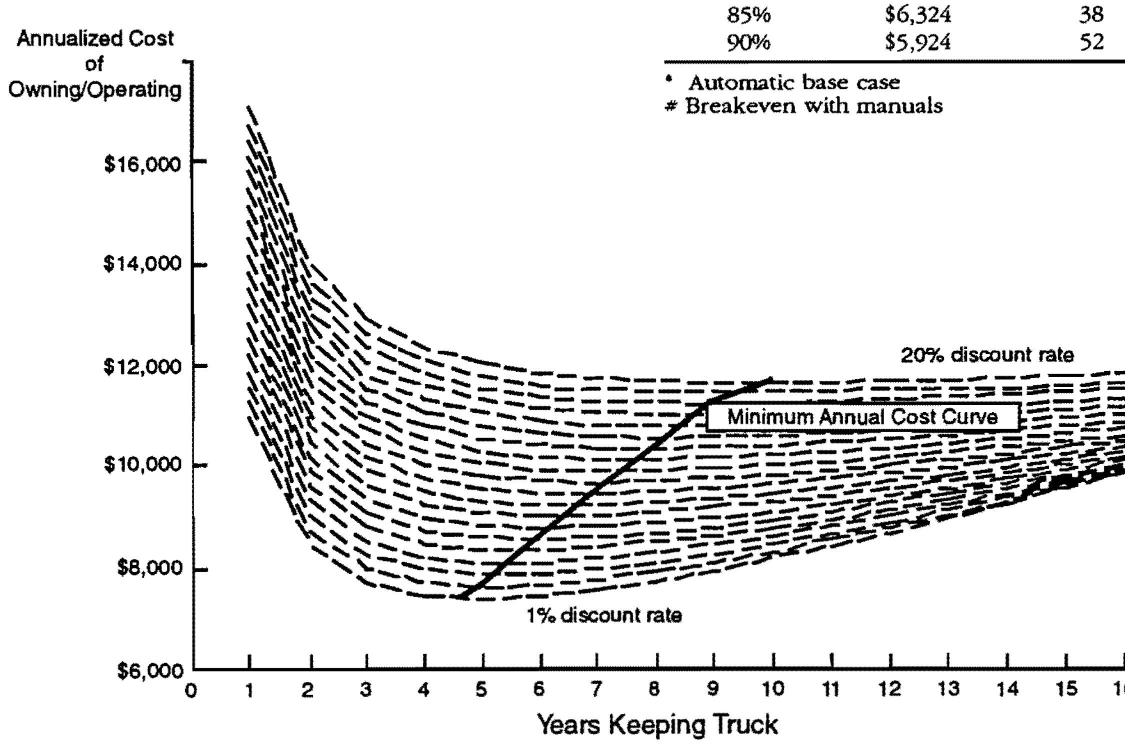


Figure 6.10 Sensitivity analysis of the base case for manuals to the discount rate

CHAPTER 7. CONCLUSIONS AND RECOMMENDATIONS

INTRODUCTION

Regarding other instances of states specifying automatic transmissions for public utility and highway department trucks, a detailed literature search revealed that: (1) the investigation was well timed (in view of recent developments in automatic transmissions); and (2) any evaluation should include all facets of the question, including truck purchasing, operation, and use (such a holistic view is important, since in addition to the more obvious financial considerations there are a number of key intangibles that relate to truck efficiency and total system cost). While at present the high initial costs do not favor automatic transmission adoption, there are potential developments that will effectively reduce these costs. Currently, TxDOT data show that the differences between manual and automatic transmissions are considerable ($3,262 for a 6-cubic-yard truck and $11,226 for a 10-cubic-yard truck). There is some concern that these differentials arose out of the present quasi-monopoly situation held by the Allison division and its agents in terms of automatic transmission supply. A more competitive bidding situation between the suppliers of alternative automatic transmissions would no doubt reduce these prices and differentials. One such development would be the electronic gear box, which has a number of advantages in terms of workshop maintenance, driver operation, and initial cost. However, this unit is still in the developmental stage and cannot affect TxDOT policy over the next 5 years.

After discussing the literature survey results with senior D-4 staff, the project team developed a number of key hypotheses. Forming the major elements of the study, these hypotheses can be summarized as follows:

1. Workshops could use automatic trucks on duties that match their special operating characteristics.
2. Automatic transmission trucks are safer to operate.
3. Drivers favor automatics, thereby improving morale and attracting new drivers.
4. Automatic transmissions are more costly to specify but have lower maintenance costs and reduced downtime. Therefore, their life-cycle costs are lower than those associated with manual transmission trucks.

WORKSHOPS THAT MATCH WORK DUTIES TO TRANSMISSION TYPES

It was thought after the literature review that trucks equipped with automatic transmissions would offer specific benefits to workshop managers when allocating job duties. CTR staff speculated that, in addition to the well-known benefits obtained from activities like herbicide spraying, there would be a range of work activities favoring automatics because of their technical characteristics. Accordingly, we reviewed the use of automatic-transmission-equipped trucks in those TxDOT workshops where automatics had recently been assigned. Surprisingly, we found that there was very little difference between the work duties of manual and automatic dump trucks. It would seem at the moment that the claims in the literature are not reflected in TxDOT workshop duties. This is a very interesting element to any evaluation of dump truck operations: If there were indeed no differences in the work duties assigned to manual and automatic trucks, then part of the rationale (clear productivity gains) for purchasing the more expensive automatic vehicles is weakened. It may be that workshop managers are as yet not used to working with these trucks, and that after several years in a workshop fleet a much higher discrimination between the two types would emerge; this, however, is pure speculation. Finally, it should be emphasized that productivity per hour of operation could well be higher for automatic trucks, but this was not the objective of our survey. What we do know for certain at the moment is that when D-4 purchases an automatic transmission dump truck and sends it to a District workshop, it is assigned duties very similar to those assigned to the manually equipped dump trucks already operating.

AUTOMATIC TRUCK SAFETY

Safety was also investigated by the study team. However, like most of the accident data associated with commercial vehicles, dump truck safety data are sparse and inconclusive. At this time it is not possible to say that automatic transmissions have resulted in lower accidents per mile of travel within the TxDOT dump truck fleet. Of course, this is directly related to the number of automatic transmission vehicles in the fleet (which are few) and to the low annual utilization of these vehicles—which affects the accident rates per mile of travel. On the other hand, the driver survey did support the view that automatics are generally easier to drive and do permit the driver more time to concentrate on other duties in the truck cab. This clearly affects the performance of the driver with respect to his driving operations and certainly conduces to the qualitative opinion voiced by current TxDOT drivers that automatics are safer vehicles.

DRIVER ACCEPTANCE AND MORALE

At the outset of this study, the project team assumed that if TxDOT had vehicles that were easier to drive and safer to operate, then the Department could compete more effectively for drivers in the next decade. This was considered important because more stringent regulations are planned for Texas concerning commercial vehicle operations. The necessity of both possessing a specific license and passing drug tests for dump truck operations will reduce the pool from which TxDOT draws its operators. The TxDOT driver profile shows that a large number of experienced truck operators are going to retire by the time the new regulations go into effect, making TxDOT especially vulnerable to workforce shortages. How should the Department respond? First, it has to compete effectively with other truck operators for the reduced driver pool. Second, it might be able to enlarge that pool of potential drivers by adopting vehicles that are easier to operate and less stressful to drive.

