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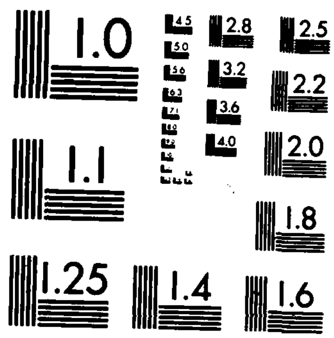

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Report 2400

FUEL CONSERVATION AND CONSTRUCTION EQUIPMENT

February 1984

United States Army
Belvoir Research & Development Center
Fort Belvoir, Virginia 22060

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The Army's energy conservation goals and methods for estimating fuel requirements as they relate to construction equipment are identified. The impact of the R&D Center's current procurement strategy and TECOM's test procedures on the Construction Engineering Division's energy conservation program is discussed. Existing methods for determining fuel consumption are identified and evaluated.

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FUEL CONSERVATION AND CONSTRUCTION EQUIPMENT

I. INTRODUCTION

1. Army Energy Program Goals. In response to the 1973 oil embargo by the OPEC nations, the U.S. Army's energy conservation program plans were revitalized. The Office of the Deputy Chief of Staff for Logistics, Army Energy Office, Headquarters, Department of the Army, compiled a comprehensive long-range Army Energy Plan. Generally, the plan identifies the Army's organization, goals, objectives, policies, and programs with respect to energy. The DA energy goals and objectives are:

a. Reduce energy consumption by 35 percent by the year 2000 (base year-FY75).

(1) Reduce energy consumption in mobility operations by 10 percent by FY85 with zero growth to the year 2000 with no degradation to readiness.

(2) Reduce energy consumption in facilities operations by 20 percent by FY85 and 40 percent by the year 2000.

(3) Expand energy conservation education/information and incentive programs for all Army military and civilian personnel and their dependents.

b. Reduce dependence on nonrenewable and scarce fuels by the year 2000.

(1) Develop capability to use synthetic/alternate fuels for mobility.

(2) Increase efficiency of mobility systems by 15 percent.

(3) Develop capability for facilities to use synthetic gas in place of natural gas.

(4) Reduce consumption of heating oil by 75 percent.

c. Attain a position of leadership in the pursuit of national energy goals.

2. Research, Development, Testing, and Evaluation (RDT&E) Program Thrusts. Because development effort is required to reach the Army's goals, Research and Development (R&D) program planning was required. The thrust of the Army's Energy R&D plan is directed at the application and development of the specific technologies to:

a. Utilize domestically produced synthetic fuels and alternate conventional fuels in military mobile systems.

b. Develop a family of military engines capable of burning a broad range of both synthetic and conventional fuels.

c. Reduce overall energy use through efficiency improvements without compromising flexibility, readiness, or performance.

d. Achieve an adequate degree of energy self-sufficiency for military installations through reduced dependence on petroleum fuels.

e. Encourage the commercialization of domestic synthetic fuels industry capable of producing mobility fuels for military use.

3. Progress Toward Achieving Program Goals. The Army has made considerable progress toward reaching established goals. Energy conservation data compiled in 1981 shows energy usage down 13.5 percent from FY75. Should this trend continue, future projections forecast an 18.4-percent reduction in energy usage by 1985. However, some analysts predict that the US petroleum supply will be nearly depleted before the year 2000. In addition, the cost of petroleum between 1973 and 1974 increased by nearly 300 percent, and the cost continues upward. Obviously from a supply and cost point of view, our dependence on foreign petroleum will continue to have a major impact on the Army's ability to perform its mission.

4. U.S. Army Belvoir Research and Development Center's Role. The Belvoir Research and Development Center plays a significant role in the areas of petroleum fuels, renewable fuels, synthetic fuels, and reduction in mobile construction equipment energy consumption. The Engineer Support Laboratory and Construction Equipment Engineering Division are working toward meeting the Army energy goals in the area of construction equipment energy conservation goals as follows: Reduce energy consumption by 45 percent by the year 2000, reduce energy consumption in mobility operations by 10 percent by FY85 with zero growth to the year 2000 with no degradation in readiness, and attain a position of leadership in pursuit of National Energy Goals.

Apparently, the thrust of the energy projects assigned to the Special Projects Branch is to motivate original equipment manufacturers (OEM) to improve the mechanical and thermodynamic efficiency of construction equipment.

