Fuel Usage Factors in Highway and Bridge Construction

DETAILS

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

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Fuel Usage Factors in Highway and Bridge Construction

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The members of the technical panel selected to monitor this project and to review this report were chosen for their special competencies and with regard for appropriate balance. The report was reviewed by the technical panel and accepted for publication according to procedures established and overseen by the Transportation Research Board and approved by the Governing Board of the National Research Council.

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AUTHOR ACKNOWLEDGMENTS

The research reported herein was performed under NCHRP Project 10-81 by the consulting team of Jack Faucett Associates, Inc. (JFA) and Oman Systems, Inc. (OSI). JFA is a transportation and economics consulting firm founded in 1963 that has completed over 750 research projects for federal, regional, state, and other clients. OSI was founded as a heavy construction contracting firm and is now an estimating software provider and preeminent source for information on the heavy construction industry.

The principal authors of this report are Jonathan Skolnik, JFA vice president and senior policy analyst, Mike Brooks, research analyst at JFA, and John Oman, president of OSI. Dr. Harry Chmelynski, senior statistician at JFA, conducted the BidTabs statistical analysis. Devon Cartwright-Smith, economist at JFA, constructed the Excel-based Contractor Fuel Usage Survey (CFUS) and the Price Adjustment Calculator Tool (PACT).

FOREWORD

By Edward T. Harrigan
Staff Officer
Transportation Research Board

This report provides updated fuel usage factors for work items in the construction and maintenance of highways and bridges. The Price Adjustment Calculator Tool, a Microsoft Excel® spreadsheet that will assist in the calculation of payment adjustments for construction projects using fuel price indices or fuel prices, is also available for download from the TRB website by searching for *NCHRP Report 744*. The report and spreadsheet tool will be of immediate interest to engineers in state departments of transportation and industry who request and respond to bids for these activities.

NCHRP Project 10-81, "Fuel Usage Factors in Highway and Bridge Construction," was conducted by Jack Faucett Associates, Inc., Bethesda, Maryland, with participation by Oman Systems, Inc., Nashville, Tennessee.

The objectives of the project were to (1) identify present highway construction contract activities that are major consumers of fuel; (2) prepare fuel usage factors for these activities, including those items of work presented in Attachment 1 of FHWA Technical Advisory T5080.3, for base year 2012; and (3) develop a recommended practice for state DOTs to implement use of fuel adjustment factors and adjust them for both state-specific conditions and changes in construction costs, methods, and equipment.

Price adjustments of selected commodities in highway construction are used in construction contracting as a way of limiting risks to the contractor arising from price fluctuations of these commodities over the life of a contract. Fuel usage factors are commonly applied by state and local agencies in calculating fuel cost price adjustments in a contract specification that permits cost escalation and de-escalation. The current federal factors, originally developed for *Highway Research Board (HRB) Circular 158* in 1974, are presented in the 1980 Federal Highway Administration (FHWA) Technical Advisory T5080.3.

The research team used three methods to examine this issue and develop the updated fuel usage factors in Technical Advisory T5080.3. The first method was a nationwide survey of highway construction contractors. The second method was an engineering estimation of fuel usage per unit for numerous highway construction work items, which was undertaken by a team of veteran construction estimators. The third method was a statistical analysis of a comprehensive industry database to determine if historical bid prices of construction pay items can be modeled and correlated to historical fuel prices. The three methods complemented one another, provided a level of redundancy in the research effort, and resulted in a well-founded update and expansion of the fuel usage factors in the technical advisory.

The report fully documents the research, presents the updated fuel usage factors, and includes Appendix A, Recommended Practice and Model Specification. In addition, the following appendixes are available for download from the NCHRP Project 10-81 web page at http://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=2712:

- Appendix B, Outreach Plan
- Appendix C, PowerPoint® Presentation and Speaker Notes, and
- Appendix D, News Brief.

Finally, the web page provides a link to download the Price Adjustment Calculator Tool, a Microsoft Excel® spreadsheet that will assist in the calculation of payment adjustments for construction projects using fuel price indices or fuel prices.

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Note: Many of the photographs, figures, and tables in this report have been converted from color to grayscale for printing. The electronic version of the report (posted on the Web at www.trb.org) retains the color versions.

SUMMARY

Fuel Usage Factors in Highway and Bridge Construction

Price adjustments of selected commodities in highway construction are used in construction contracting as a way of limiting risks to the contractor arising from price fluctuations of these commodities over the life of a contract. Fuel usage factors are commonly applied by state and local agencies in calculating fuel cost price adjustments in a contract specification that permits cost escalation and de-escalation. The current federal factors, originally developed for Highway Research Board (HRB) Highway Research Circular Number 158 in 1974, are presented in the 1980 Federal Highway Administration (FHWA) Technical Advisory T5080.3. The advisory contains fuel usage factors, in gasoline and diesel, for a number of heavy construction activities, including excavation, aggregates, hot mix asphalt production and hauling, and Portland cement concrete production and hauling. HRB Circular 158 established fuel usage factors for structures and miscellaneous construction in gallons per $1,000 of construction cost, with no provision for any adjustment for inflation.

NCHRP Project 10-81 is the first research effort to revisit these factors on the federal level and attempts to account for more than 30 years of inflation, commodity cost increases, and changes in construction practices. The objectives of this research were to (1) identify present highway construction contract activities that are major consumers of fuel; (2) prepare fuel usage factors for these activities, including those items of work presented in Attachment 1 of FHWA Technical Advisory T5080.3, for base year 2012; and (3) develop a recommended practice for state DOTs to implement use of fuel adjustment factors and adjust them for both state-specific conditions and changes in construction costs, methods, and equipment.

The study team employed a three-pronged research methodology to examine this issue and develop updated fuel usage factors. The primary methodology was a nationwide survey of highway construction contractors using a variety of survey tools. The second methodology was an engineering estimation of fuel usage per unit for numerous highway construction work items, which was undertaken by a team of veteran construction estimators. The third methodology was a statistical analysis of the Oman Systems BidTabs Database to determine if historical bid prices of construction pay items can be modeled and correlated to historical fuel prices. The three methodologies complemented each other, provided a level of redundancy in the research effort, and resulted in a positive project outcome.

The Original Fuel Factors Documents

The original research on fuel usage factors includes *Highway Research Circular 158* by the Highway Research Board (now the Transportation Research Board) in July 1974. A mailed survey of 3,000 highway contractors netted 400 responses, and the FHWA compiled and analyzed the data. Factors were computed for construction activities such as excavation, aggregate and asphalt production, and structure construction. Each of these activities received a high, low, and average factor. Both diesel and gasoline were included.

The FHWA incorporated Circular 158 factors in Technical Advisory T5080.3, originally released in 1980. The FHWA website provides the updated version of this advisory. It contains methods for developing price adjustment provisions such as downward and upward contract provisions, using an average of quotes to avoid manipulation, triggers based on a 5 percent change in fuel price indices, and ad hoc adjustments on fuel usage factors in cases of extreme elevation, rough terrain, etc. It also provides the original fuel usage factors as well as additional fuel usage factors developed by the states.

The Contract Administration Section of AASHTO's Highway Subcommittee on Construction (AASHTO SOC) maintains a spreadsheet that summarizes the current use of price adjustment clauses for fuel, asphalt, cement, steel, and other highway materials. The 2009 version of a summary spreadsheet includes general information regarding trigger values, indices, Web references, general comments, and state DOT contacts. This set of literature also includes the individual state policies for which the spreadsheet provides Web references.

Methodology Development Phase

NCHRP Project 10-81 is divided into three major phases. The first phase proceeded as an initial methodology development phase. The goals for this phase were to ascertain the data needs and perceptions of state DOTs and contractors as well as to determine the fuel intensity of highway construction tasks. These goals were accomplished using three methodologies: state DOT and contractor surveys of needs and perceptions, an initial engineering analysis of fuel intensity, and a statistical analysis of fuel intensity.

State DOT Survey of Needs and Perceptions

The study team conducted a nationwide survey of state DOTs. The purpose of the survey was to ascertain the current implementation of fuel usage factors, the states' satisfaction with their current programs, and their perceptions on how to upgrade them. The survey, provided in a user friendly SurveyMonkey format, received responses from all 50 state DOTs.

The use of fuel factors in bridge/structure contracting is common, but several flaws act as a hindrance to their effectiveness. Fuel factors for bridges/structures were present in 20 states, 40 percent of the total surveyed. When asked to divulge perceived flaws in bridge/structure fuel factors, 28 out of 37 states responded with at least one criticism. Changes in construction methods and fuel intensity and differences in structure type, size, and complexity were perceived as the largest flaws, receiving 12 selections each.

Respondents had similar perceptions of the activities that were most fuel intensive. Asphalt paving and grading/excavation were the decisive top choices when ranking construction activities by fuel intensity, sharing all 48 first-place rankings between them.

Respondents had mixed opinions on whether they desired fuel factors for a broader spectrum of items. A total of 33 out of 47 states believe it is unnecessary to include fuel factors for additional pay items due to limited fuel use. Administrative burden was cited by 16 states as justification for limiting the number of fuel factors.

State DOTs had definite, although sometimes conflicting, ideas on the form fuel factors should take and how often they should be updated. The ability to convert units of measure in the new system received support from 26 states, while the inclusion of high-medium-low factor ranges would be useful for 16 states. Urban/rural and hauling distance were the most popular options when selecting additional variables for the system, receiving 20 and 19 selections respectively, although 16 states would not want any additional variables. Seventy percent of states would like the system to be configured at the state (23) or regional (12) level. A majority of 34 states would like the factors to be updated every 5 years or less.