Results from the drivers' survey demonstrate that automatic vehicles enhance the likelihood that TxDOT can successfully recruit operators during this sensitive period. About 80 percent of the respondents thought that automatics were easier to use on congested streets. About 75 percent thought that automatics allowed the operators to concentrate on driving duties—a response that directly relates to perceptions of safety. Another issue considered was the level of operator satisfaction that comes with mastering the more challenging system represented by manual transmissions. Although 50 percent of the drivers surveyed thought manuals were more rewarding to drive, 70 percent still considered automatic transmissions preferable. And in view of the fact that manual transmission are extremely stressful on the body's muscle and nervous systems, an important finding of the study was the discovery that older drivers benefited greatly from the adoption of automatic transmissions. A number of older drivers suffering from backache and spinal problems reported that automatic transmissions permitted them to work more effectively and to avoid early retirement. Given that the age profile of TxDOT drivers is highly skewed towards older drivers, improving driver environment becomes critical. In addition, the study found that automatic transmissions are associated with high morale, high productivity, and fewer days of sick leave required among older drivers. Thus, the specification of automatic transmissions can attract new drivers while at the same time postponing the retirement of older drivers.

FINANCIAL EVALUATION OF AUTOMATIC TRUCKS

The financial evaluation, based on an extensive analysis of workshop data for all TxDOT dump trucks over the 1986–1990 period, resulted in reliable life-cycle cost profiles for 6- and 10-cubic-yard manual dump trucks. Life-cycle cost data available for the automatic models, in contrast with the vast amount of data available for the manuals, are scarce and allow only for the reliable calculation of the initial cost of purchase. However, two important questions may be answered by the available data. First, how much more does it cost, in terms of annualized costs, to own and operate an automatic dump truck? This assumes the only difference between the life-cycle cost profiles of manual and automatic dump trucks is the purchase cost and, consequently, there are no gains through reductions on the down time and repair costs. Second, how much better, in terms of downtime and repair costs, do automatic dump truck models have to perform in order to outperform manual dump trucks on an annualized-cost basis? Answers to these two questions were investigated for a 10-percent discount rate and for a $20 per hour unit cost for the downtime.

For the first scenario, the annualized cost difference between automatics and manuals is $641 for 6-cubic-yard trucks and $1,800 for 10-cubic-yard trucks. In any full-system cost evaluation, such cost differentials should be balanced by productivity, safety, morale, and driver recruiting (presently not quantified by the model).

For the second scenario, repair and downtime annual rates of increase need to be reduced by 22 percent for 6-cubic-yard automatic trucks and by 33 percent for 10-cubic-yard trucks for these to outperform the manuals on an annualized-cost basis. There is an indication in the literature (Ref 14) that these are feasible goals for the reduction of the repair and downtime. On the other hand, there are reports from the Wyoming DOT of higher repair costs for automatic transmission dump trucks in comparison with manuals.

However, combining the quantitative analysis with the qualitative features of safety and driver morale significantly supports the case for adopting automatic transmissions in purchasing specifications.

SUMMARY

The key recommendations of the project are twofold: First, under present pricing there is little financial and economic justification for purchasing automatic transmissions. Second, benefits accruing to the workforce appear to be extremely significant. A critical feature of this study was to evaluate these impacts by developing a financial model, one that allows users to input such variables as the purchase cost of the equipment to determine the cost performance required by a particular piece of equipment. This model will allow the D-4 staff to evaluate future specifications proposed by manufacturers of automatic transmissions. Once the purchase prices are input, the model will predict how long the vehicles must be kept by the workshops. Moreover, this model is generically structured so that it may be used in *any* decision-making process where improvements to workshop equipment are being offered to the Department. To assist D-4 staff, the model was written in a user-friendly format for operation on PC units.

Because the results of the financial analyses were limited by lack of operating data for automatic dump trucks, it is therefore vital that the existing automatic trucks are, over their service lives, carefully monitored and periodically reviewed by D-4 staff. If these truck types turn out to have significantly lower repair costs and downtime rates, the case for their widespread adoption by TxDOT will be strengthened, especially given the findings on driver preferences for automatic transmissions.

REFERENCES

1. Stark, J. A., "Heavy Duty Transmissions," 24-29, Automotive Transmissions, T&OH, December 1978.
2. Records provided by Allison Transmission Division, U.S.A., State Government Total Vehicles with Allison Penetration, November 1989.
3. "Transmissions for the '90s," 88-96, Fleet Owner, April 1989.
4. Patterson, D. J., A. J. Houtman, R. Mitchell, "Power-assisted Steering and Automatic Transmissions in Line Haul Truckload Trucks," Dept. of Applied Mechanics and Mechanical Engineering, University of Michigan, 1989.
5. Smiley, C. H., "The Changing World of Transmissions," 94-96, Truck Talk, 1978.
6. Abbott, R. L., "Automatic Transmission for Trucks, Buses, and Off-Highway Vehicles," Society of Automotive Engineers, Inc. 710202.
7. Tanaka, S., F. Momiyama, M. Terasawa, and S. Innami, "Electronically Controlled Mechanical Automatic Transmission for Heavy Duty Trucks and Buses," SAE paper 861050.
8. "Truck Transmissions Have Electronic Management," 37-39, Automotive Engineering, January 1986.
9. Myers, G. L., "Electronically Controlled Semi-Automatic Transmissions for Heavy-Duty Trucks," SAE paper 740266.
10. "Future Commercial Vehicle Transmissions," 57-58, Automotive Engineering, January 1989.
11. "Eaton Offers Automatic Transmission," 42, Transportation Executive Update, September/October 1989.
12. Cottingham, E. R., "An Automatic Transmission in Line Haul Vehicles After Two Years of Fleet Evaluation," SAE paper 750730.
13. "Transmission Comparison Test Allison AT 540 / 5-Speed Manual Conducted by USAC," USAC, August 1977.
14. J. C. Penney White Paper, "J. C. Penney Internal Correspondence," October 1977.
15. "AT 545 Automatic Transmission Fuel Economy Tests," Detroit Diesel Allison, August 1984.
16. "P&D Maintenance Costs," Go West, 23-26, November 1987.
17. Interoffice Memorandum, "Diesel Dump Truck Automatic Transmission Survey," October 1989.
18. Cover letter from Tim Westphal to Joe Howard, dated November 15, 1989, for Dump Truck Market Vocational Study.
19. "Automatic Transmissions: Reports from the Field," Public Works, November 1987.
20. "City Cuts Costs with Automatic Transmissions," Public Works, September 1987.
21. "South Carolina's Fleet Goes Entirely Automatic," School Bus Fleet, June/July 1988.
22. "Test Results," brochure by Detroit Diesel Allison, April 1986.
23. "Driver Stress and Fatigue as Economic Factors in the Trucking Industry," Allison Transmission Division, 1989.
24. Lane, L., "Possible Automatic Transmission Breakthrough for TL Trucking," Intermodal Trends Vol. 7, No. 16, American Association of Railroads, Washington, D.C., 1989.
25. Patterson, D. J., A. J. Houtman, and R. Mitchell, "Power Assisted Steering and Automatic Transmissions in Line-Haul Truckload Trucks," Dept. of Applied Mechanics and Mechanical Engineering, University of Michigan, April 1989.

26. Cameron, C., "A Theory of Fatigue," Ergonomics, No. 16, pp 633-648, 1973.

27. Musio, B., "Is a Fatigue Test Possible?" British Journal of Psychology, No. 12, pp 31-46, 1921.

28. Bills, A. G., General Experimental Psychology, New York: Longmans Green, 1934.

29. Bartley, S. H., and E. Chute, Fatigue and Impairment in Man, New York: McGraw-Hill, 1947.

30. Caldwell, L. S., and J. M. Lyddan, "Serial Isometric Fatigue Functions with Variable Intertrial Intervals," Journal of Motor Behavior, No. 3, pp 17-30, 1971.