II. PURPOSE AND SCOPE

5. Purpose. The primary purpose of the report is to recommend an approach for determining the efficiency of construction equipment. During the course of this work, it became clear that more than consideration of construction equipment efficiency is required if we expect to reach the Army's FY1985 energy consumption goals.

6. Scope. The scope of the work was expanded to include a review of all the literature made available through the center's library research services.

III. BACKGROUND

7. Non-Development Items (NDI). Belvoir Research and Development Center's current procurement strategy as it relates to construction equipment is to procure NDI.

NDI procedures are as follows: NDI will undergo test or evaluation or on-site operational test/evaluation for directed procurement items and items to be procured in small quantities, prior to type classification. Test data available from commercial contractors, Government agencies, or other sources will be used to satisfy test requirements to the maximum extent possible to eliminate unnecessary testing by the test activity. NDI are:

a. Items commercially available.

b. Items developed and accepted by other military services.

c. Items of other governmental agencies or countries.

Procurement of NDI to meet the new requirements will be made only to satisfy DA approved materiel requirement documents. Normally NDI materiel acquisition programs have certain characteristics:

- Greatly reduced acquisition leadtimes.
- Combined acquisition phases, decisions and milestones.
- Limited control of materiel design and configuration.

8. Significant Events. Much of the construction equipment that will be in the Army's inventory in FY85 was recently bought or is now under contract. Efficiency was not made a specific requirement so far as the technical data package was concerned.

9. Other Considerations. The efficiency of the equipment now or soon to be in the inventory is not known. Also, the efficiency of the replaced equipment is unknown. Our search through the available literature did not yield information that could be used to determine the efficiency of construction equipment; past or present. The impact of the background information on our energy program efforts will be discussed in Section IV of this report.

IV. DISCUSSION

10. Discussion. The field of energy conservation is tremendous and occasionally confusing. Everything we do or don't do impacts energy consumption in one way or another, but what that impact will be is not always understood. We also found that word usage is not consistent. Different authors will use the same word, such as efficiency, to describe a multi-facetted concept such as fuel consumption. This report organizes the concept of fuel consumption as it relates to construction systems into the following general areas of interest: system design, system selection, system operating procedures, system maintenance and operator training. In the real world, these areas are not mutually exclusive. Together they interrelate and contribute to fuel consumption. Efficiency is a concept well defined by engineers, and the concept is closely related to system design. Appendix A lists some general definitions for the word efficiency. From a review of the definitions, we can conclude without equivocation that efficiency is a ratio of some output over some input. On the surface, establishment of the ratio may appear simple, and in some cases it is simple. But, when accuracy is required, the process requires careful attention to detail and application of knowledge from many different disciplines. The accuracy point can become paramount, should the Army attempt to compare the products of competing manufacturers. During our literature review, we found many units associated with the ratios.

The most common ones were: $\frac{yd^3}{gal}$, $\frac{ton.}{gal}$ $\frac{mi.}{gal}$ $\frac{(lb)}{bph \times H.}$ Based upon the general definition for efficiency, a strong argument can be made for equating useful work to production in all its forms. In some cases, the above efficiency ratios would be satisfactory, but for our purpose we need more control. In this report, the meanings of the terms given below will be controlled by using the following units (Table 1).

Table 1. Control Units of Terms

Term	Units
Fuel consumption	gal, lb (mass)
Fuel consumption rate	$\frac{gal}{h}$, $\frac{lb}{h}$ (time may be in min or s)
Fuel conservation	gal, lb (mass)
Efficiency	$\frac{Btu}{Btu}$, $\frac{ft\text{-}lb}{ft\text{-}lb}$, $\frac{hp}{hp}$ (usually expressed in percent)
Fuel economy	$\frac{dol.}{gal}$ $\frac{mi.}{gal}$ $\frac{yd^3}{gal}$, $\frac{ton\ mi.}{gal}$ etc.

The above efficiency units were selected because they require conversion of production units such as cubic yards into work or power units, and that conversion will highlight many of the problems associated with determination of the output portion of the efficiency ratio found in some of the literature.

Determining the output portion of the efficiency ratio as generally defined for earthmoving operations is a complex task. Some of the factors affecting the determination of the useful work (output) performed during earthmoving operations are as follows:

Method of measuring the production.
Conversion to mass (soil density and water content).
Environment.
Operator.
Machine configuration.
Condition of soil.
Condition of machine.
Machine efficiency (mechanical and thermodynamic).
Machine speed (all functions).