State DOTs shared a high level of interest in new research on fuel factors. For example, almost two-thirds of those responding (30 out of 46) would begin a fuel factor program or implement changes to their fuel factor adjustments if presented with revised factors and a software tool. Only 12 states with fuel factor programs would retain their existing methods, while five states that do not implement fuel factors would continue to refrain from utilizing them. Several states said they would evaluate the delivered products and consult with the contracting industry before moving forward.

Initial Contractor Survey of Needs and Perceptions

The study team also conducted a nationwide survey of contractors. Designed as a precursor to the more detailed Contractor Fuel Usage Survey, this survey explored the basic components of the fuel usage experiences and methodologies of construction firms. An additional goal was to determine methods to maximize the visibility and effectiveness of the later survey.

Nearly 80 percent of the responding contractors operate primarily in states that use fuel factors. A sizable majority (39 out of 46) of responding contractors have updated their fuel consumption rates or factors within the last 3 years, while less than one-third of state DOTs have done the same. Individual contractors would seem to have an incentive to update this information regularly as a means of increasing bid accuracy and eliminating uncertainty.

The results for the contractor survey illustrate several trends that may be ameliorated by updated fuel usage factors. Contractors update their fuel consumption rates or factors more often than do state DOTs. Fluctuations in commodity pricing have a larger effect on contractors than DOTs, primarily due to smaller operating budgets. Contractors would then have an incentive to update and maintain factors. While 60 percent of the responding contractors expressed satisfaction with the accuracy of their primary state's fuel factors, nearly 40 percent found them to be somewhat inaccurate at best. Inaccuracies can be compounded if a contractor's estimating tool cannot calculate the amount of fuel used on a project, which nearly 40 percent of respondents indicated.

Initial Identification of High Fuel Use Pay Items

In addition to collecting state DOT and contractor perceptions on fuel intensity, the study methodology included two other methods designed to investigate fuel intensity. As part of the study team's three-pronged approach to addressing the research problem, the project team conducted an initial investigation to identify construction pay items that had high fuel intensity. An expert panel of professional estimators and contractors rated the fuel use of over 1,000 specific pay items. The ratings of individual estimators were averaged to create a composite ranking of fuel use. Reviewer D is a member of the research team and Reviewers A through C performed as consultants for the research team. Each member of the panel possesses at least 25 years of experience in the highway construction and/or cost estimation fields.

The initial engineering analysis consisted of the following three parts:

- Creating a list of pay items to study by filtering unsuitable pay items,
- Creating a ranking system to apply to the pay items, and
- Performing the fuel use ranking of each pay item and pay item category.

Historically, the most common categories of pay items used for fuel use factors are grading, asphalt, base stone, and concrete pavement. All four of these categories ranked high in both the summary and detailed analysis. Several items were later excluded due to being bid in small quantities or because of the inclusion of lump sum pay items.

Initial Statistical Analysis of Fuel Prices and Bid Prices

In the initial statistical analysis, the objective was to examine which pay item prices are sensitive to changes in fuel prices in order to develop a list of items for which to develop fuel use factors. The thesis was that if there is no association between fuel prices and pay item prices, it would not be necessary to provide a price adjustment clause for those pay items.

The initial statistical analysis consisted of three steps. The first step was to tabulate unit prices for pay items over time. The second step was to develop price indices for fuel. The third step was to conduct an initial statistical analysis using pay item level bid data from the Oman Systems BidTabs Database for 48 states.

The overall conclusion of the initial statistical analysis is that there is a positive relationship between fuel prices and bid prices. The positive relationship is strongest where the significance of the correlation is strongest. However, there is a large amount of variation in the results for individual pay items within the categories of construction. The negative coefficients indicate the fuel price is not always an important factor for determining bid prices for many types of purchases. It may be concluded that fuel consumption is significant in most types of highway construction, but perhaps is not limited to only certain construction activities, as previous studies have suggested.

A major goal of the initial analysis was to identify construction tasks that consume large amounts of fuel and are fuel intensive. These items would be obvious candidates for newly calculated fuel factors. The initial statistical analysis indicated that a larger number of activities than previously envisioned are heavy users of fuel and/or are fuel intensive. Many heavy construction tasks, such as asphalt paving and grading, were confirmed as being heavy users of fuel. However, additional items appear to be more fuel intensive than anticipated. For example, the roadway lighting/electrical and signalization categories ranked second and third in the initial statistical analysis. Those categories did not rank within the top ten of the other initial methodologies.

Data Collection Phase: Final Methodology

Following the initial phase was the data collection phase. The data collection phase utilized the three project methodologies to directly estimate fuel consumption. The survey approach provided much of the data used in formulating the new factors. The engineering approach confirmed the survey data and provided additional detail when the survey approach did not garner sufficient observations for particular work items.

Final Contractor Fuel Usage Survey

The first effort of the data collection phase was the Contractor Fuel Usage Survey. This effort aided in the identification of heavy fuel use activities and allowed the project team to establish current levels of fuel use across a variety of construction activities and project conditions. The project team utilized several surveys, including an Excel spreadsheet tool and several industry-segment-specific SurveyMonkey surveys, to elicit contractor responses. To maximize contractor participation, the project team received cooperation from several industry organizations, including the Associated General Contractors of America (AGC), the American Road & Transportation Builders Association (NAPA), the National Asphalt Pavement Association (NAPA), the American Concrete Pavement Association (ACPA), and the National Ready Mixed Concrete Association (NRMCA).

In total, respondents provided over 500 fuel consumption observations for over 40 different activities. As stipulated in the outreach efforts to highway construction contractors and organizations, this report provides results as an average of the valid responses for each activity and does not provide information reported by individual respondents.

The fuel consumption estimates represent the simple mean (average) of all of the responses that met two criteria. The first criterion was that the respondent provided the estimate in either the default unit suggested in the survey or an alternative unit that the project team could convert to the base unit with a conversion factor. For example, for most activities, a subset of respondents reported results in terms of gallons consumed per hour. Conversion of these estimates to gallons per unit of work was not possible without assuming a production rate.

The second criterion was that each individual response included in the estimate had to be within a range that the engineering staff judged to be reasonable. In some instances, respondents provided estimates that varied from the majority of estimates by a factor of 10 or more. For example, one respondent provided fuel consumption per unit estimates for the six types of milling that ranged from 8.8 to 9.5 times greater than the mean estimate for all of the respondents. In each case, this respondent's estimate was at least 6.6 times higher than any other estimate. These out-of-range estimates were not included in the calculation of mean values.

The number of observations was sufficient to constitute a valid sample for most work items. With the exception of several outlying responses that would have skewed the calculated averages, the fuel usage estimates provided by the contracting community were within a reasonable range of accuracy as determined by the research team's engineering experts. Results within categories demonstrated consistency as well. The survey results provided utility throughout the remainder of the project, especially as a means to complement and verify the engineering results.

Final Engineering Analysis of Fuel Usage

Building on the results from the initial engineering analysis, which aimed to identify high fuel use activities, the project team extended the analysis to calculate the fuel use per unit for each work task. Using the initial phase calculations as well as estimated quantities of work for a typical project, the project team was able to estimate a fuel usage factor for each work task. As in the initial engineering analysis, the study team utilized an expert panel of four construction engineers and estimators. Each panel member employed their industry expertise to compile a list of construction activities, assign equipment and crews to work tasks, and calculate production rates. Panel Members A, B, and C each independently calculated fuel use per unit for each work task. Panel Member D acted as a mediator during this effort and investigated discrepancies, resolved differences in calculations, and compiled the results.

The fuel use calculations, arrived at through a consensus-building process among the expert engineering panel, provide accurate average fuel use specifications for a variety of work tasks prevalent in the highway construction industry. Although any given estimator might choose approaches and equipment that differ slightly from those presented, the fuel use calculations provided represent realistic baseline numbers for a detailed set of average work tasks.

Final Statistical Analysis of Fuel Usage

The objective of the BidTabs statistical analysis was to estimate the fuel usage of construction activities using a statistical model that incorporates changing fuel prices and bid prices. This included specification of the model, testing of different combinations and forms of the variables, exploration of lagged variables, evaluation of residuals and error terms, and exploration of different combinations of pay items both within and across states.

The original methodology envisioned that the database would contain prices over 3 to 5 years. The study team selected a start date of 1/1/2006 and an end date of 12/31/2010, resulting in 3 additional months of data and a full 5-year data set. In total, 363,137 separate pay items are available in the Oman Systems BidTabs Database. For these pay items, there were more than 4.1 million low bids. Note that low bids are the unit price bid for the item in the winning low bid as opposed to the lowest bid for that item.

The regression results produced by the analysis demonstrated some degree of consistency. The fuel required for a ton of asphalt is a factor of approximately 10 higher than for a ton of base stone. The fuel required for asphalt per square yard is slightly smaller than the fuel required for the pay item grouping of bridges per square yard (mainly organic surface coatings). Drainage pipe has a higher fuel requirement per linear foot than fencing, which in turn has a higher requirement than erosion control. Guard rails require only slightly more fuel input per linear foot than roadway lighting/electrical.

On the other hand, however, several of the estimates generated by this analysis clearly do not appear to represent actual fuel usage. For example, the statistical estimate of fuel usage for grading on a cubic yard basis differs from the engineering and contractor survey estimates by a large factor of magnitude.

Despite the high level of aggregation, the number of states is small for many pay item groups. For example, seven pay items rely on data for only one state, while 15 more rely on data from only two or three states. State-defined pay items are at a finer level of detail than the pay item groups used for this study. As a result, the estimates for these groupings are not as robust as those for pay items that are common to many states.

The statistical analysis demonstrated that most highway construction activities consume large amounts of fuel and are fuel intensive. However, the approach does not appear to have generated estimates of fuel usage that would be accurate enough to contribute to the development of the final fuel usage factors. In developing these fuel factors, the results of the statistical analysis were considered where it was felt that they might be useful.