31. Public Works, "Automatic Transmissions: Reports from the Field," Public Works, pp 51-52, November 1987.

32. Hockey, R., *Stress and Fatigue in Human Performance,* John Wiley & Sons, Ltd, 1983.

33. Parasuraman, R., and D. R. Davies, "A Taxonomic Analysis of Vigilance Performance," in R. R. Mackie (ed.) Vigilance: Theory, Operational Performance Physiological Correlates, New York: Plenum Press, 1977.

34. Bartlett, F. C., "Fatigue Following Highly Skilled Work," Proceedings of the Royal Society, Series B, No. 131, pp 247-257, 1943.

35. Guest, D., R. Williams, and P. Dewe, *Job Design and the Psychology of Boredom.* Paper presented at the 19th International Congress of Applied Psychology, Munich, Germany, 1978.

36. McBain, W. N., "Arousal, Monotony and Accidents in Line Driving," Journal of Applied Psychology, No. 54, pp 509-519, 1970.

37. P&D Specing, "For P&D, This One Is Ready-Made," P&D Magazine, pp 15-16, May/June 1991.

38. Rollins, B. R., and W. F. McFarland, "Costs of Motor Vehicle Accidents and Injuries," Transportation Research Record, No. 1068, pp 1-7, 1986.

39. Allison Transmission Division, *An Investment in Savings and Stress Reduction,* Report SA2254, 1989.

40. Allison Transmission Division, *Driver Stress and Fatigue as Economic Factors in the Trucking Industry,* Report SA2263, 1989.

41. Dhilon, B. S., *Life Cycle Costing,* Gordon and Breach Science Publishers, New York, 1988.

42. "Highway Statistics," Federal Highway Administration, Washington, D.C., 1989.

43. Brown, R. J., and R. R. Yanuck, *Introduction to Life Cycle Costing,* Prentice Hall, Englewood Cliffs, 1985.

44. Vorster, C. M., and J. M. Garza, "Consequential Equipment Costs Associated with Lack of Availability and Downtime," Journal of Construction Engineering and Management, ASCE, Vol. 116, No. 4, December 1990.

45. Smith, G. W., *Engineering Economy,* 3rd edition, The Iowa State University Press, Ames, Iowa, 1979.

46. White, A. J., M. H. Agee, and K. E. Case, *Principles of Engineering Economic Analysis,* John Wiley & Sons, New York, 1988.

47. Grant, E. L., W. G. Ireson, and R. S. Leavenworth, *Principles of Engineering Economy,* John Wiley & Sons, New York, 1990.

APPENDIX A:

MANUAL AND SOURCE CODE FOR THE PROGRAM ANCOS

MANUAL FOR THE PROGRAM ANCOS

The program ANCOS (Annualized Costs), discussed in Chapter 6 of this report, allows for the conversion of life-cycle costs into EUAC (Equivalent Uniform Annual Costs). In prompting the user through a series of screens, this program allows for a sensitivity analysis by storing a base case in a permanent file in a computer disk. The program is invoked by inserting the disk with the executable module of the program ANCOS and typing ANCOS. The first screen that will be displayed is presented in Figure A.1. Press any key to continue the processing.

```
------------------------------------------------------------
          ŒŒŒŒ    ŒŒŒ  ŒŒ  ŒŒŒŒŒŒ  ŒŒŒŒŒŒ  ŒŒŒŒŒŒ
          ŒŒŒŒ    ŒŒŒ  ŒŒ  ŒŒŒŒŒŒ  ŒŒŒŒŒŒ  ŒŒŒŒŒŒ
         ŒŒ  ŒŒ   ŒŒŒŒ ŒŒ  ŒŒ      ŒŒ  ŒŒ  ŒŒ
         ŒŒŒŒŒŒ   ŒŒ ŒŒŒŒ  ŒŒ      ŒŒ  ŒŒ  ŒŒŒŒŒŒ
         ŒŒŒŒŒŒ   ŒŒ  ŒŒŒ  ŒŒ      ŒŒ  ŒŒ      ŒŒ
         ŒŒ  ŒŒ   ŒŒ   ŒŒ  ŒŒŒŒŒŒ  ŒŒŒŒŒŒ  ŒŒŒŒŒŒ
         ŒŒ  ŒŒ   ŒŒ   ŒŒ  ŒŒŒŒŒŒ  ŒŒŒŒŒŒ  ŒŒŒŒŒŒ

                 Annualized Cost For Vehicles
                 Version 1.0 - October 1991

                  Developed under Project 979
              Center for Transportation Research
               The University of Texas at Austin
                             and
              Texas Department of Transportation
                        Austin, Texas
                        Programmed by
                   J. Weissmann & T. Dossey
------------------------------------------------------------

           Press (Almost) Any Key to Continue ...
```

Figure A.1 First screen for the program ANCOS

The second screen for the program ANCOS includes default values for the life-cycle cost attributes. At this point, it is possible to move from one input field to another (by using the RETURN key, the TAB key, or the arrow keys) to edit the contents of each field. The F1 key gives access to a pop-up menu that allows for different selections; the second screen, with the pop-up menu displayed, is depicted in Figure A.2. Several alternatives are accessed from this pop-up menu. Pressing F2 retrieves a previously saved worksheet (a feature that is useful for performing sensitivity analysis). Pressing the F3 key allows the user to save the current version of the worksheet in a disk file for future sensitivity analysis. For both the F2 and F3 keys, a sub-menu prompts the user for a file name either to be retrieved or to be stored as a worksheet. Figure A.3 depicts screen 2 of the program ANCOS with the file sub-menu enabled. This is accomplished by pressing the F2 key after pressing the F1 key while in editing mode.