The factors listed above are not all inclusive, but the list shows the depth and breath of the problems encountered when attempts are made to predict machine efficiency based on real world production tests. Unfortunately, none of the available literature quantitatively addressed the interrelationships of the output factors in an organized fashion. To compound the problem, we must add the fact that equipment efficiency is only a subset of fuel consumption. The Army's final energy goals are expressed in terms of consumption, and the factors controlling petroleum consumption include those identified in the list above in addition to those listed below.

Quantity of work performed.
Environment.
Operator (performance and training).
Machine configuration (including size).
Condition of soil.
Machine efficiency (mechanical and thermomodynamic).
Machine speed (all functions).
Work management.
Machine maintenance.
Fuel evaporation.
Waste.
Pilferage.
Contaminated fuel.
Selection of engine oil and fuel.

Our literature search yielded little information on the interrelationships among the factors. It is also conceivable that improvements in one factor may adversely impact fuel conservation. As an example, improving the efficiency of a hydraulic control may change the feel or response of a loader bucket operation in a manner that reduces production because of human factors considerations. In addition, the magnitude of the impact of each factor on petroleum conservation is unknown. Much more research and testing is needed before we can identify those factors that would yield the greatest fuel savings with the least expenditure of program resources. The need for initiating in the construction operations field a petroleum management program that considers all of the areas and factors mentioned is great.

Another area in the field of petroleum consumption is the development and establishment of methods to predict required petroleum supply. The Army Energy R&D Plan lists seven existing methods and states that three additional methods are being reviewed by the Logistics Center, Fort Lee, Virginia. These methods are listed in Appendix B of this report for information. Appendix B of the Army Energy Plan contains a review and evaluation of each method. Of interest here is recognition that the fuel consumption within an Army organization is related to many factors. The factors identified in the plan include: intensity of conflict, level of commitment, terrain temperature, type of equipment, and quantity and type of subordinate units. Also, the best methodology for estimating fuel consumption will balance accuracy with economics. The methodology must be accurate in the sense that it predicts the consumption of a given unit under given conditions within a narrow range of expected values and with a high degree of confidence. The methodology selected should make predictions quickly and at low cost, using existing data or data that can readily be extracted from available sources. Also, implied is that the prediction of fuel requirements, once made, can be useful for the purpose intended. The Army hopes to use the fuel consumption data base developed to support the fuel consumption estimating methodologies and to assess the impact of energy conservation R&D projects on the Army's fuel requirement. TECOM's field testing procedures for determining vehicle fuel consumption are uniquely set up to support methodology B-6, Appendix B.

One of the objectives of this report is the investigation of existing methods used to determine the fuel consumption of mobile construction equipment. Five methods were found and they will be discussed in the following order:

- TECOM Test Operating Procedures (TOP).
- Original Equipment Manufacturers' (OEM) Field Tests (Caterpillar Tractor Co.).
- Society of Automotive Engineer (SAE) Recommended Practice (SAE J1166).
- Dynamometer Testing Procedures.
- Math Models.

The first three procedures are field tests and the fourth is a simulated load procedure. Math models should not be used to determine fuel consumption because their purpose is to predict. They were included here because of their wide-spread usage in fuel conservation studies.

a. TECOM has prepared TOP and test guidance for many types of construction equipment. The test objective is to determine to what degree an end item and its components perform their mission as described in the requirements documents (specification, LR, etc.) and to determine the suitability of the end item and accompanying maintenance test package for Army use. Most of the TOPs reviewed (see Appendix C) no longer require determination of fuel and oil consumption tests except for cranes (TOP 9-2-064). However, fuel consumption tests may be added to any equipment test by the responsible developer. For vehicles, TOP 2-2-603 is used whenever a fuel consumption test is required. TOP 2-2-603 is used to determine the fuel consumption of transportation and engineer type vehicles. Procedure for controlled tests and tests to simulate service operations are described. Controlled tests are used to determine fuel consumption in the road-load, full-road, no-load, APGs standard fuel consumption course and work-function modes of operation. Full-load tests are performed with drawbar pull tests as described in TOP 2-2-604. No-load tests are performed with the transmission in neutral and the engine operated at speeds ranging from rated idle speed to governed engine speed. Road-load testing is performed with the vehicle loaded to its rated payload. Then, the vehicle is operated at constant speeds over a level, paved test course at not less than four equal increments of speed over the operating range of the vehicle in each gear. The test method used to determine fuel consumption with the vehicle performing in its normal work modes is described as follows: Measure fuel consumption while the vehicle is performing each work function for which it is designed. The following data are collected:

(1) Work function performed.