Comparison of Fuel Usage Estimates and Fuel Factor Development Phase

The final project phase consisted of comparing the fuel usage data gathered during the previous phase, modifying select items based on the knowledge of the expert engineering panel, and developing a final fuel usage factor for construction work tasks. This phase also examined the alternative uses for the final fuel usage factors.

Data Comparison and Fuel Usage Factor Development

In developing the final fuel usage estimates by pay item, the study compares the information available in the existing literature with the fuel usage data developed using the three project methodologies. These sources are as follows.

1. **Technical Advisory T5080.3.** This technical advisory presents the fuel factors calculated in the original effort during the Nixon era. These factors are still used by a large number of contractors and state DOTs.
2. **Contractor Survey.** The Contractor Fuel Usage Survey represents a cooperative effort by the NCHRP, study team, and industry organizations to engage the highway construction contracting community. The objective of this effort was to ascertain fuel use information from contractors representing a broad sample of regions, firm sizes, project locations, and work activities. Utilizing an Excel spreadsheet tool and several iterations of a SurveyMonkey survey, this effort resulted in over 500 data observations.
3. **Engineering Analysis.** For this methodology, the study steam convened an expert panel of veteran construction engineers and estimators. The engineering team first collaborated to rank construction activities by fuel use intensity and recommend items that should be further analyzed. In later efforts, the engineering team then calculated the fuel use for these activities under average project parameters. This was done by calculating the equipment needed for each activity, the fuel consumed by this equipment, production rates, and the average length of time expected to complete each project. The result is a calculation for each work activity that expresses the gallons of fuel consumed per a unit of measure, such as the number of gallons of diesel fuel consumed for each linear foot of sewer pipe.
4. **BidTabs Statistical Analysis.** This experimental methodology attempted to track the relationship between fuel prices and bid estimates. Unlike other elements of a typical construction bid, commodity prices (including fuel) exhibit historical fluctuations due to market variables. This methodology attempted to isolate fuel prices, coalesce them to historical BidTabs data as maintained in the Oman Systems database, and observe any correlations.

For this effort, the research team compared data across the three study methodologies and the original fuel factors as presented in Technical Advisory T5080.3. Where the research had enough data to make a valid comparison, there was substantial agreement between the sources regarding activity fuel use. In particular, the survey data validated the engineering estimates. Where there was disagreement among the data sources, the engineering estimates were reassessed and generally revised to reflect the figures garnered from the survey effort.

Other Potential Uses and Applications for Project Data

The research team explored other potential applications of the fuel usage data. The primary intended audience or “market” for the products of this study will be the state DOTs and, in particular, the contracting authorities that request bids for highway construction or maintenance. However, this guidance will also be useful for a variety of other entities and uses.

The research team undertook a variety of activities in order to explore these other potential activities. First, the team queried selected state DOT representatives to ascertain whether they envisioned additional uses for the fuel factor data. Second, the team reached out to the members of the NCHRP project panel for their input and assistance. In both instances, the inquiries polled respondents on their impressions as to the usefulness of the data to potential users. Finally, the team reviewed pertinent literature collected throughout the study for information on potential additional audiences.

The research revealed six major additional markets for the results of this study. These include

- Other agencies responsible for highway contracting;
- Agencies responsible for construction of facilities for other transportation modes;
- Associations representing industries that build highways or provide goods to highway builders;
- Officials interested in improving planning and budgeting;
- Contractors interested in better understanding and managing their fuel use or in preparing more accurate cost estimates; and
- Researchers examining energy requirements, emissions, and climate change.

A range of potential uses exists for the fuel factors data collected in this study. The data can be used by entities other than state DOTs for both highway contracting and construction of facilities for other transportation modes. Associations may value the data for dissemination of information and policy guidance for their members. Officials interested in improving planning and budgeting may find information on fuel use in their projects extremely useful. At the same time, contractors interested in better understanding and managing their fuel use or in preparing more accurate cost estimates will find value in the fuel factors. Finally, researchers examining energy requirements, emissions, and climate change, can use the data in preparing estimates, inventories, and action plans.

Appendices and Other Research Products

Several project efforts are included as appendices for this report. These efforts, which are briefly described below, include the Recommended Practice and Model Specification and the Outreach and Dissemination Plan.

Recommended Practice and Model Specification

One of the major research products of this project is Appendix A, Recommended Practice and Model Specification. The Recommended Practice and Model Specification document contains a table that displays the revised fuel usage factors and also explains the procedures for development and use of fuel price adjustment contract provisions. Exhibit S-1 contains the project work tasks, original fuel usage factors (when available), revised and new fuel usage factors, and units of measurement. The Recommended Practice and Model Specification also presents information on criteria for application of the fuel usage factors, sample wording successfully used in specifications by various states, and example calculations and worksheets. The document contains two payment adjustment clauses. The first model specification is designed to be used by states that calculate price adjustments through the use of a price index. The second model specification is designed to be used by states that perform price adjustments with the actual fuel prices. Each of the specifications contains the following sections and elements:

- The source for historical commodity prices (entered by user),
- The positive and negative trigger values that trigger a price adjustment (entered by user),
- The letting date and base commodity prices (entered by user),
- The relevant fuel factors (entered by user),
- The price adjustment calculation formula,
- Definitions for formula inputs, and
- Sample calculations.

Exhibit S-1. Fuel usage factor summary table.

Category	Item of Work	Units	FUF	1980 FUF
Clearing and Removal	Clearing	Gallons/Acre	191.200	200.000
	Pipe Removal	Gallons/L.F.	0.863	
	Pavement Removal - Asphalt	Gallons/C.Y.	1.397	
	Pavement Removal - Concrete	Gallons/C.Y.	0.562	
	Structure Demolition (House/Building)	Gallons/Each	375.000	
	Structure Demolition (Bridge per S.F. of Deck)	Gallons/S.F.	0.626	
Excavation	Excavation - Earth - Off Road - Long Haul	Gallons/C.Y.	0.320	0.440
	Excavation - Earth - Off Road - Short Haul	Gallons/C.Y.	0.263	
	Excavation - Earth - On Road - Long Haul	Gallons/C.Y.	0.687	
	Excavation - Earth - On Road - Short Haul	Gallons/C.Y.	0.319	
	Excavation - Rock - Off Road - Long Haul	Gallons/C.Y.	0.402	0.570
	Excavation - Rock - Off Road - Short Haul	Gallons/C.Y.	0.311	
	Excavation - Rock - On Road - Long Haul	Gallons/C.Y.	0.740	
	Excavation - Rock - On Road - Short Haul	Gallons/C.Y.	0.465	
	Strip Topsoil	Gallons/C.Y.	0.167	
	Roadway Finishing	Gallons/S.Y.	0.073	
Base Stone	Base Stone - Short Haul (Haul and Place)	Gallons/Ton	0.406	0.510
	Base Stone - Long Haul (Haul and Place)	Gallons/Ton	0.558	0.810
Asphalt	Asphalt Production (Diesel)	Gallons/Ton	2.040	2.570
	Asphalt Production (Natural Gas)	Gallons (GGE)/Ton	2.144	
	Asphalt Production (Natural Gas) (Support Equipment)	Gallons/Ton	0.090	
	Warm Mix Asphalt Production (Diesel)	Gallons/Ton	1.632	
	Warm Mix Asphalt Production (Natural Gas)	Gallons (GGE)/Ton	1.715	
	Warm Mix Asphalt Production (Natural Gas) (Support Eqp.)	Gallons/Ton	0.072	
	Asphalt Hauling (0-5 miles)	Gallons/Ton	0.183	0.770
	Asphalt Hauling (6-15 miles)	Gallons/Ton	0.293	
	Asphalt Hauling (>15 miles)	Gallons/Ton	0.514	1.070
	Asphalt Placement	Gallons/Ton	0.273	0.280
Milling	Milling - 0-1" (0-5 mile haul)	Gallons/Ton	0.028	
	Milling - 0-1" (6-15 mile haul)	Gallons/Ton	0.030	
	Milling - 0-1" (>15 mile haul)	Gallons/Ton	0.038	
	Milling - 2-4" (0-5 mile haul)	Gallons/Ton	0.062	
	Milling - 2-4" (6-15 mile haul)	Gallons/Ton	0.071	
	Milling - 2-4" (>15 mile haul)	Gallons/Ton	0.090	
Structures	Reinforcing Steel	Gallons/Lbs.	0.004	
	Steel Beams	Gallons/L.F.	0.180	
	Substructure Concrete	Gallons/C.Y.	4.700	
	Superstructure Concrete	Gallons/C.Y.	4.150	
	Bridges	Gallons/Contract $	5.200	41.000
	Bridges (per S.F. of deck)	Gallons/S.F.	0.616	
Misc. Concrete	Concrete Production (Support Equipment)	Gallons/C.Y.	0.090	0.430
	Concrete Hauling - Short Haul	Gallons/C.Y.	0.600	1.000
	Concrete Hauling - Long Haul	Gallons/C.Y.	1.100	1.000
	Concrete Placement	Gallons/C.Y.	0.267	0.470
	Concrete Curb/Gutter	Gallons/L.F.	0.152	
	Concrete Sidewalk	Gallons/S.F.	0.090	
	Retaining Wall (Cast in Place)	Gallons/S.F.	0.646	
	Noise Wall (Pre-Cast)	Gallons/S.F.	0.304	
	Concrete Median Barrier	Gallons/L.F.	0.309	0.300
Drainage Pipe and Structures	Large Pipe Crew	Gallons/L.F.	4.338	
	Medium Pipe Crew	Gallons/L.F.	1.481	
	Small Pipe Crew	Gallons/L.F.	0.871	
	Drainage Structures	Gallons/Each	26.175	
Specialty Items	Fence Gates	Gallons/Each	4.200	
	Fencing	Gallons/L.F.	0.043	
	Grassing (Hydro Seeding)	Gallons/Acre	3.497	
	Grassing (Seedbed Preparation)	Gallons/Acre	10.000	
	Sodding	Gallons/S.Y.	0.017	
	Guardrail Posts	Gallons/Each	0.042	
	Guardrail - Steel	Gallons/L.F.	0.037	0.230
	Guardrail - Wire/Cable	Gallons/L.F.	0.105	
	Intersection Signalization (2 Lane)	Gallons/Each	170.000	
	Intersection Signalization (4 Lane)	Gallons/Each	304.000	
	Pavement Marking	Gallons/L.M.	4.500	