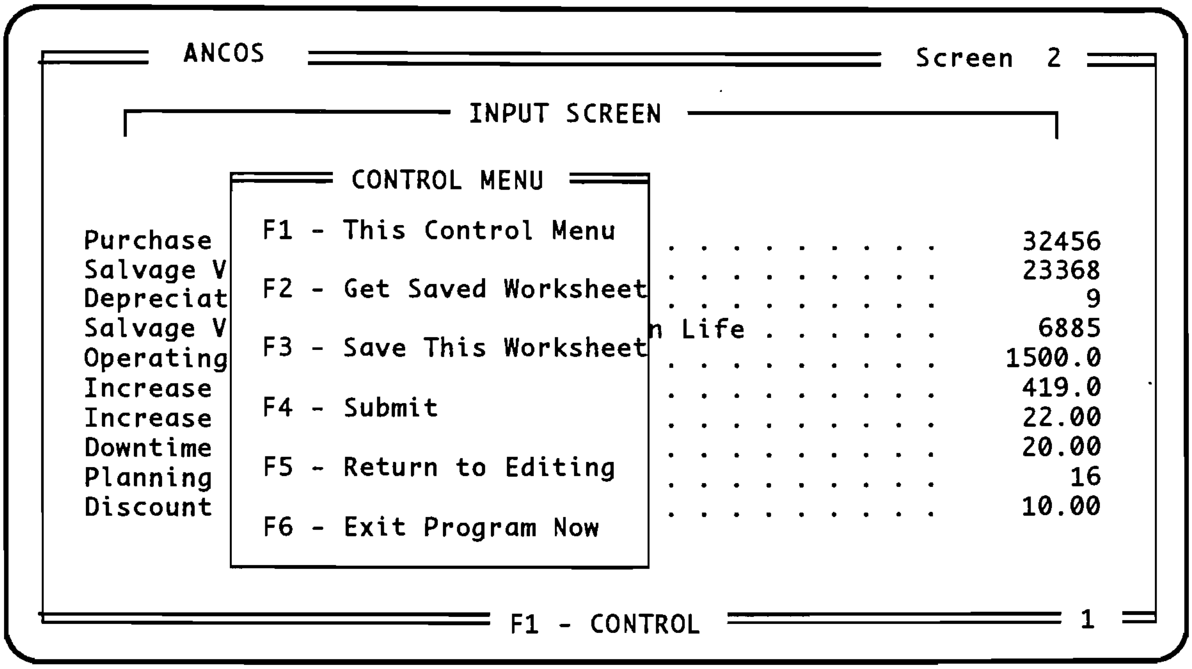


Figure A.2 Second screen for the program ANCOS with the pop-up menu enabled

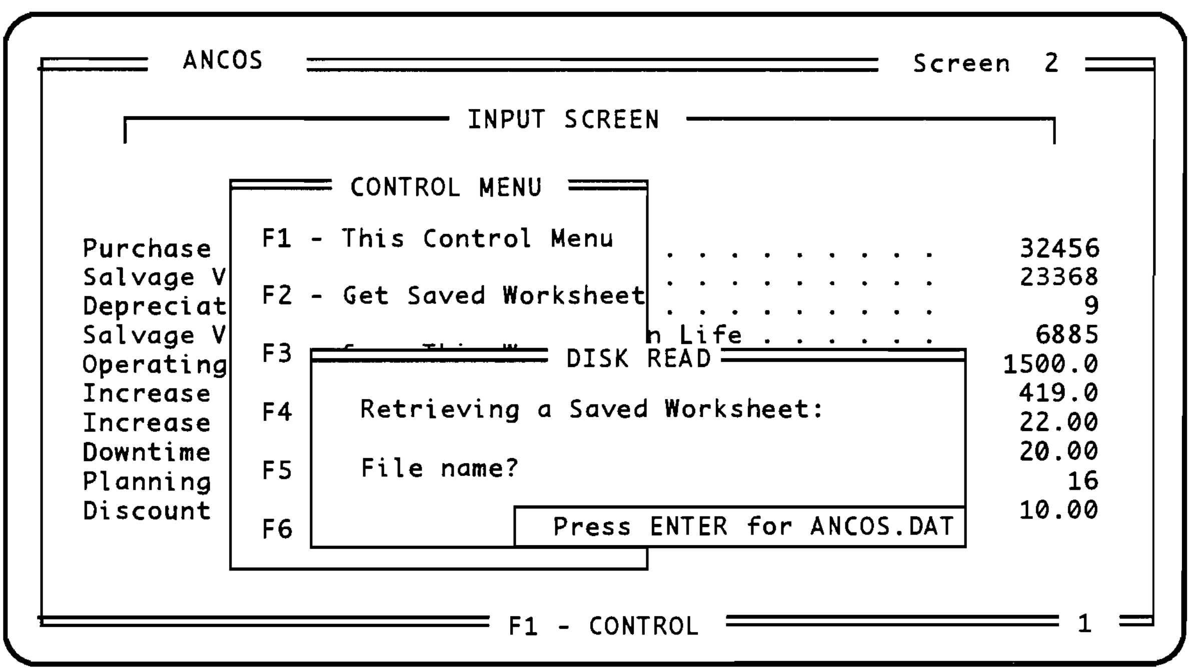


Figure A.3 Second screen for the program ANCOS with the file menu enabled

After saving or retrieving data to or from the disk, ANCOS returns to the edit mode, displaying the data retrieved or saved to or from the disk and allowing the user to modify the inputs further. At any point after pressing the F1 key the user may return to the editing of the inputs by pressing the F5 key. The F6 key allows the user to exit ANCOS and return to DOS without performing any calculations.

When the user is satisfied with the inputs in the worksheet on the input screen, the calculations may be performed by pressing the F1 key followed by the F4 key of the pop-up menu. ANCOS then generates the output screens depicted in Figs A.4 and A.5. After all the numerical results are displayed by the Figure A.4 screens, ANCOS displays the annualized cost chart and reports the minimum annual cost within the planning horizon on a screen depicted in Figure A.5. After pressing any key in Figure A.5, ANCOS exits to the operating system DOS.

---------------------------- OUTPUT SCREEN ----------------------------

Years Kept	Annual Operating Cost	Annual Ownership Cost	Total Annual Cost
1	1500	12334	13834
2	1909	9150	11059
3	2305	7850	10154
4	2686	7055	9741
5	3055	6484	9539
6	3410	6041	9451
7	3752	5682	9434
8	4081	5382	9463
9	4397	5129	9526
10	4700	4911	9611
11	4991	4723	9714
12	5270	4560	9829
13	5536	4417	9953
14	5791	4291	10082
15	6035	4180	10215
16	6267	4083	10350

Press (Almost) Any Key to Continue ...