(2) Length of time function was performed (operating hours).

(3) Fuel consumed per work function cycle (gallons or pounds).

(4) Fuel temperature.

(5) Road and engine speed, where applicable.

Fuel consumption may be measured in lb/h or gal/h.

b. Original equipment manufacturers (OEM) are studying and comparing the fuel consumption of their equipment to other OEM equipment. Caterpillar Tractor Co. has reported the results of fuel consumption studies of wheeled loaders, tractors, and road graders. Simulation and typical work mode test procedures were used in the field tests. A design blade load simulation test procedure was used to evaluate road graders which were tested in Iowa. Three different drawbar loads were applied to the blade by attaching it to a load-carrying sled. The sled load was changed to simulate the blade loads. Tractors were tested in the soils and work modes as shown in Table 2.

Table 2. Tractor Tests

Work Mode	Soil	Place
Ripping	Caliche	Arizona
Pushloading	Caliche	Arizona
Dozing (uphill, downhill) level	Caliche	Arizona
Dozing	Clay loam	Peoria
	Sandy loam	Arizona

Loaders were tested in three typical work modes: load and carry-level and uphill, truck-loading (bank and stockpile material), and trench backfill. Caterpillar Edwards Demonstration Area was used during the test.

The weight of fuel consumed and volume of soil displaced and/or moved were collected for each test. The units of production for the tests were reported in ratio form as follows (Table 3):

Table 3. Production Units

Item	Ratio	
Loader	$\frac{LCY}{gal}$	
Grader	$\frac{gal}{h}$	$\frac{mi}{gal}$
Tractor	$\frac{BCY}{gal}$	$\frac{gal}{h}$

where: LCY - Loose cubic yards, and
BCY - Bank cubic yards.

c. Society of Automotive Engineer (SAE) Recommended Practice. SAE has published procedures for testing the fuel consumption of passenger cars and light trucks, but procedures for construction equipment have not been published. Of interest is SAE J1166a–Operator Station Sound Level Measurement Procedure for Earthmoving Machinery - Work Cycle test, because work cycles that could be useful for fuel consumption testing are described for the machinery listed as follows:

- Crawler loaders.
- Wheel loaders.
- Dumpers - rear, side, and bottom.
- Tractor scrapers.
- Graders.
- Crawler tractor with dozer.
- Wheel tractor with dozer.
- Pad foot wheel compactor with dozer.
- Backhoes.
- Hydraulic Excavator.

In addition to specifying the operating conditions for each item of machinery, the general test site requirements applicable to fuel consumption testing are given as follows: The site should be a uniform plane of earth with a maximum slope of 3 percent in any direction; all material in the test area should have a density of approximately 3000 lb/yd^3 where machinery configuration or location makes it impractical to use a test site as described above; sites with other conditions, such as field job sites, may be used. The operating conditions for each category of machine are generally based upon normal field use, practical test considerations, and most importantly, the impact the procedures would have on the accuracy of the noise level measurement. Engine speed, gear range, and duration of the work cycle are controlled for each test. Table 4 shows the engine speed criteria for each machine category and work cycle.

Table 4. Engine Speed Criteria

Equipment Category	Engine Speed	Other Conditions
Crawler loader	Max governor setting	Loose stockpile
Wheel loader	Max governor setting	Loose stockpile
Dumper	Max governor setting	Loaded haul, intermediate speed[1]
	3/4 of max governed speed	Empty return, high speed[2]
Tractor scraper	Max governor setting	Loading mode
Crawler tractor	Max governor setting	Dozing, low speed[3]
Pad foot wheel compactor with dozer	Max governor setting	Safe speeds
Back hoe	85% ± 2% of rated engine speed	Trenching, virgin soil
Hydraulic excavator	Max governor speed	Trenching, virgin soil

Notes:

1. Intermediate speed - Second gear of 3- or 4-speed transmission.
   Third gear of 5- or 6-speed transmission; and
   Fourth gear of a 7- or 8-speed transmission.