Project Outreach Plan

Another product of this research effort is the outreach and dissemination plan to publicize the results of NCHRP Project 10-81. This project includes a variety of products that will be useful in educating and assisting the highway construction community in the adoption of revised and updated fuel usage factors. The outreach plan details a strategy to best inform the potential users of this information, including its existence, potential benefits, and ease of use. The products of this effort include the following:

- A list of action items;
- A list of stakeholders to contact;
- A draft PowerPoint presentation for briefing agency executives on key products and recommendations;
- A plan for a webinar including a draft agenda, potential survey questions, and presentation materials; and
- A plan to further inform the highway construction community through presentation of the research and results at annual meetings, conferences, and workshops.

CHAPTER 1

Background

Chapter 1 of this report details the background information, purpose, and the existing literature relevant to NCHRP Project 10-81. The introduction section provides a brief overview of fuel usage factors and the research problem that this report addresses. The purpose section outlines the stated goals and objectives of the project. The literature review presents and describes sources germane to the project, including government sources, state DOT literature, academic studies, and media reports.

1.1 Introduction

Price adjustments of selected commodities in highway construction are used in construction contracting as a way of limiting risks to the contractor arising from price fluctuations of these commodities over the life of a contract. The benefits to contracting agencies are bids that better reflect actual construction costs, without added costs for risk of increased commodity cost. Fuel is one commodity for which price adjustments are allowed. Fuel usage factors are commonly applied by state and local agencies in calculating fuel cost price adjustments in a contract specification that permits cost escalation and de-escalation. The original fuel usage factors were published in Highway Research Circular Number 158 by the Highway Research Board (HRB, now the Transportation Research Board) in July 1974.

These factors, which were later incorporated in the 1980 Federal Highway Administration (FHWA) Technical Advisory T5080.3, have remained unchanged for over three decades despite the continuous effects of price inflation and changes in construction-dollar purchasing power, construction methods, industry processes, equipment efficiency, and fuel type. HRB Circular 158 established gasoline and diesel fuel usage factors for excavation, aggregate, hot mix asphalt production and hauling, and Portland cement concrete production and hauling. Additionally, HRB Circular 158 established fuel usage factors for structures and miscellaneous construction in gallons per $1,000 of construction cost, with no provision for any adjustment for inflation.

1.2 Purpose

The objectives of this research were to

1. Identify present highway construction contract activities that are major consumers of fuel;
2. Prepare fuel usage factors for these activities, including those items of work presented in Attachment 1 of FHWA Technical Advisory T5080.3, for base year 2012; and
3. Develop a recommended practice for state DOTs to implement use of fuel adjustment factors and adjust them for both state-specific conditions and changes in construction costs, methods, and equipment.

1.3 Literature Review

This literature review presents the most relevant and helpful sources available. Its purpose is to provide necessary background information while framing the research objectives: factoring inflation and 30 years of technological advancement into a dated set of fuel usage factors, reducing risk for both agencies and contractors, and ensuring the availability of an improved system to state DOTs. The following subsections of this chapter coincide with the major categories of sources utilized during the research process: the original federal guidelines, more recent FHWA/AASHTO surveys outlining state DOT practices, academic research conducted for state DOTs and other entities, information provided in media reports, and citations from international sources.

1.3.1 Original Federal Guidelines

The original research on fuel usage factors includes Highway Research Circular Number 158 by the Highway Research Board (now the Transportation Research Board) in July 1974. A mailed survey of 3,000 highway contractors netted 400 responses, and the FHWA compiled and analyzed the data. Factors were computed for construction activities such as excavation, aggregate and asphalt production, and structure construction. Each of these activities received a high, low, and average factor. Both diesel and gasoline were included. This early research did not fully investigate the effects of different terrain and did not account for contingencies such as high altitude.

The FHWA incorporated these factors in Technical Advisory T5080.3, originally released in 1980. The advisory contains methods for developing price adjustment provisions such as downward and upward contract provisions, using an average of quotes to avoid manipulation, triggers based on a 5 percent change in fuel price indices, and ad hoc adjustments on fuel usage factors in cases of extreme elevation, rough terrain, etc. It also provides the original fuel usage factors, which are reproduced in Exhibit 1-1, as well as additional fuel usage factors developed by the states.

Prior to this study, these factors had not been revisited on the federal level since the issuance of Technical Advisory T5080.3. Since the original survey was conducted, the costs of fuel and structure construction have changed and may be outdated due to changes in technology, work practices, material haul distances and other factors. In addition, the original survey established gallons per $1,000 as the unit of measure for work on structures, yet no adjustments for inflation have been conducted.

1.3.2 FHWA and AASHTO Surveys

Another important set of literature pertains to the current practices of the states. The Contract Administration Section of AASHTO's Highway Subcommittee on Construction (AASHTO SOC) maintains a spreadsheet that summarizes the current use of price adjustment clauses for fuel, asphalt, cement, steel, and other highway materials. The 2009 version of a summary spreadsheet includes general information regarding trigger values, indices, Web references, general comments, and state DOT contacts. This set of literature also includes the individual state policies for which the spreadsheet provides Web references. The most recent survey shows that 41 states utilize price adjustments on fuel, while 40 states adjust asphalt pricing. Three states (Arkansas, Michigan, and Texas) adjust neither fuel nor asphalt pricing.

Related to these first two items is state DOT research on fuel usage factors. The FHWA advisory provides some of this data, but does not identify sources. In the 2008 AASHTO SOC Survey, New Jersey reported that they were "currently working with industry to review fuel usage factors." The larger issue of rising costs and uncertainty has been addressed by many state DOTs. The

Exhibit 1-1. Fuel usage factors, Highway Research Circular 158/FHWA Technical Advisory T5080.3.

Item of Work	Units	Diesel			Gasoline		
		Low	Avg.	High	Low	Avg.	High
Excavation							
Earth		0.27	0.29	0.30	0.11	0.15	0.21
Rock		0.37	0.39	0.42	0.17	0.18	0.22
Other	Gallons/C.Y.	0.33	0.35	0.38	0.15	0.16	0.18
Aggregates							
Onsite Production		0.25	0.28	0.36	0.08	0.09	0.11
Aggregate Base							
0-10 Mi. Haul		0.24	0.27	0.33	0.22	0.24	0.28
10-20 Mi. Haul	Gallons/Ton	0.35	0.42	0.54	0.27	0.39	0.49
Asphalt Concrete							
Production		1.75	2.43	3.50	0.07	0.14	0.18
Hauling							
0-10 Mi. Haul		0.28	0.33	0.34	0.35	0.34	0.53
10-20 Mi. Haul		0.30	0.49	0.56	0.35	0.58	0.89
Placement	Gallons/Ton	0.06	0.14	0.20	0.08	0.14	0.22
Portland Cement							
Production		0.15	0.28	0.45	0.12	0.15	0.21
Hauling		0.33	0.48	0.67		0.52*	
Placement	Gallons/C.Y.	0.13	0.22	0.31	0.08	0.14	0.22
Structures	Gallons/$1,000	10.00	19.00	25.00	10.00	22.00	35.00
Miscellaneous	Gallons/$1,000	10.00	19.00	30.00	10.00	19.00	30.00

*Estimated due to insufficient data.

average price per ton of asphalt in Florida, for example, increased from $34.66 in 1990 to $97.04 in 2008. Such increases reinforce concerns with inflationary risks and doubts over the efficacy of current escalator clauses (Prasad 2010). The FHWA's 2007 report "Growth in Highway Construction and Maintenance Costs" points to a nationwide issue, with 42 states reporting large increases in construction costs. The study identifies rising costs of each major commodity input group as the primary cause. The study notes that other potential causes, such as employee wages, insurance and engineering costs, and profit margins, experienced gradual and/or limited growth (Federal Highway Administration 2007). Other FHWA studies, such as the 2006 "Survey on Construction Cost Increases and Competition," show large majorities of states facing increased bid costs due to rising fuel/asphalt prices (AASHTO 2006). The sponsors of this study believed that providing an updated set of fuel usage factors could alleviate some of these concerns.

Another interesting data point is the FHWA Highway Statistics series that, through 2005, provided Table PT-4, "Usage Factors for Major Highway Construction Materials and Labor." This table provides weighted averages for all federal-aid highway construction contracts over $1 million on the national highway system reported as completed during calendar years 2002, 2003, and 2004. The estimate for petroleum products, defined as fuel and lubricants for equipment and trucks, is 12,279 gallons per million dollars of construction cost, down from 19,909 gallons 3 years earlier. Over the same time period the usage of bituminous material declined only slightly, going from 344 to 329 tons per $1 million. FHWA obtained the data in this table from Form FHWA-47, which FHWA used to develop the FHWA Highway Construction Cost Index. FHWA discontinued this form and the collection of this data after 2004. FHWA has developed a new National Highway Construction Cost Index using data from Oman Systems' BidTabs data.