Figure A.4 Output screen for the program ANCOS

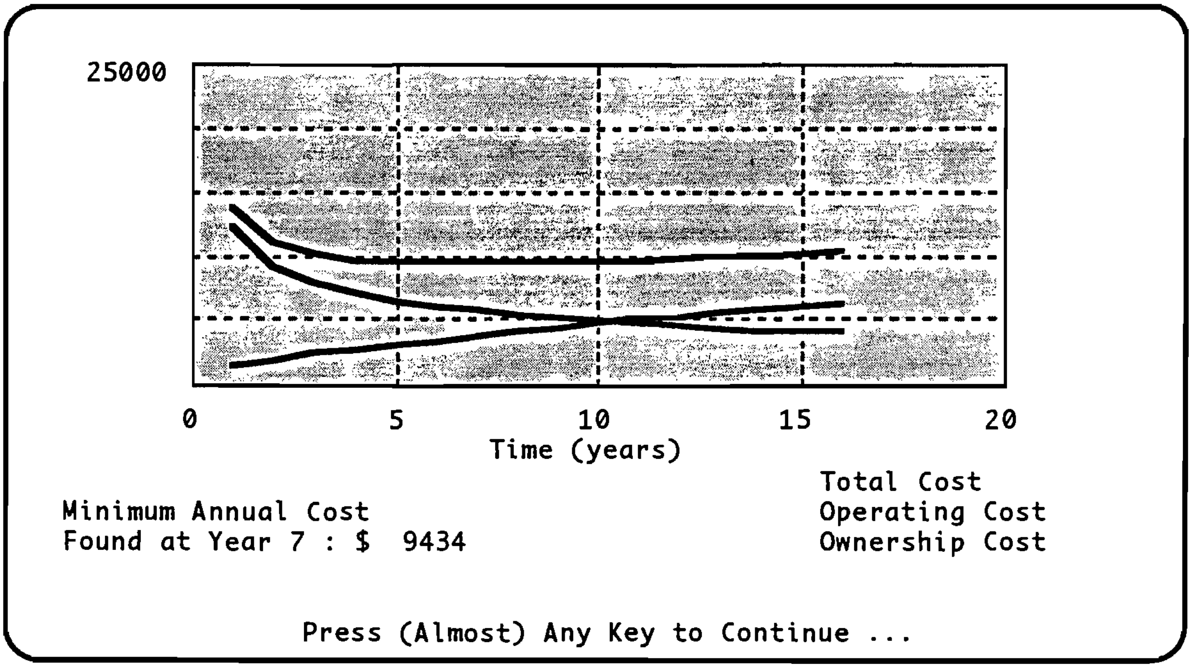


Figure A.5 Graphics output screen for the program ANCOS

SOURCE CODE FOR THE PROGRAM ANCOS

```
REM*******************************************************************
REM*                                                                 *
REM*  PROGRAM ANCOS - Version 1.0, September 1991                    *
REM*  Center for Transportation Research                             *
REM*  University of Texas at Austin                                  *
REM*  Programmed by Terry Dossey & José Weissmann                    *
REM*                                                                 *
REM*******************************************************************
REM
DIM F(160, 7), FF(30), dat$(160), A(160): GOSUB 95000: REM Initialize field data
DIM AOC(100), AIC(100), tot(100): REM Output Arrays
DF$ = "ANCOS.DAT": REM — Default Worksheet Save Name


REM*************** SOME HANDY CONSTANTS *****************************
bl$ = STRING$(80, " "): REM 80 Blanks
AB$ = " abcdefghijklmnopqrstuvwxyz": AB$ = AB$ + UCASE$(AB$)
AB$ = AB$ + "'!@#$%^&*()-_+=/?:;<>.,[]\{}|0123456789": REM Valid alphanumerics
NU$ = "0123456789.+-": REM Valid numeric digits
```

```
REM**************** TRAP ALL ERRORS **********************************
REM ON ERROR GOTO 99000: REM RESTORE ERROR HANDLER
SCREEN 1
REM ************* MAIN PROCESS ***************************************
GOSUB 11000: GOSUB 90100: c = 1: REM — Display title screen
1 REM —— Start w/screen 2, field 1 ——————————————
fx = 1: scr = 2:  S4 = 1: S3 = 1: GOSUB 12000: LOCATE F(1, 1), F(1, 2), 1, 0, 7
REM —— CALL INPUT SUBROUTINE ————————————————————
2 GOSUB 90300
REM ************ INPUT FINISHED, PERFORM EXECUTION CHOICE *************
c = 0: GOTO 1: REM Back to Field 1, keep editing
REM —— Choice 1 - Run Analysis and print results ————

COLOR 15, 8, 8: CLS : END
11000 REM****************   Screen 1   ********************************
SCREEN 1: WIDTH 80: SCREEN 0: COLOR 15, 1, 8: CLS : LOCATE 1, 15, 1
PRINT TAB(10); STRING$(60, "-"):
X = 3: Y = 20: REM** SOLID BLOCK CHARACTER **
A$ = " ****   ***  **  ******  ******  ****** ": GOSUB 11500
A$ = " ****   ***  **  ******  ******  ****** ": GOSUB 11500
A$ = "**  **  **** **  **        **  **  **     ": GOSUB 11500
A$ = "******  ** ****  **        **  **  ****** ": GOSUB 11500
A$ = "******  **  ***  **        **  **      ** ": GOSUB 11500
A$ = "**  **  **   **  ******  ******  ****** ": GOSUB 11500
A$ = "**  **  **   **  ******  ******  ****** ": GOSUB 11500

PRINT : PRINT
PRINT TAB(27); "Annualized Cost For Vehicles"

PRINT TAB(27); "Version 1.0 - October 1991": PRINT
PRINT TAB(27); "Developed under Project 979"
PRINT TAB(23); "Center for Transportation Research"
PRINT TAB(24); "The University of Texas at Austin"
PRINT TAB(38); "and"
PRINT TAB(23); "Texas Department of Transportation"
PRINT TAB(33); "Austin, Texas"
PRINT TAB(33); "Programmed by"
PRINT TAB(28); "J. Weissmann & T. Dossey"
PRINT TAB(10); STRING$(60, "-"):
RETURN
11500 REM****** SUB TO PRINT BLOCK LETTERS *************
LOCATE X, Y: L = LEN(A$): FOR I = 1 TO L: X$ = MID$(A$, I, 1)
IF X$ = "*" THEN X$ = CHR$(206)
PRINT X$; : NEXT:  X = X + 1: RETURN
END
12000 REM************* SCREEN 2 SUBROUTINE *****************
IF c = 0 THEN GOTO 12035
REM — PRINT TITLES ———
scr = 2: X$ = "INPUT SCREEN"
GOSUB 90200: REM Screen Header
lm = 10: ll = 55

r = 7: X$ = "Purchase Cost": GOSUB 90600
r = 8: X$ = "Salvage Value (first year)": GOSUB 90600
r = 9: X$ = "Depreciation Life (yrs)": GOSUB 90600
r = 10: X$ = "Salvage Value at End of Depreciation Life": GOSUB 90600
r = 11: X$ = "Operating Costs (fuel, tires, etc.)": GOSUB 90600
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  r = 12: X$ = "Increase in Repair Costs ($/yr)": GOSUB 90600
  r = 13: X$ = "Increase in Down Time (hr/yr)": GOSUB 90600
  r = 14: X$ = "Downtime Rate ($/hr)": GOSUB 90600
  r = 15: X$ = "Planning Horizon (yr)": GOSUB 90600
  r = 16: X$ = "Discount Rate (%)": GOSUB 90600

12035 REM — UPDATE FIELDS ——
  f1 = 1: f2 = 10: GOSUB 94800: REM Field update sub
  RETURN
13000 REM *********** EXECUTION SCREEN ***********************
  RETURN

  REM*****************************************************************
  REM*            GENERAL SUBROUTINES                                  *
  REM*****************************************************************
90000 REM******* Get keypress, put into A$ ********************************
  A$ = INKEY$: IF A$ = "" THEN GOTO 90000
  N = LEN(A$): A = ASC(LEFT$(A$, 1)): B = ASC(RIGHT$(A$, 1))
  RETURN
90100 REM******* PRESS ANY KEY TO CONTINUE SUB *******
  LOCATE 24, 22: PRINT "Press (Almost) Any Key to Continue ...";
  GOSUB 90000: RETURN

90200 REM******* GENERAL SCREEN HEADER SUB *****************
  REM — scr is screen number, x$ is title
  CLS : B$ = STRING$(8, 205): A$ = STR$(scr)