2. High speed - Highest working gear (manual transmission).
   Requirements for automatic, hydrostatic transmissions are also given.

3. Low speed - First gear of a 5-speed transmission, and
   Second gear of a 6- or greater-speed transmission.

d. Dynamometer. When vehicle fuel consumption measurements are performed on a chassis dynamometer, the dynamometer is usually adjusted to simulate the road experience (road-load) of the vehicle. Apparently, many methods are used to determine road-load, and the chosen method is selected because it best fits a particular situation. Some commonly used methods for road-load determination are: drive line force or torque measurements, manifold pressure measurements, and deceleration or coast down technique. The concept of the coast down is to determine the deceleration rate of a freely coasting vehicle. The coast down method was used in a study undertaken to develop math models to predict the dynamometer adjustment forces appropriate to simulate the on-road experiences of light-duty transportation trucks. This study concluded that the aerodynamic drag of light-duty trucks and vans is a more accurate method of predicting the dynamometer power absorption than predictions based on the vehicle weight. The mathematical relationship between vehicle frontal area and speed was used to calculate the dynamometer adjustments to be used for each test.

The Environmental Protection Agency (EPA) uses dynamometer tests to determine the fuel consumption quantities shown on new fuel economy labels. The EPA test procedure requires that a vehicle shall be driven over a prescribed driving cycle on a chassis dynamometer and that the fuel consumed shall be calculated from the measured composition and quantity of exhaust gas produced.

e. Math Models. All of the mathematical model studies investigated recognize the need to quantify the relationships between a vehicle's expected performance and the efficiency of the vehicle's functional subsystems. Most of the work was done in the area of transport type trucks and cars. However, reports dealing with the fuel consumption of crawler tractors and the fundamental parameters of vehicle on- and off-road fuel economy were also found. Some of the reasons for performing the studies are as follows:

(1) To evaluate the effect of changes in different performance parameters.

(2) To evaluate the effect of powertrain choice on fuel utilization of heavy articulated vehicles.

(3) To determine the fuel consuming characteristics of a typical crawler tractor with bulldozer under various operating regiments. The results were used to suggest various methods to reduce fuel consumption.

(4) To be used in computer simulations of vehicle behavior over typical duty cycles.

(5) To evaluate trade-offs between fuel consumption and desired performance.

Apparently, construction of a mathematical model is a relatively straight forward matter provided that the operating characteristics of each subsystem and component are adequately defined and all the necessary parametric data are available. Some investigators were unable to get all the information needed and their models are semi-empirical. Other investigators reported going through the long and tedious procedure of building and testing numerous prototypes for each subsystem and for the working parts of each vehicle to obtain the required engineering data. After a suitable data base is established, the use of computer-simulation for predicting vehicle behavior and performance over specific duty cycles saves time and money. Also, analysis of the results of the simulations has disproved some commonly held ideas about vehicle drivelines. Computer simulation techniques can be used to optimize engine capacity, select equipment size, predict fuel consumption, and analyze the impact of design changes on vehicle performance and fuel consumption, to mention only a few of an endless number of possible applications. Some investigators have reported good correlation between the fuel consumption predicted by computer simulations and the actual amount of fuel measured during field tests.

The five methods just reviewed all show the connection between fuel consumption and performance, and the concept of efficiency is embedded to some degree in each one. TECOM's TOP measures the time a machine spends performing a specific function but does not measure or record the quantity of earth removed. On the other hand, Caterpillar Tractor Co. highlights the relationship between fuel consumption and performance. They recently began to publish fuel consumption/performance information on competitor machines as well as their own. The method used to measure the quantity of earth moved was not identified. A discussion of the methods used to calculate earthwork and their accuracy is contained in Appendix D. The EPA is required by law to publish fuel economy information on all automobiles sold in the United States. The initial controversy over EPA'S methods for determining fuel economy has subsided, and it now appears to have gained some acceptance because no one has come up with a better way.

f. Advantages and Disadvantages. All of the methods discussed have advantages and disadvantages when viewed from a specific point of view. In this report, a brainstorming technique was used to list advantages and disadvantages for each method as follows:

TECOM:

Advantages	Disadvantages
Procedures are available now for all items of construction equipment.	Cost.
Addresses the details associated with safety, maintenance, pretest considerations, instrumentation, and required data collection.	Production is not measured.
Realistic.	Test subject to weather.
Simple to perform.	Accuracy is unknown.
Builds data base that is compatible with method F of Appendix B for estimating fuel requirements.	Fuel economy measurement is not the primary purpose for testing.