1.3.3 Academic Research

Another set of literature consists of university-based research studies conducted for state DOTs on various aspects of price adjustment clauses. One such study is the June 2007 "Best Practice for Developing the Engineer's Estimate," a SCDOT research project with FHWA funding, written by Karl Niedzwecki, Greaton Sellers, and Lansford Bell of Clemson University. The study is concerned mostly with comparing two methods of project cost estimation: the unit cost line item approach and the cost-based approach. The authors reached the conclusion that cost-based estimation requires impractical investments in time and expertise and cannot be broadly adapted (Niedzwecki and Bell 2007). This conclusion stands in contrast to the opinions of George Bradfield, chief estimator of the Georgia DOT, who criticizes the inclusion of low bids in the historical data and asserts that a cost-based estimate is more accurate and ultimately more cost effective when applied to the project at hand (Bradfield). Also of note in this study is a figure (see Exhibit 1-2) that presents the results of a survey question concerning the data source fuel cost adjustments. Most states are currently using factors they developed over older FHWA estimates. The Associated General Contractors of America (AGC) is currently absent from these processes and the states acquire their fuel cost adjustments through other entities.

The second volume of the report uses the SCDOT bid data to conduct statistical analysis of the influence of fuel price fluctuations on bid prices. The authors note, "the SCDOT Research Steering Committee identified a total of 44 different pay items, also referred to as Unit Cost Line Items, which were believed to be impacted by fuel and asphalt price" (Sellers and Bell 2007). The authors conclude in the first volume that the unit cost line item is preferable to the cost-based method. Two of the most substantial limitations relate to the long-term nature of the unit cost line item: prices can be affected by past unbalanced bids, while database prices for items could have been affected by now-irrelevant economic conditions. With the prices of 44 items being affected by fuel cost, which historically fluctuates quite rapidly, state DOTs that use the unit cost line item (currently 30 out of 50) seem to be at a disadvantage. It is later demonstrated that the engineer's estimate can often take up to a year to adjust to fluctuations in the low bid. Sellers and Bell believe this effect is caused by the unit cost line item methodology, as its historically averaged price indexes would be unresponsive to rapid changes. They conclude, "Many of the unit cost line items examined in this research have bid prices correlated with either the fuel price index or bidding volume. Many of the items tended to rise or fall with the cost of fuel as price trended up or down." The use of statistical analysis of bid data on pay items with fuel price indexes is significant, because this is one of the methodological approaches examined in this study.

Another university study is the "Evaluation of Fuel Usage Factors in Highway Construction in Oregon" by Ken Casavant, Professor at Washington State University, with co-authors Eric Jessup and Mark Holmgren. This study confronts many of the same research problems addressed in this study. This analysis compiles information regarding how other states address the issue of inflation in fuel factors and develops an approach to updating the estimation of fuel factors used for various types of structures. The authors present three major errors with the current fuel adjustment system. The first is the effects of inflation on construction costs exacerbated by the

Exhibit 1-2. How states obtain fuel cost adjustments.

Source	Bid History	Cost-based/Combo
Through AGC contacts or resources	0%	0%
Use of quoted FHWA adjustment factors	23%	0%
Use of US DOT resources	0%	13%
Use of state DOT factors developed through self-determined investigation	38%	13%
Other	38%	38%

failure to correct for the effects of inflation on the 1980 fuel adjustment factors for structures and miscellaneous costs. The second is improvements in construction practices and fuel efficiency. Lastly, fuel preferences have shifted, with the change from diesel to natural gas in asphalt plants being the most notable (Holmgren et al. 2010). The study proceeds with an overview of state practices for formulating fuel adjustments and a survey of state DOTs, which found that most consider their current fuel adjustments to be fair despite contractor complaints and recently implemented or planned changes in many of their fuel adjustments. Two primary recommendations are presented. The first is to cut the fuel usage factors for structures approximately in half—from 19 to 9 for cast-in-place and from 10 to 5 for pre-cast. A review and recalculation of fuel usage factors every 3 years is also suggested.

A third study in this group is a 2009 paper, "Materials Risk Management—Beyond Escalation Clauses and Price Indexing," by Larry Redd of a private firm and Tim Hibbard, Assistant Chief Engineer, Operations, Wyoming Department of Transportation (WYDOT). The paper discussed the WYDOT study, "Asphalt Risk Management at WYDOT." That study examined outcomes after 3 years of an escalation "option" for contractors. The WYDOT escalation clause stipulates that contractors must opt in within 10 days of the pre-construction conference. Triggering of the escalation clause occurs after a 10 percent change in the base price of the commodity. The contractor will then be reimbursed for 90 percent of upward index movement, whereas they would pay back 90 percent of downward movement to WYDOT. The study encompassed a 3-year period from 2006–2008 with careful attention paid to summer 2008, when a pronounced spike in oil prices resulted in remarkable volatility in asphalt price and availability (the price of asphalt ballooned from approximately $350 per ton to $700 per ton during the construction season). Although the agency disbursed over $7 million in repayments during the summer of 2008, assuming a substantial amount of contractor risk in the process, WYDOT expressed its satisfaction with its current mechanisms for price adjustment (Redd and Hibbard 2009). Contractors did not achieve full protection from the volatility of the market. Some contractors ended up paying more to their suppliers than the adjusted price due to short-term increases in the supplier's pricing. This difference was not covered by WYDOT because the suppliers' prices were already over the index amount. One contractor received a higher-than-expected bill from his supplier, who was calculating cost based on the previous month's index even though commodity prices had begun to decline. Additionally, WYDOT does not cover adjustments when a contractor has a fixed price agreement with a supplier. In this case, contractors have to hope that suppliers will honor the agreed upon price. In addition, concerns arose that price indexing may have long-term adverse consequences in the asphalt market regarding price competition.

"Fuel Price Adjustment Techniques: A Review of Industry Practice," prepared by Rutgers University at the behest of the Monmouth County (NJ) Department of Human Services, provides a useful overview of the different types of fuel adjustments as well as their varying implications (Rutgers University 2004). The main methods presented are contract pricing, fixed price with adjustment, direct refueling using agency-operating fueling facilities, and floating price-direct cost reimbursement. The study also offers several observations about the use of fuel price provisions in bidding and construction. For example, fluctuation in fuel price creates risk that is detrimental to all parties involved, and expecting the contractor to bear all the risk will often portend inflated costs as a means to reduce liability. The authors also have a favorable opinion of escalator triggers and re-adjustment as well.

Prepared for AASHTO by researchers at Arizona State, "Project Cost Estimating: A Synthesis of Highway Practice" is a broad survey of current cost estimation practices by the states. Of particular concern to the authors is the tendency for the actual costs of large transportation projects to exceed cost estimations during planning and even the beginning of construction. The frequency and magnitude of estimation errors remains analogous to projects from 70 years ago despite ostensible improvements in estimation methodology (Schexnayder et al. 2003). The authors set forth several recommendations, such as the inclusion of contingency budgeting and annual adjustments on inflation so costs would be in current-year amounts. An update system of factors could improve estimation accuracy and make fuel costs more predictable.

The final university study is the Georgia Tech Research Institute's "A Study of Liquid Asphalt Price Indices Applications to Georgia Pavement Contracting." This study included a survey of state DOTs and conducted statistical analysis of price trends using price indices. The authors weighed the costs and benefits of implementing an asphalt index pricing system in Georgia. Expected costs included: high start-up costs, increased costs and labor to generate the index, the manpower required to calculate adjustments in the field, a higher price paid for asphalt when the market price increases over the period of the contract, possible price manipulation by suppliers, and possibly reduced contractor payments in the event of a decline in liquid asphalt price. Anticipated benefits included: a lower price for asphalt when market prices decline, more rapid completion of contracts, no assignment of risk for contractors at the time of the bid, more competition in the market from price risk reduction, and regional uniformity for Georgia and its neighbors (Eckert and Eger III 2005). Finding that the Georgia DOT had a lower quoted price on liquid asphalt than any of its neighbors, each of which employs a price index, the authors recommended that the Georgia DOT retain its existing protocols.

1.3.4 Media Reports

Another set of literature is comprised of news articles. Media items can provide useful opinions and identify contacts and data sources. For example, the Albany (New York) Business Journal ran an article in 2008, entitled "Asphalt Costs, Tied to Climbing Oil Prices, put the Squeeze on Paving Contractors." Written at the height of the surge in fuel costs during the summer of 2008, this article examines the effects of rising asphalt prices on contractors. The New York State index price for liquid asphalt rose from $335 in July 2007 to $588 in July 2008. Subsequently, the price of a ton of blacktop jumped from $65 in April to $73 in June (Business Review [Albany] 2008). As a result, contractors had to weather both increased costs and falling demand as property owners increasingly canceled or postponed jobs. The article included an interview with a state DOT official.

More recent media coverage further illustrates the volatility inherent in construction contracting. The Illinois bituminous index rose 35 percent between October 2009 and March 2010. Upward movement on most materials is probable for the short term (Associated General Contractors of America 2010). One effect of the ongoing recession has been plummeting demand for construction contracts, especially in the private sector. Contractors are increasingly submitting bids that are lower than normal for public projects in an effort to secure work. A new toll plaza on the Florida Turnpike, originally estimated to cost $37,000,000, received a low bid of $17,000,000. Broward County engineer Richard Tornese comments that bids for projects in 2008 and 2009 were 10 percent below budget estimates (Streeter 2010). The competition is so intense in Louisiana that many contractors have resorted to examining winning bids for errors in an effort to reopen bidding on public contracts. The decline of private construction is one underlying explanation for this glut of contractors. Although several recent hurricanes have necessitated a large number of public projects in Louisiana, future construction will slow as the state's large debt begins to limit the amount of money it can borrow for construction (Roberts 2010).