  PRINT CHR$(213); B$; " ANCOS "; STRING$(44, 205); " Screen ";
  B2$ = B$: IF scr > 9 THEN B2$ = LEFT$(B$, 7)
  PRINT A$; " "; B2$; CHR$(184)
  FOR I = 1 TO 22: PRINT CHR$(179); TAB(80); CHR$(179): NEXT
  PRINT CHR$(212); STRING$(32, 205); " F1 - CONTROL "; STRING$(32, 205); CHR$(190);
  LOCATE 3, 9: A = INT((60 - LEN(X$)) / 2): B$ = STRING$(A, 196)
  PRINT CHR$(218); B$; " "; X$; " "; B$ + CHR$(196); CHR$(191)
  RETURN
90300 REM****** SCREEN INPUT SUBROUTINE ********************************
  REM FX = Current field number
  REM —— Show Field Number in Lower Right Screen Corner ————————
  zz1 = CSRLIN: zz2 = POS(0): LOCATE 24, 75: PRINT fx; : LOCATE zz1, zz2
  REM —— Get keypress and ASCII code ———————————————
90320 z = 0: GOSUB 90000: REM Wait for keypress
  REM ——— If ENTER pressed on toggle field, select field ———
  IF A = 32 AND F(fx, 4) = 2 THEN z = 1: GOSUB 92300: SOUND 2000, .2: GOTO 90300
  REM —— If movement key, perform movement ————————
  GOSUB 91100: REM Check for movement key (tab, arrow, etc)
  REM —— Perform movement, check for end of entry ———
  IF X = 1 THEN GOSUB 91000: IF fin = 1 THEN RETURN: GOTO 90300
  IF F(fx, 4) > 1 THEN GOTO 90300: REM Toggle field, dont allow entry
  REM ———————— FIELD ENTRY ———————————
  IF F(fx, 4) = 1 THEN V$ = NU$ ELSE V$ = AB$: REM Select valid character set
  IF 0 = INSTR(V$, A$) THEN GOTO 90300: REM Invalid char.
  REM —— User has pressed a valid key, started field entry ————
  z = 1: c$ = A$: old$ = dat$(fx): f1 = fx: f2 = fx: L = F(fx, 3)
  r = F(fx, 1): c = F(fx, 2): LOCATE r, c: COLOR 15, 3, 8: PRINT LEFT$(c$ + bl$, F(fx, 3)):
COLOR 15, 1, 8
  IF L = LEN(c$) THEN A = 13: GOTO 90402: REM Out of room, press enter
90375 LOCATE r, c + LEN(c$): GOSUB 90000: REM Wait for keypress
  N = LEN(A$): A = ASC(LEFT$(A$, 1)): B = ASC(RIGHT$(A$, 1))
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  REM —— Oops, user made a typing error ——————————————
  OOPS = (A = 8 OR N = 2 AND B = 75 OR N = 2 AND B = 83): LB = LEN(c$)
  IF NOT OOPS OR LB <= 0 THEN GOTO 90392: REM User didn't press delete
  c$ = LEFT$(c$, LB - 1): LOCATE r, c: COLOR 15, 3, 8: PRINT LEFT$(c$ + bl$, L)
  COLOR 15, 1, 8: GOTO 90375: REM Return for next keypress
90392 REM —— If key ok, add to string and print ——————————————
  IF 0 = INSTR(V$, A$) THEN GOTO 90400: REM Branch on invalid keypress
  c$ = c$ + A$: LOCATE r, c: COLOR 15, 3, 8: PRINT LEFT$(c$ + bl$, F(fx, 3))
  COLOR 15, 1, 8: LOCATE r, c + LEN(c$)
  IF L = LEN(c$) THEN A = 13: GOTO 90402: REM Out of room, press enter
90400 GOSUB 91100: IF X <> 1 THEN GOTO 90375: REM Ignore invalid key
90402 REM —— Check for range of numeric ——————————
  IF F(fx, 4) = 0 THEN GOTO 90450
  d = VAL(c$): IF d < F(fx, 6) OR d > F(fx, 7) THEN BEEP: c$ = old$: B = 0: A = 0
90450 REM —— Save data and update field ——————————
  dat$(fx) = c$: f1 = fx: f2 = fx: GOSUB 94800: c = 0: SOUND 1000, .2
  GOSUB 91200: REM Update screen
  GOSUB 91000: IF fin = 1 THEN RETURN: REM All over
  GOTO 90300: REM Perform movement and reset for next field

90500 REM****** FORMAT STRING ********************************************
  REM - x$ = STRING TO BE FORMATTED
  REM - ND = NUMBER OF DECIMAL PLACES
  REM - L  = LENGTH
  s$ = "": X = VAL(X$): IF X < 0 THEN s$ = "-"
  X = INT(ABS(X) * 10 ^ ND + .500001): X$ = LTRIM$(STR$(X))
  d$ = ".": IF ND = 0 THEN d$ = ""
  M = LEN(X$) - ND: IF M < 0 THEN M = 0
  X$ = s$ + LEFT$(X$, M) + d$ + RIGHT$("00000" + X$, ND)
  IF VAL(X$) = 0 AND ND > 0 THEN X$ = "0" + X$
  X$ = RIGHT$(bl$ + X$, L)
  RETURN
90600 REM********** ADD TRAILING DOTS TO CHARACTER STRING **********
  REM — x$ = String, LM = left margin, LL = length, R=Row
  do$ = ". . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . ."
  L = LEN(X$): IF 2 * INT(L / 2) <> L THEN do$ = " " + do$
  ll = 64 - lm
  X$ = LEFT$(X$ + do$, ll): LOCATE r, lm: PRINT X$: RETURN
90700 REM********** BLANK SELECTED RECTANGLE ON SCREEN ********************
  REM — R1 = 1st row, R2 = last row, C1 = 1st col, C2 = last col
  X$ = STRING$(c2 - c1 + 1, " ")
  FOR I = r1 TO r2: LOCATE I, c1: PRINT X$: NEXT: RETURN
91000 REM********** PERFORM SCREEN MOVEMENT ******************************
  REM —— Check for F1 keypress ——————————
  IF N = 2 AND B = 59 THEN GOSUB 92400: RETURN
  old = scr: c = 0: FO = fx: SI = 1: fin = 0
  REM —— Next field if tab, enter, down arrow, or -> ——————————————
  IF A = 9 OR N = 2 AND (B = 77 OR B = 80) OR A = 13 THEN DIR = 1: fx = fx + 1: GOTO
91050
  REM —— Previous field if BSP, <-, up arrow or shift tab ——————————
  IF A = 8 OR N = 2 AND (B = 75 OR B = 15 OR B = 72) THEN DIR = -1: fx = fx - 1: GOTO
91050
  REM —— Next screen if page down key ——————————————————
  IF N = 2 AND B = 81 THEN fx = FF(scr + 1): DIR = 1: GOTO 91050
  REM —— Previous screen if page up key ————————
  IF N = 2 AND B = 73 THEN fx = FF(scr - 1): DIR = 1: GOTO 91050
91050 IF fx < 1 THEN fx = 1: REM Can't back up past screen 2 (field 1)
```