OEM Tests:

Advantages	Disadvantages
Production is measured	Cost.
Realistic.	Test subject to weather.
Operating conditions defined.	Procedures have not been established for all type of construction equipment.

Some control of soil type.	Procedures may not be acceptable to all OEM.
Fuel economy measurement is primary purpose for testing.	

SAE J1166 Test Procedures:

Advantages	Disadvantages
Operating procedures defined	Production is not measured.
Some control of soil type.	Test subject to weather.
Realistic.	Cost equivalent to TECOM test.
Simple to perform.	Fuel economy measurements are not primary purpose for testing.

Dynamometer Tests:

Advantages	Disadvantages
Repeatable.	Realism may be questioned.
Vehicle load is controlled.	Compatibility of dynamometer output may not be suitable for construction equipment.
Not subject to weather.	Limited information on compatibility with tracked vehicles.
Vehicle load is measured.	Procedures for exercising all machine functions are not available.
Well suited to comparing different makes and models of equipment.	Complex.
Less costly than field tests.	
Each vehicle function could be load simulated on test stand and load computer controlled.	

Credible.

Energy input and output can be measured.

Test equipment can be used for other purposes.

Machine efficiency is primary purpose for test.

Math Models:

Advantages	Disadvantages
Many iterations of the model are possible in a short time period.	Lacks realism.
Little petroleum is consumed.	Models not available.
No construction equipment required.	Only predicts fuel consumption.
A good investigating tool.	Required data base not available.
Best description of theoretical efficiency.	High initial cost.
	Highly complex.
	Field tests required to confirm models.
	Many different models may be required for each equipment type.
	Accurate construction equipment data will be difficult to acquire.
	Results will be long in coming.

The five methods were also subjectively evaluated poor, fair, good, and best against the following criteria: Accuracy. quantifiability, repeatability, cost, and acceptability. This evaluation was made from an efficiency determination point of view as shown in Table 5.

Table 5. Evaluation of Five Methods

Method	Accuracy	Quantifiability	Repeatability	Cost	Acceptability
Criteria					
TECOM TOP	Poor	Poor	Fair	Good	Poor
OEM	Fair	Good	Fair	Fair	Fair
SAE	Fair	Poor	Fair	Good	—
Dynamometer	Best	Best	Best	Good	Best
Math Models	Good	Good	—	Best	Poor

Our effort (Construction Equipment Division) to reduce the fuel consumption of construction equipment is focused on the estabishment of equipment efficiency requirements for end items and development of a vehicle test procedure to confirm compliance with those efficiency requirements. Apparently, that approach was selected because of NDI policy constraints; i.e., limited control of materiel design and configuration. Our progress is hindered because the data base needed to establish efficiency requirements for construction equipment is not available to the Army. Incident to all of this is the realization that the data base needed by the Army to estimate fuel supply requirements is also being eroded by NDI policy and a change in TECOM TOP. TECOM no longer tests commercial construction equipment and even if they did, fuel consumption data are no longer gathered routinely. Also, the opportunity to conserve petroleum in the 1984 to 2000 time frame is slipping away because we are now buying the equipment that will be used during that period. Working to our advantage is the notion that the construction equipment industry is continually improving the efficiency of their machines. The industry is motivated to do so, because of the following:

(1) Contractors are cost conscious and profit motivated.

(2) Computers make it practical for the contractor to build a fuel consumption data base for different makes of machines.

(3) Foreign competition.

On the other hand, contractors are not motivated to buy machines based on impressive efficiency percentages alone. More efficient machines must contribute to higher profits. Consequently, the equipment manufacturers seek out and implement hardware changes that satisfy the contractors profit goals. We may capitalize on the above notions by taking advantage of the R&D work being done by industry. The literature is full of studies aimed at improving machine efficiency and production. Some of the work going on is listed below:

(1) Development of light-duty diesel engines.

(2) Development of instrumentation to detect and measure machine operating parameters useful in petroleum management.

(3) Development of instrumentation and system to provide equipment operators with the information they need to optimize performance and fuel consumption.

(4) Development of multi-fuel engines.