1.3.5 International Sources

One of the aims of this study was to examine whether the international community had conducted any research on fuel factors or fuel usage. However, little relevant literature was found, despite numerous contacts with entities such as the United Kingdom's Highways Agency. Perhaps the best source currently available is the "International Construction Cost Survey 2009," published by Turner & Townsend. This report has limitations, such as not including international pricing for fuel and petroleum-based commodities like asphalt, and is best viewed as a survey of general international economic trends. The near disappearance of inter-bank lending and granting of loans forced the postponement or cancellation of many planned projects. Many of the hardest hit countries are in Europe: construction costs in Scotland were predicted to fall by 8 percent in 2009, and the construction sector's contribution to the Irish economy fell from 14–16 percent to 5–6 percent in 2009 (Emmett 2010). The most common attempt to rectify the crisis has been to inject massive amounts of public funds into the construction industry with the intent of creating jobs and improving infrastructure.

An article from Uruguay details the rise of construction costs in both Uruguay and Argentina. In 2009, overall construction costs rose by 10.8 percent, mainly due to increases in the prices of materials. Inflation on materials and increased labor costs are expected to further raise costs (Sainz 2010). There is no mention of the contribution of bridges and highways to that figure.

CHAPTER 2

Initial Research and Research Approach

Chapter 2 of this report details the initial research and the research approach undertaken by the study team. Specifically, this chapter provides an overview of the initial efforts conducted using the three study methodologies: statistical analysis, engineering estimation analysis, and DOT and contractor surveys of fuel usage. The initial efforts under these methodologies were then evaluated and modified to best ensure that the later data collection phase would be best suited to accurately measure highway construction fuel use.

As an initial step, the study team surveyed all 50 state DOTs and a select number of construction contractors. These responses informed the study team of the current state of fuel usage factor and price adjustment clause implementation, perceptions of high fuel use activities, the analytical needs of the targeted end users, and the features and information to include in the full contractor fuel usage survey. The first two sections of this chapter describe the DOT and contractor surveys, respectively. The third section provides a brief overview of the initial engineering estimation effort. The fourth section briefly describes the initial statistical evaluation of fuel intensity. The fifth section provides an overview of the initial test efforts undertaken for each of the three research methodologies. This section includes a discussion of the work performed for each of the three potential methodologies, the results, any unanticipated occurrences, and any modifications made to the three approaches in preparation for the full data collection phase of the project.

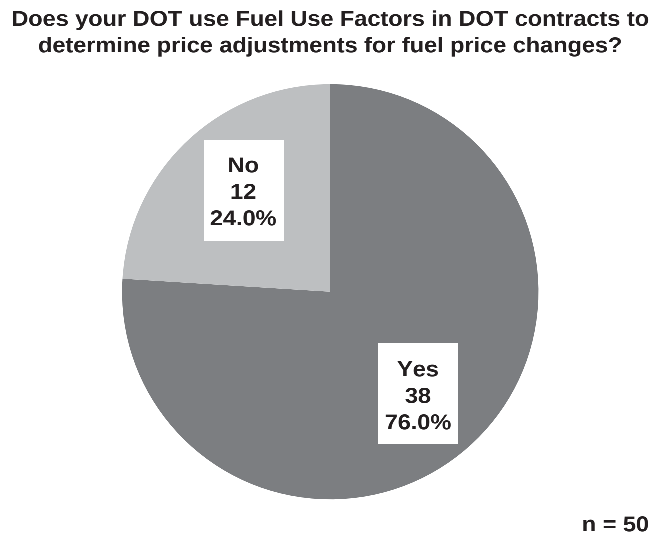
2.1 DOT Needs and Perceptions

The study team conducted a nationwide survey of state DOTs. The purpose of the survey was to ascertain the current implementation of fuel usage factors, the states' satisfaction with their current programs, and their perceptions on how to upgrade them. This report section presents the team's findings. The first subsection describes the survey methodology. Subsections 2.1.2 through 2.1.8 report on individual sections of the survey. Subsection 2.1.9 summarizes the DOT survey and offers conclusions.

2.1.1 Survey Methodology and Response

The study team provided the NCHRP project panel with a draft copy of the state DOT survey on August 24, 2010. On September 1, 2010, invitations were sent out to officials from all 50 state DOTs to participate in the online version of the survey available on SurveyMonkey. The survey requested a response by September 10, 2010, and 28 state DOTs responded by the initial deadline. An additional request was sent out to non-responding DOT officials on September 10, 2010. Additional requests were sent out to non-responding DOTs. The study team received the 50th state response on December 10, 2010. This chapter incorporates survey results from all 50 state DOTs.

Exhibit 2-1. Implementation of fuel usage factors.



2.1.2 Extent of Fuel Factor Implementation

The first survey question asked the respondents whether or not their state uses fuel usage factors to determine price adjustments for fuel. Among the 50 state DOTs, 38 states employ fuel usage factors while 12 do not. Exhibit 2-1 presents these results.

This question shows that most states utilize some form of fuel factor. The scope of their use is not uniform, however. Nebraska only adjusts for fuel on grading projects. Alabama does not use the term "fuel factor" but adjusts for fuel price fluctuations in the case of hot mix asphalt (HMA) and other bituminous mixes. It also employs a bid item for lump sum construction fuel.

Several states amplified their response regarding the future of their programs in response to other survey questions. Oklahoma is in the process of composing a provision for fuel price adjustment but plans have not yet been finalized. California currently does not employ fuel factors but is working with the contracting industry to study the feasibility of adding them. Michigan does not utilize fuel factors and currently has no plans to adapt them, citing a lack of interest from local contractors.

2.1.3 Current Program

This section of the survey asked respondents to comment on the origin of their fuel usage factors as well as to describe their current systems. The first question in this section provided respondents with the opportunity to select the sources for their fuel use factors. The most popular answer choices among state DOTs were Attachment 1 in the original FHWA Technical Advisory T5080.3 and contractor/industry data, which 16 and 15 of the 37 states selected, respectively. Internal DOT data followed with 14 selections. Of the 37 affirmative respondents, 18 states selected a single option. Exhibit 2-2 displays a tabulation of the sources of DOT fuel usage factors.

In addition, 18 states further explained the source of their factors or entered an option not included above. Note that collaboration with the contracting industry was mentioned six times, while four states commented that their factors were quite old and/or had not been updated for some time. Exhibit 2-3 displays additional comments from state DOTs regarding the source(s) of their factors.

Exhibit 2-2. Sources of fuel factors.

What are the sources of your current Fuel Use Factors (check all that apply)?		
Answer Options	**Response Percent**	**Response Count**
FHWA Technical Advisory T5080.3 (Original 1980 Data in Attachment 1)	42.1%	16
FHWA Technical Advisory T5080.3 (Other State Data in Attachment 2)	13.5%	5
Internal DOT Data	37.8%	14
Contractor-Supplied Data	13.5%	5
Contractor Organization/Industry Data	40.5%	15
Other Data Collected or Developed by Your State	35.1%	13
		n=37
		Total Selected=68

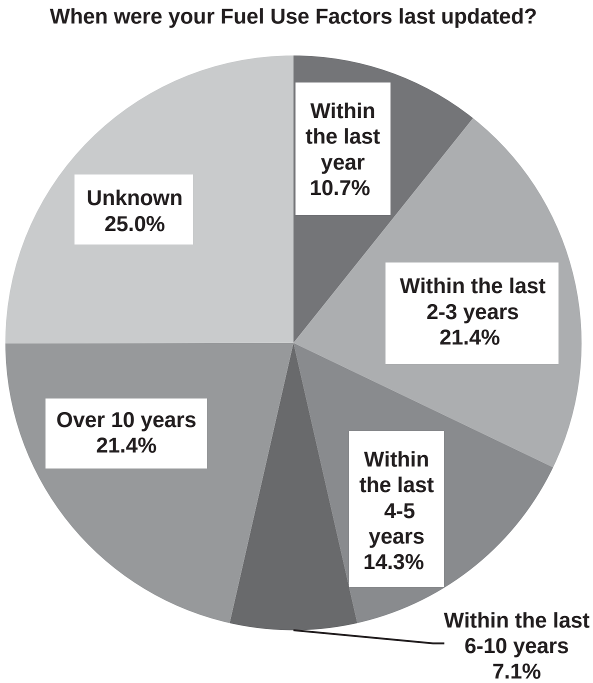
In a related question, the survey queried respondents as to when the states' factors were last updated. The survey provided a set of responses ranging from within the past year to over 10 years ago. The survey also included an option for unknown. Exhibit 2-4 provides a summary of the 37 responses provided to this question.

The responses indicate that the fuel factors used by state DOTs are often quite dated. Only 16 of the 37 respondents identified their factors as having been updated within the last 5 years. In contrast, 11 respondents replied that their factors had not been updated within the last 10 years and another 8 did not know when they were last updated. Several respondents indicated that their factors were very old and that they did not know when, or if, they had ever been updated.

Exhibit 2-3. Additional comments on sources of fuel factors.

State	Response
Alabama	Fuel factor for HMA production was developed jointly with industry reps
Connecticut	Oil Price Information Service (OPIS)
Georgia	The state construction engineer (now retired) developed the factors we started to use in 2007
Idaho	Factors were developed by the department in consultation with industry
Illinois	Meetings with industry and equipment manufacturers
Kentucky	Unsure on what is used. This was done prior to my appointment to this position. There were no records concerning the item.
Louisiana	Factors developed in the early 80s by materials and testing lab
Massachusetts	Our fuel usage factors were developed by the Highway Research Board in Circular 158, dated July 1974
Minnesota	OPIS daily rax fax
New Jersey	The basic factors were unchanged –we added newer items using comparable factors as part of an update of NJDOT's standard specification
New York	Unknown, very old - historical data has been lost
Ohio	ODOT used fuel usage factor information from other states. Productivity Rates and Equipment Watch operating cost information was also considered.
Oregon	Adjusted to Oregon. I don't know the process used to make the adjustments.
Rhode Island	They are only for bituminous items and are fixed at 2.5 gallons of fuel per ton of bituminous
South Carolina	Developed in coordination with contracting industry
Tennessee	Originally from T5080.3, but survey of industry personnel and DOT calculations updated to current rates
Washington	Developed by following FHWA Technical Advisory
West Virginia	A task force was formed from the DOH, industry (contractors and suppliers), and local FHWA

Exhibit 2-4. Dates of last fuel factor updates.