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91055 REM —— Skip over deactivated fields ————
  IF fx > 10 THEN fin = 1: RETURN: REM End of entry, return finish code
  REM IF A(FX) = 0 THEN FX = FX + DIR: GOTO 91050
  IF A(fx) < 1 THEN fx = fx + DIR: GOTO 91050
  GOSUB 94000: IF scr <> old THEN c = 1: REM C=1 if screen has changed
  REM —— Handle backing up to a completely inactive screen ————
  IF N = 2 AND B = 73 AND c = 0 AND fx > 1 THEN SI = SI + 1: fx = FF(scr - SI): GOTO 91050
  IF c = 1 THEN GOSUB 91200: REM Screen update

  REM — If a(fx)=0 now, then field has been turned off beneath cursor
  REM — by Screen Update routine.  Since prior field may have activated
  REM — Only thing to do is retreat to top of screen and try again
  IF A(fx) = 0 THEN fx = FF(scr): c = 0: old = scr: GOTO 91055

  LOCATE F(fx, 1), F(fx, 2), 1, 0, 7
  RETURN
91100 REM********* CHECK FOR MOVEMENT KEYPRESS ************************
  X = 0: IF N = 2 THEN GOTO 91120
  IF A = 9 OR A = 13 OR A = 8 THEN X = 1
  RETURN
91120 IF B = 77 OR B = 80 OR B = 75 OR B = 15 OR B = 72 OR B = 81 OR B = 73 OR B = 59
THEN X = 1
  RETURN
91200 REM********* PERFORM SCREEN UPDATE ******************************
  LOCATE , , 0: REM Kill cursor
  ON scr GOSUB 11000, 12000, 13000
  LOCATE , , 1: REM Restore cursor
  RETURN
92300 REM********* SELECT A TOGGLE FIELD ********************************
  IF F(fx, 6) = 1 AND A(fx) = 2 THEN A(fx) = 1: GOTO 92325: REM On/Off
  A(fx) = 2: K = fx + 1
92310 ok = (F(K, 5) = F(fx, 5) AND F(K, 4) = 2): IF ok AND A(K) = 2 THEN A(K) = 1
  IF ok THEN K = K + 1: GOTO 92310
  K = fx - 1
92320 ok = (F(K, 5) = F(fx, 5) AND F(K, 4) = 2): IF ok AND A(K) = 2 THEN A(K) = 1
  IF ok THEN K = K - 1: GOTO 92320
92325 GOSUB 91200: REM Screen update
  LOCATE F(fx, 1), F(fx, 2): RETURN
92400 REM********* DO F1 POP-UP MENU **************************************
  COLOR 15, 5, 8: lmp = 22: tp = 6: REM Color, l. margin, top
  FOR II = tp TO tp + 13: LOCATE II, lmp - 2, 0: PRINT SPACE$(29): NEXT
  LOCATE tp, lmp - 2: PRINT STRING$(8, 205); " CONTROL MENU "; STRING$(7, 205)
  LOCATE tp + 2, lmp: PRINT "F1 - This Control Menu"
  LOCATE tp + 4, lmp: PRINT "F2 - Get Saved Worksheet"
  LOCATE tp + 6, lmp: PRINT "F3 - Save This Worksheet"
  LOCATE tp + 8, lmp: PRINT "F4 - Submit"
  LOCATE tp + 10, lmp: PRINT "F5 - Return to Editing"
  LOCATE tp + 12, lmp: PRINT "F6 - Exit Program Now"
92405 GOSUB 90000: REM Get keypress
  REM —— Scan for active function keys ————————
  IF A = 27 THEN GOTO 92490: REM ESC key, Back to edit
  IF N <> 2 THEN GOTO 92405
  IF B = 60 THEN GOSUB 93200: GOTO 92490: REM F2, Get Saved Worksheet
  IF B = 61 THEN GOSUB 93000: GOTO 92490: REM F3, Save this Worksheet
  IF B = 62 THEN GOSUB 92600: END: REM F4, Submit
  IF B = 63 THEN GOTO 92490: REM F5, Back to edit
  IF B = 64 THEN COLOR 15, 8, 8: CLS : END: REM Abort Program
```

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  IF B = 65 THEN GOSUB 92500: GOTO 92490: REM F7! Undocumented Directory
  GOTO 92405

92490 REM —— Go back to screen in progress ————————————
  COLOR 15, 1, 8: c = 1: GOSUB 91200:
  LOCATE F(fx, 1), F(fx, 2), 1, 0, 7
  RETURN
92500 REM********* F7 SUBROUTINE (Not used currently) ********************
  CLS : SHELL "dir /W": GOSUB 90100
  RETURN
92600 REM********* F4 SUBROUTINE (Calculations ) **************************

  ph = VAL(dat$(9)): b9 = VAL(dat$(5)): i1 = VAL(dat$(10)) / 100: b4 = VAL(dat$(2))
  b7 = VAL(dat$(4)): b6 = VAL(dat$(3)): b1 = VAL(dat$(1)): e3 = VAL(dat$(6))
  e6 = VAL(dat$(7)): e9 = VAL(dat$(8))

REM —— Draw Header for Output ————————————————
COLOR 15, 6: CLS : GOSUB 92900: REM Page Header



REM —— Calculate Yearly Values ————————————————
  b11 = e3 + e6 * e9: max = 0: min = 99999999
  FOR year = 1 TO ph
  AOC(year) = b9 + b11 * (1 / i1 - year / ((1 + i1) ^ year - 1))
  rate = (b7 / b4) ^ (1 / (b6 - 1))
  salvage = b4 * rate ^ (year - 1)
  IF salvage < 0 THEN salvage = 0
  AIC(year) = b1 * (i1 * (1 + i1) ^ year / ((1 + i1) ^ year - 1)) - salvage * (i1 / ((1 + i1) ^ year -
1))
  tot(year) = AOC(year) + AIC(year)
  row = (year / 16 - INT(year / 16)) * 16
  IF row = 0 THEN row = 16

  IF tot(year) > max THEN max = tot(year)
  IF tot(year) < min THEN min = tot(year): myear = year
  LOCATE 6 + row, 10: PRINT USING "#########"; year;
  PRINT USING "##############"; AOC(year); AIC(year); tot(year)
  IF INT(year / 16) = year / 16 THEN GOSUB 90100: IF ph > year THEN GOSUB 92900
  NEXT year: year = year - 1
  IF INT(year / 16) <> year / 16 THEN GOSUB 90100

  REM ———————— DRAW GRAPH ——————————————————————
  SCREEN 9: COLOR 15, 14
  VIEW (110, 12)-(620, 190), 8: VIEW
  VIEW (100, 20)-(610, 200), 9, 1

  REM ——————— Determine Vertical Scale ——————————————————
  top = 5000: IF max > top THEN top = 10000: IF max > top THEN top = 25000
  IF max > top THEN top = 50000: IF max > top THEN top = 100000
  rgt = 20: IF ph > rgt THEN rgt = 40: IF ph > rgt THEN rgt = 80
  LOCATE 2, 7: PRINT USING "######"; top
  WINDOW (0, 0)-(rgt, top)

  REM ——————— Draw dotted grid lines ——————————————————
  FOR I = 1 TO 4: Y = top / 5 * I: LINE (0, Y)-(rgt, Y), 7, , &H8888
  IF I < 4 THEN LINE (rgt / 4 * I, 0)-(rgt / 4 * I, top), 7, , &H1111
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   NEXT

   REM ——— Draw Graphs ————————————————
   FOR I = 1 TO ph - 1
   LINE (I, AOC(I))-(I + 1, AOC(I + 1)), 10
   LINE (I, AIC(I))-(I + 1, AIC(I + 1)), 12
   LINE (I, tot(I))-(I + 1, tot(I + 1))
   NEXT


   LOCATE 16, 13:
   IF rgt = 20 THEN PRINT "0          5          10          15          20"
   IF rgt = 40 THEN PRINT "0         10          20          30          40"
   IF rgt = 80 THEN PRINT "0         20          40          60          80"
   LOCATE 17, 37: PRINT "Time (Years)": LOCATE 20, 10
   COLOR 8, 3
   ok = tot(myear - 1) > min AND tot(myear + 1) > min
   IF ok THEN PRINT "Minimum Annual Cost"; : PRINT TAB(10); "Found at Year "; myear; ": "; :
min = INT(min + .5): PRINT "$"; min: LINE (0, min)-(myear, min), , , &H6666: LINE (myear, 0)-
(myear, min), , , &H6666
   COLOR 8, 3



   IF NOT ok THEN PRINT "No minimum found within"; : PRINT TAB(10); "planning horizon."
   LOCATE 20, 58: COLOR 10, 0: PRINT "Operating Cost"
   LOCATE 21, 58: COLOR 4, 0: PRINT "Ownership Cost"
   LOCATE 19, 58: COLOR 15, 0: PRINT "Total Cost"




   COLOR 8, 3: GOSUB 90100
   RETURN
92900 REM ——— Draw Header for Output ————————————————
CLS

PRINT "———————————— OUTPUT SCREEN ————————————————"
LOCATE 3, 15: PRINT "         Annual       Annual      Total"
LOCATE 4, 15: PRINT "Years    Operating    Ownership     Annual"
LOCATE 5, 15: PRINT " Kept      Cost         Cost       Cost"
LOCATE 6, 15: PRINT "——      ————      ————      ————"
RETURN

93000 REM********* WRITE WORKSHEET TO DISK *******************************
   x1$ = "SAVE ": X2$ = "Saving worksheet to disk:": ER = 0
   GOSUB 93300: IF ER = 1 THEN RETURN: REM Get file name from user
   WRITE #1, "ANCOS V1.0"
   FOR I = 1 TO 10: WRITE #1, F(I, 6), F(I, 7), A(I), dat$(I): NEXT
93100 CLOSE #1
   ON ERROR GOTO 99000: RETURN
93200 REM********* GET WORKSHEET FROM DISK *******************************
   x1$ = "READ ": X2$ = "Retrieving a Saved Worksheet:": ER = 0
   GOSUB 93300: IF ER = 1 THEN RETURN: REM Get file name from user
   REM —— Check for valid worksheet format ————————
   INPUT #1, xx$: IF xx$ = "ANCOS V1.0" THEN GOTO 93205
   REM —— Not valid ———
```