(5) Development of continuously variable-ratio transmissions (CVT).

(6) Production of transmissions with many gear ranges.

(7) Development of more efficient hydraulic components and systems (multiple flow pumps, load sensing valves).

(8) Production of hydrostatic transmissions.

(9) Production of tires that reduce rolling resistance.

(10) Studying the impact of maintenance practices on fuel conservation.

(11) Radiator shutters.

The use of diesel engines in our equipment could have a quick and significant impact (25 to 30 percent improvement) on our efforts to reduce petroleum consumption. A review of the divisions TDPs was made and we found 10 specifications that specify the use of gasoline engines. This is not to imply that we should simply convert all gasoline engines to diesel engines; a thorough investigation and evaluation is necessary.

Another approach for achieving results in a reasonable amount of time is to determine the efficiency of state-of-the-art subsystems and components, and where appropriate, specify thier use. For example, the desired engine efficiency could be added to existing engine requirements in a TDP. A high degree of success with this approach is possible if good judgement and a systematic approach to the problem is used. As a minimum, the effort should include the following.

(1) Mission definition for each item of equipment.

(2) Preparation of a work breakdown structure (WBS) for each type of equipment.

(3) Knowledge of the current efficiency of the subsystems at all levels for each type of equipment.

(4) Allocate efficiency improvement goals for appropriate subsystems based upon the efficiency of emerging designs and products.

(5) Evaluate the impact of efficiency requirements on performance and cost.

If we are to meet our energy goals, the search to find ways to conserve petroleum must be broad based.

V. CONCLUSIONS

11. Conclusions: It is concluded that:

a. Dynamometer load simulation techniques for evaluating efficiency are best suited to our needs.

b. The data base needed to establish efficiency requirements does not exist within the Army.

c. A broad based petroleum management program for earthmoving and construction operations is needed.

d. Current program resources are inadequate for achieving timely results.

e. Some tasks that have not been accomplished are:

(1) Near Term:

(a) Research and evaluate usefulness of existing data bases such as EPA engine emission test procedures.

(b) Evaluate conversion from gasoline to diesel or stirling engines.

(c) Evaluate conversion from bias to radial tires for selected items of contruction equipment.

(d) Develop a program plan for petroleum conservation management in the earthmoving and construction areas.

(e) Acquire the necessary resources.

(2) Far-Term:

(a) Acquire dynamometer based procedures for determining the fuel economy of each type of construction in the inventory, starting with the high petroleum consumption items.

(b) Initiate a test program to build the data base needed to establish fuel consumption requirements for state-of-the-art end items and subsystems.

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APPENDIX A

DEFINITIONS OF EFFICIENCY

A-1. The ratio of the useful energy delivered by a dynamic system to the energy supplied to it.

A-2. The ratio of the work done or energy developed by a machine, engine, etc., to the energy supplied to it.

A-3. The ratio of the useful energy delivered by a dynamic system (as a machine engine or motor) to the energy supplied to it over the same period or cycle of operation.

A-4. Thermodynamic efficiency. The ratio of the net energy output in the form of useful work to the heat energy input.

A-5. Efficiency of a two-element machine. The ratio of the useful work performed to the total work received. Also, if a machine consists of a train of mechanisms having the respective efficiencies e_1, e_2, e_3, ...e_n, the combined efficiency of the machine is equal to the product of these efficiencies.

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APPENDIX B

METHODOLOGIES FOR ESTIMATING FUEL CONSUMPTION REQUIREMENTS*

B-1. Old FM 101-10-1 Method (superseded by B).

B-2. New FM 101-10-1 Method.

B-3. Pounds/Man/Day Method.

B-4. Gallons/Man/Day Method.

B-5. Gallons/Kilometer/Vehicle/Day Method.

B-6. Gallons/Operating Hour.

B-7. STANAG 2115.

Other methods are being considered by a variety of sources. Significant are the following techniques under review by the Logistics Center, Fort Lee, Virginia:

B-8. Percentage of Intensity Method.

B-9. Discrete Posture Method.

B-10. WAFF Method (as described by CAA in (CF)^2 Conference Report).

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* US Army Energy R&D Plan, dated 1982.