The age of the fuel factors is highly correlated with data source. For example, only 25 percent of DOTs using the 1980 Attachment 1 data and 36 percent of those using internal DOT data stated that their factors had been updated within the past 6 years (the North Carolina DOT conducted a review of the 1980 data and found that they were still acceptable for contracting in North Carolina). Conversely, 10 of 16 DOTs that utilize contractor-based data have updated their fuel factors within the last 6 years.

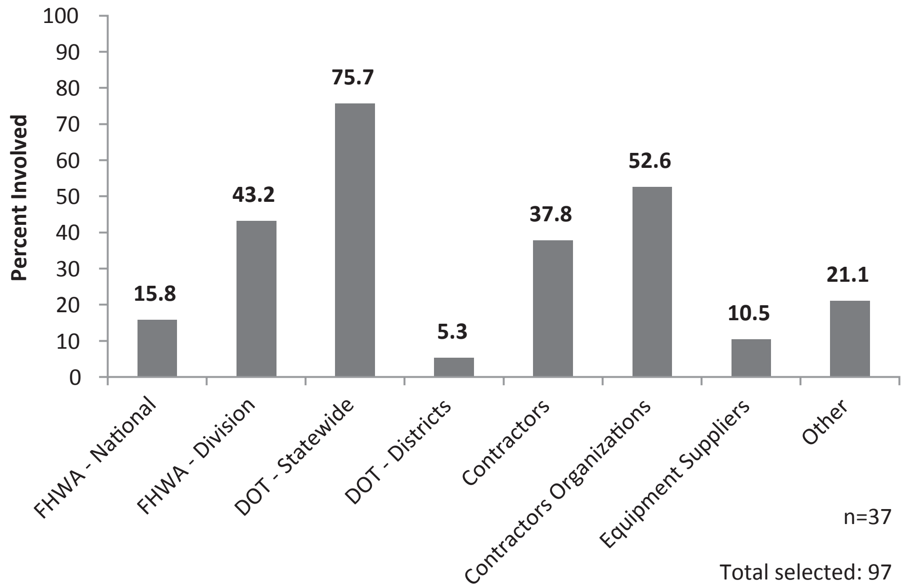
The DOTs were then asked to identify which organizations were involved in the formulation of their state's fuel factor policy. The DOTs themselves had the highest rates of participation, with 28 out of 37 state DOTs (76 percent) being involved in the creation of their fuel factors. Contractor organizations contributed slightly more than half the time. FHWA divisional offices and contractors followed shortly thereafter with approximately 43 and 38 percent participation, respectively. Maryland and Vermont reported that they took the fuel factor policies of neighboring states into consideration, although they did not identify the states with which they consulted. Exhibit 2-5 displays a tabulation of the organizations involved in the creation of state fuel usage factors.

The vast majority of DOTs who responded (29 out of 36) have shared, or are willing to share, their fuel factors with outside organizations such as municipal or local agencies. Several commented that their fuel factors were available online, while others stated that the factors are public information. Some respondents provided more specific situations in which they would share the factors, such as if requested by county governments and consultant engineers (Minnesota) or on projects where the state DOT writes the specifications (Louisiana).

The survey also ascertained the current abilities of state DOTs, through software or other means, to develop and/or calculate fuel factors and price adjustment clause payment. Exhibit 2-6 provides the results.

Only three states have software programs used to develop the fuel factors themselves: Minnesota and Nevada, which use an Excel spreadsheet program, and Arizona, with a custom Web application. Each of these states has updated their fuel factors within the last 3 years.

Exhibit 2-5. Organizations involved in fuel factor creation.



Approximately half of the states (23) use Excel spreadsheets and custom applications to calculate price adjustment clause payments. The other systems option yielded 11 responses. Five states employ Site Manager, Arizona uses another Web application, Maine uses Transport—CAS, West Virginia uses the Project Record System (PRS), New Jersey uses the Automatic Construction Estimate System, and North Carolina uses HiCAMS, an in-house calculation index. Alabama, Illinois, and Utah do not currently have applications to calculate price adjustment clause payments.

2.1.4 Bridges/Structures and Design/Build

An important goal of the survey is to gain insight on the current state of fuel factor application in bridge/structure contracting. The study team composed questions designed to determine current

Exhibit 2-6. DOT fuel factor development and calculation methodology.

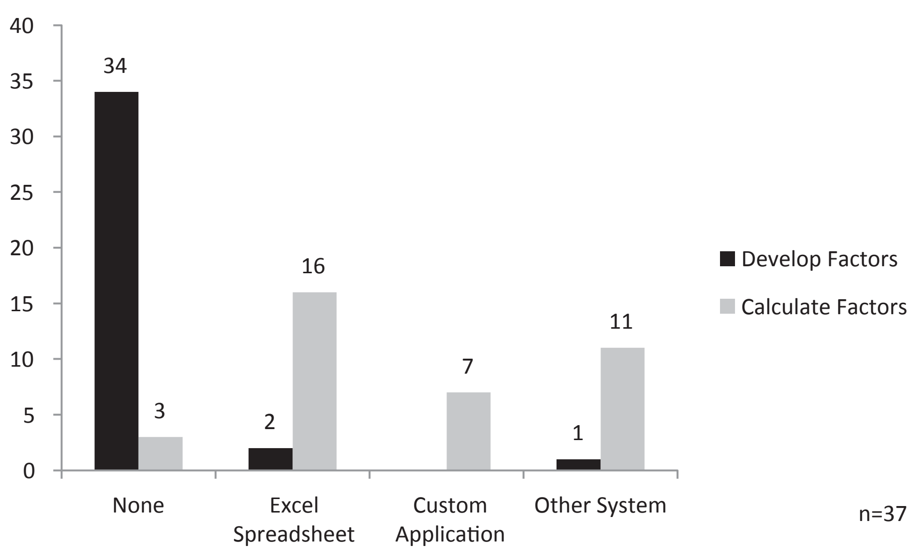
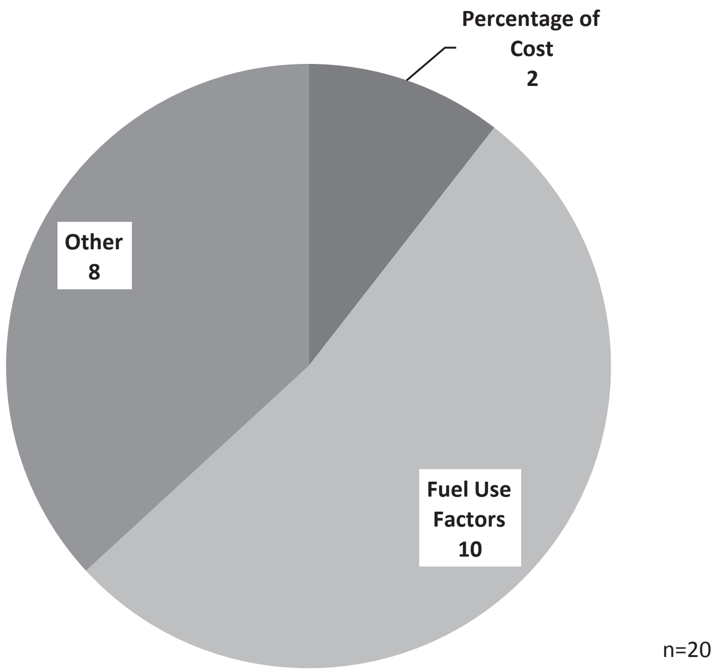


Exhibit 2-7. Methods of developing bridge/structure fuel factors.



practices, perceptions, and future improvements. The first question in this section asked state DOTs if they use fuel factors in bridge/structure contracting. Of the 37 responding states that employ fuel factors, 20 have factors applicable to bridges/structures (including decking). These states are concentrated in the East and West.

Exhibit 2-7 provides the results of a question as to how the DOTs developed fuel factors for structures/bridges. Ten state DOTs responded that they use fuel factors for appropriate items. Eight states use other methods. Arizona and Georgia are the two states that employ percentage of cost. States that selected the "We do not develop Fuel Use Factors for structures/bridges" option have been omitted.

The survey form provided the 12 states that chose "Other" with an opportunity to describe their fuel factor development methodology. Six out of 12 states chose to elaborate; Exhibit 2-8 displays their comments.

Exhibit 2-8. Details of other fuel factor development systems.

State	Response
Connecticut	Based on contract value, which is currently set for contracts greater than $50 million. Please refer to specification for information on how factor derived.
Idaho	Developed in consultation with industry
New York	Unknown
Oregon	The factors are in gallons per $1,000 of work
Pennsylvania	Diesel Fuel Use Factor of 4 gallons per $1,000 of work performed applied to applicable component items only.
South Dakota	Data submitted by contractor

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Exhibit 2-9. Perceived problems.