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  COLOR 15, 4, 8
  LOCATE 17, 40: CLOSE #1: BEEP: PRINT "Not an ANCOS data file!": SLEEP 3: RETURN
  REM —— Valid, continue reading ———
93205 FOR I = 1 TO 10: INPUT #1, F(I, 6), F(I, 7), A(I), dat$(I): NEXT
  CLOSE #1
  fx = 1: scr = 2: c = 1: REM Start from screen 2
  ON ERROR GOTO 99000: RETURN
93300 REM********* GET DISK FILE NAME ***********************************
  COLOR 15, 6, 1: lmp = 29: tp = 12: REM Color, l. margin, top
  FOR II = tp TO tp + 6: LOCATE II, lmp - 2, 0: PRINT SPACE$(52): NEXT
  LOCATE tp, lmp - 2: PRINT STRING$(20, 205); " DISK "; x1$; STRING$(21, 205)
  LOCATE tp + 2, lmp: PRINT X2$: ld = INT(LEN(DF$) / 2)
  COLOR 15, 8, 1: LOCATE tp + 6, lmp + 14 - ld: PRINT "  Press ENTER for ";
  PRINT UCASE$(DF$) + "  ": COLOR 15, 6, 1
  LOCATE tp + 4, lmp: INPUT "File name"; F$
  F$ = LTRIM$(F$): IF F$ = "" THEN F$ = DF$ ELSE DF$ = F$
  LOCATE tp + 4, lmp + 11: PRINT LEFT$(F$ + bl$, 20): SLEEP 1
  ON ERROR GOTO 93400
  IF x1$ = "READ " THEN OPEN F$ FOR INPUT AS #1
  IF x1$ = "SAVE " THEN OPEN F$ FOR OUTPUT AS #1
93399 RETURN
93400 REM——— Handle any disk error ——————
  LOCATE 17, 40: ER = 1: BEEP: COLOR 15, 4, 8
  IF ERR = 64 THEN PRINT "ERROR - Bad file name": GOTO 93405
  IF ERR = 61 THEN PRINT "ERROR - Disk full": GOTO 93405
  IF ERR = 71 THEN PRINT "Disk not ready - try again  ": GOTO 93405
  IF ERR = 72 THEN PRINT "ERROR - Bad disk media": GOTO 93405
  IF ERR = 68 THEN PRINT "ERROR - No such disk drive": GOTO 93405
  IF ERR = 53 THEN PRINT "ERROR - File not found": GOTO 93405
  IF ERR = 75 OR ERR = 76 THEN PRINT "ERROR - Bad Path": GOTO 93405
  IF ERR = 70 THEN PRINT "ERROR - Write Protected": GOTO 93405
  IF ERR = 62 THEN PRINT "Not CRCP7 input file": GOTO 93405
  PRINT "Unknown Disk error - try again"
93405 SLEEP 3
  CLOSE #1
  RESUME 93399


94000 REM********* DETERMINE WHICH SCREEN FROM FIELD NUMBER ***************
  FOR I = 1 TO 20
  IF fx < FF(I) THEN scr = I - 1: RETURN
  NEXT I: RETURN
  REM********* GET FIELD # FOR NEXT SCREEN ****************************
  FF = FF(scr + 1): RETURN
94800 REM****** UPDATE SELECTED SCREEN FIELDS *****************************
  REM F1 - First field to update, F2 - Last field to update
  REM L = Length , T=data type (0-Alpha 1-Numeric 2-Toggle)
  bl$ = STRING$(80, " "): REM LOCATE , , 0: REM kill
  FOR I = f1 TO f2
  LOCATE F(I, 1), F(I, 2): L = F(I, 3): t = F(I, 4)
  REM — Hidden field ——
  REM IF A(I) = 0 AND F(I, 4) < 2 THEN x$ = LEFT$(bl$, L): COLOR 15, 1, 8: PRINT x$: GOTO
94835
  X$ = dat$(I)
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REM — Alphabetic field ——
  IF t = 0 THEN X$ = LEFT$(X$ + bl$, L): COLOR 15, 3, 8: PRINT X$: GOTO 94835

  REM — Numeric field ———
  F = 7: B = 1: REM No entry allowed - background blue, letters gray
  IF A(I) = 1 THEN F = 15: B = 3: REM Entry allowed, backgr. aqua
  IF A(I) < 0 THEN F = 1: B = 1: REM Totally hidden

IF t = 1 THEN ND = F(I, 5): GOSUB 90500: COLOR F, B, 8: PRINT X$: GOTO 94835
  REM — Toggle field ——
  F = 7: B = 1: REM Not an option - background blue, letters gray
  IF A(I) = 1 THEN F = 15: B = 1: REM Option ok, not selected
  IF A(I) = 2 THEN F = 15: B = 3: REM Option selected
  IF F(I, 7) = 1 AND A(I) = 0 THEN F = 1: B = 1: REM Completely hide field
  COLOR F, B, 8: PRINT X$
94835 NEXT I: COLOR 15, 1, 8: RETURN
95000 REM****** INITIALIZE SCREEN FIELDS **********************************
  REM — Row, Col, Length, A/N, Decimals, Low lim, Up lim, A(I), default
  REM — A/N: 0 = alpha, 1=num, 2=toggle
  REM — NOTE -> For toggle fields, F(*,5) is group number
  REM — F(*,6) is 1 for non-grouped, F(*,7) is 1 to totally hide
  REM — A(I) = Select vector - 0=hidden, 1=visible, 2=selected
  REM ———— Items for screen 2 ————1-10 ————————
  DATA 7,67,6,1,0,0,999999,1,"29000":        REM Purchase Cost
  DATA 8,67,6,1,0,0,999999,1,"19000":        REM Salvage Value
  DATA 9,71,2,1,0,0,99,1,"9":                REM Depreciation Life
  DATA 10,67,6,1,0,0,999999,1,"6800":        REM End Salvage Value
  DATA 11,65,8,1,1,0,99999,1,"1500":         REM Operating costs
  DATA 12,65,8,1,1,0,99999,1,"400  ":        REM Increase in RC
  DATA 13,67,6,1,2,0,999,1,"25   ":          REM Inc in Down Time
  DATA 14,67,6,1,2,0,999,1,"40   ":          REM Down Time Rate
  DATA 15,71,2,1,0,0,99,1,"16   ":           REM Planning Horizon
  DATA 16,68,5,1,2,0,99,1,"10":              REM Discount Rate


  REM ———— ITEMS FOR SCREEN 9 ———— 11 ————
  DATA 17,45,1,1,0,1,4,1,"1":                REM Execution options

  REM — Read field data ————
  FOR I = 1 TO 11: FOR J = 1 TO 7: REM KILL
  READ F(I, J): NEXT J: READ A(I), dat$(I): NEXT I

  REM — Read first field number for each screen —
  DATA 0,1,11,999
  FOR I = 1 TO 4: READ FF(I): NEXT
  RETURN

99000 REM************** ERROR HANDLER ************************************
  COLOR 15, 4, 8: CLS : BEEP: BEEP: BEEP
  LOCATE 6, 37: PRINT "- SORRY -"
  LOCATE 10, 10: PRINT "  An Unforseeable error has occurred.  A restart operation"
  LOCATE 12, 10: PRINT "will be attempted to  preserve any data you may have entered."
  LOCATE 14, 10: PRINT "   Please contact customer service if the problem recurs."
  LOCATE 16, 30: PRINT "*** Error #"; ERR; " ***"
  GOSUB 90100: COLOR 15, 1, 8: RESUME 1
  END
```