APPENDIX C

TECOM FIELD TESTING PROCEDURES FOR CONSTRUCTION EQUIPMENT

Test Operations Procedure No.	*Equipment Description*
9-2-071	Earth loading
9-2-082	Earth moving
9-2-111	Paving equipment
9-2-063	Crane, truck, warehouse
9-2-166	Air compressors
2-2-100	Trucks and tractors
9-2-064	Crane
9-4-001	Desert environmental testing of construction service and support
2-2-603	Vehicle fuel consumption

APPENDIX D

EARTHWORK COMPUTATION METHODS
(Prepared by J. Rodrigues)

D-1. The computations of earthwork involve the calculation of earth volumes and the determination of initial and final grades. There are several methods utilized by engineers to compute earthwork. The exactness of the computations depends upon the extent and accuracy of field measurements. Some methods by which to compute earthwork are the following:

a. Average end area method.

b. Prismoidal formula method.

c. Grid method.

d. Contour method.

D-2. To compute earth volumes by either of the above mentioned methods, it is necessary to determine the area of two parallel planes. The following is a list of the various end area determination methods listed in according order of accuracy.

a. Trapezoidal Rule. By this rule, the area of the individual trapezoids from a cross section are added to find the total area. The computations are tedious, and its accuracy depends on the number of regular trapezoids formed.

b. Stripper Method. This is a variation of the trapezoidal rule. The vertical lines should be closer together to insure greater accuracy.

c. Double Meridian Method. This method is similar to the method of coordinates, but the computation does not involve the direct use of coordinates. Meridian distances are found to form trapefolds and triangles. The double area of any triangle or trapezoid formed by projecting a given course upon the meridian is the product of the double meridian distance of the course and the altitude of the course. The algebraic sum of the double areas are found, and the area is determined by dividing the sum of two.

d. Planimeter Method. A planimeter is an instrument that will measure the area of a plane figure when its tracing point is moved around the perimeter of the figure. It is the most accurate method for area determination. Although its accuracy depends in finding the precise settings, which can only be approximated. The efforts of planimeter measurements are due principally to the inability of the observer to follow exactly the boundary of the figure with the tracing points. Values of area should be determined to 0.01 in.^{2}.

D-3. Volume Determination. Volumes of earthwork are calculated by various methods. If cross-sections have been taken, their areas are determined as described in preceding paragraphs, and the volumes of the prismoids between successive cross-sections are calculated by any of the following methods:

a. Average End Areas. This is the most common method of determining volumes of excavation. The area of the cross-sections is averaged and multiplied by the distance between them. This method is sufficiently precise for ordinary earthwork only.

b. Prismoidal Formula. The use of this formula is justified if cross sections are taken at short intervals, and also, when surface deviations are observed and when successive cross-section areas differ widely.

c. Grid Method. This is a common method where the volume of a borrow pit is found by cross-sectioning the area before and after excavating. The area is divided into rectangles, triangles, and trapefolds. The volume is found for the individual sections and then added.

d. Contour Method. Volumes of earthwork can be estimated from contour maps using vertical cross-sections from contour maps. A profile is shown for each cross-section. The profile is shown with the original ground line before and after the proposed grade. The area between these ground lines is averaged for the two cross-sections and is multiplied by the distance between them. The calculated volumes using this method should be used only for preliminary estimates.

D-4. Precision of Determining Volumes. There are many factors which affect the precision of determining earth volumes. The following factors are the most relevant to be considered:

a. Soil Shrinkage. Shrinkage denotes the fact that 1 yd^3 of earth before excavation will occupy less than a yd^3 of space when excavated, hauled, and compacted. The loss of material and compaction to greater than original density might contribute to this difference.

b. Soil Swell. Swell could be produced by the increase of voids content after loosening or blasting rocks.

c. Horizontal Measurements. Horizontal measurements errors are introduced principally by the manner of holding and reading the tape.

d. Vertical Measurements. Vertical errors are due to rod reading and variation in the elevation of the ground surface where the rod is held.

Accuracy depends on the method selected, amount of cross section, and control of the above mentioned factors. The size of these errors varies under various field conditions but a probable error of ± 0.05 can be assumed for average field conditions under controlled procedures.

A reliable computation of area can be obtained with a planimeter and the use of the prismoidal formula to compute volumes controlling the amount of cross-section and field measurements. The shrinkage and swell percentage of the soils should be predetermined. Also, variations of the surface could introduce significant errors when small volumes are calculated. Their effect diminishes when high volumes of earth are under consideration.

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