What problems do you perceive with Fuel Use Factors for structures/bridges? (Check all that apply.)		
Answer Options	**Response Percent**	**Response Count**
Inaccuracies due to inflation	13.5%	5
Inaccuracies due to differing structure types, sizes, and complexities	32.4%	12
Many items are bid lump sum	27.0%	10
Changes in construction methods and fuel intensity over time	32.4%	12
Differences in construction methods	29.7%	11
None	24.3%	9
Other (please specify)	29.7%	11
		n=37
		Total selected =70

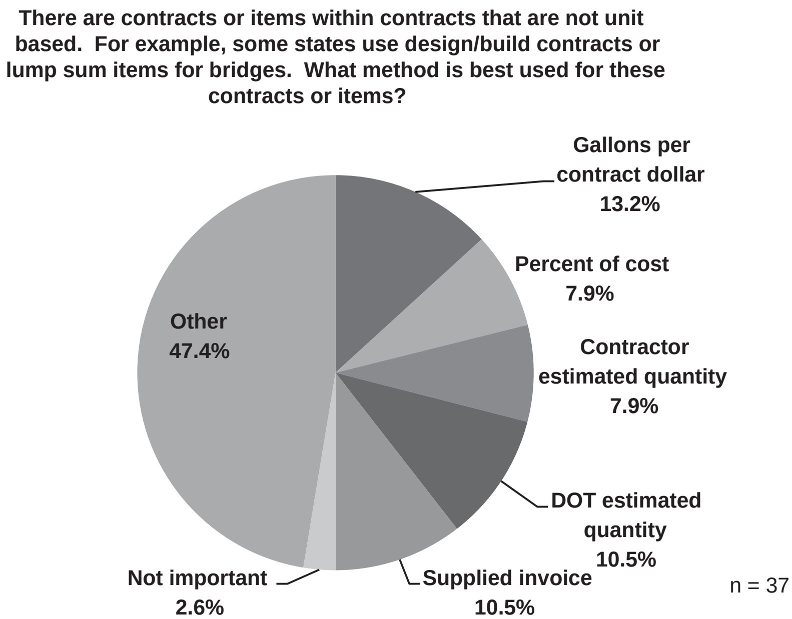
Exhibit 2-9 provides the responses concerning perceived flaws associated with fuel factors for bridges/structures. The two largest areas of concern are changes in construction methods and fuel intensity and inaccuracies due to differing structure types, sizes, and complexities. Each of these options received 12 selections. Changing construction is an understandable response for states that have not updated their factors for some time, as seven of the respondents who chose this option either have not updated their factors within the last 6 years or do not know when the factors were last updated. This may be explained by changes in construction technology, improved fuel efficiency, and other factors that may have changed over the last 6 years or more. The differences in construction methods option and the lump sum option followed with 11 and 10 selections, respectively. Exhibit 2-10 provides substantive responses from the other category. Half of the six responses cited low fuel intensity for these items.

The survey also queried respondents as to their methods for fuel factor adjustment in the circumstance where the state used design/build contracts or lump sum items for bridges/structures. Of the 37 states who responded, 20 chose one of the following options: gallons per contract dollar, percent of cost, contractor estimated quantity, DOT estimated quantity, supplied invoice,

Exhibit 2-10. Other bridge/structure fuel factor concerns.

State	Response
Colorado	Fuel use factors are for items of work, i.e., pile driving or caissons, not by structure type, size, or complexity. Any item of work that fuel usage can be measured can have a factor calculated for it based on unit of measurement, i.e., gals/ft. for pile or caissons. But fuel PACs should only be used for high fuel consumption items. They are not for every item. The idea is try to reduce the risk on contractors, not totally eliminate it.
Iowa	Comparatively smaller amounts of fuel used
Massachusetts	All of the above, except “None”
Mississippi	Typically, the fuel usage in this area of construction is not as high as other areas such as excavation, and fuel adjustments may not be necessary. Some contractors may include fuel usage in their unit prices so the adjustment may not be necessary.
Pennsylvania	Since Fuel Use Factor is applied to applicable component items only, portions of the monthly lump sum payment amount must first be reduced to discount non-applicable component items before factor can be applied.
West Virginia	Small quantities on the items we adjust

Exhibit 2-11. Methods for design/build and lump sum adjustments.



or not important. The methods varied widely across states. For example, five states use gallons per contract dollar, three use percent of cost, three use a contractor-estimated quantity, four use a DOT estimated-quantity, and four use a supplied invoice. Of the 37 responses, 17 were under the "Other" category. Ohio stated that they use, "contractor-provided quantity based on calculated plan line verified through in-place measurements by the DOT," while Maryland applies fuel factors after receiving a lump sum breakdown from the design builder. Seven states responded that they do not adjust on design/build contracts and lump sum items. The remaining states either have not considered the issue or do not use fuel factors for bridges/structures. Exhibit 2-11 provides a tabulation of the selected methods for design/build and lump sum adjustments.

The final question of this section asked the DOTs to volunteer any ideas they had for improving fuel adjustments for bridges/structure design/build contracts and lump sum items. Four states responded. The most detailed suggestion came from Pennsylvania, which responded, "for lump sum structures and design/build projects, contractor must submit component item breakdown for use in determining payments, as well as computing price adjustments."

2.1.5 Perceptions—Fuel Intensity/Volatility

The objective of this section of the DOT survey was to determine the fuel intensity of various construction activities with the goal of pinpointing certain types of pay items that could benefit from updated fuel factors. DOTs were asked to rank the following construction activities in terms of fuel intensity (defined in terms of gallons of fuel used per contract dollar): grading/excavation, drainage, asphalt paving, concrete paving, base stone/aggregates, and structures. Ties were not allowed. A ranking system was devised that gave each activity an average hierarchical rating. A "most" rating is worth one point, a "second most" rating is worth two points, and so on. The total assigned points for each activity were then added together and divided by 34 (the number of respondents) to determine each activity's average ranking. Exhibit 2-12 provides the responses to this question and each activity's average ranking.

Exhibit 2-12. Fuel intensity by construction activity.

Please rank these activities in terms of fuel intensity, in gallons per contract dollar, in highway construction in your state (use your best judgment for ties).							
Answer Options	**Most**	**2nd Most**	**3rd Most**	**4th Most**	**5th Most**	**6th Most (Least)**	**Rating Average**
Asphalt Paving	25	16	6	0	0	1	**1.69**
Grading/Excavation	23	17	6	1	1	0	**1.75**
Base Stone/Aggregates	0	8	20	12	7	1	**3.44**
Concrete Paving	0	2	10	18	9	9	**4.27**
Drainage	0	3	5	9	16	15	**4.73**
Structures	0	2	1	8	15	22	**5.13**
							n=48

Grading/excavation and asphalt paving dominate the top of the list, securing 100 percent of the first-place selections and slightly less than 70 percent of the second-place selections between them. Both activities require heavy machinery and equipment with high fuel consumption. Asphalt paving also necessitates the inclusion of petroleum-intensive asphalt cement. Strictly speaking for the purpose of fuel factors, asphalt is considered a material and is not fuel. However, it is not clear if this convention was assumed by the respondents. Structures came in as the least fuel-intensive activity. Overall, fuel consumption on bridge/structure projects is significant but additional costs such as the purchase of materials and staff salaries lower the percent contribution. Vermont suggested adding cold planing and reclaiming to the list of fuel intensive activities, New Jersey suggested milling, and Connecticut suggested environmental excavation and disposal of hazardous or contaminated materials and site work on building construction for rail yards, airports, and train stations.

The states were asked if recent fuel price fluctuations (such as during the summer of 2008) had altered their data/analytical needs when conducting fuel price adjustments. A large majority, 39 of the 48 states that responded to the question, replied that their existing methods remained sufficient. Exhibit 2-13 provides the responses of the other nine states. In general, these nine states made incremental changes to their programs. Exhibit 2-13 provides state responses regarding the effects of fuel price fluctuations.

2.1.6 Perceptions—Pay Item Selection

The survey posed several questions related to pay item selection. Responses from state DOTs were useful in developing a list of pay items for which the study would develop fuel factors.

Exhibit 2-13. Effects of fuel price fluctuations.

State	Response
South Carolina	Expanded catalog of items eligible for fuel adjustments.
Arizona	We updated the formula.
Pennsylvania	During 2008 construction season, DOT did attempt to develop projections of potential price adjustment expenditures for planning purposes. This was primarily due to fluctuations in the cost of asphalt cement; however, diesel fuel was also included.
Vermont	Difficult to account for market volatility and time to respond for project budgets.
Minnesota	Changed from a 50% change from the base to 25%.
West Virginia	We had to watch the adjustment levels and budget appropriately.
New Jersey	Construction industry has appealed to NJDOT to revise its fuel usage factors.
Connecticut	Adjustments have been made to the formula for determining fuel cost and adjustment to better represent use and costs.
Ohio	Ohio has had a fuel price adjustment in place since 2005. Obtaining and maintaining index information has necessitated data collection and adjustment processing.

When asked how to account for fuel use on pay items not already included in their state's adjustment programs, a majority of 33 out of 48 states (68 percent) stated that additional factors were not necessary because the fuel use on additional items is limited. Only respondents from Idaho, Montana, Nebraska, New Jersey, Virginia, and West Virginia indicated that they would add fuel factors for additional items. New Jersey is considering using a contract-wide gallons per construction contract dollar application. Several respondents intimated that some new factors would be beneficial, but only for large projects or items.

The next question queried respondents on the reasons for limiting the number of pay items. Insignificant fuel use for such items was cited by 31 states, 16 chose administrative cost/time, and 10 stated a lack of contractor interest. The respondent from Colorado indicated that fuel factors should only apply to high fuel use items, mentioning that the goal of a fuel adjustment program should be to lessen contractor risk without eliminating it completely. In a similar vein, the respondent from South Carolina stated that fuel adjustments and other indexes can lead to reductions in payments, something that contractors would like to avoid on low impact pay items. The respondent from New Jersey replied that NJDOT has been unable to quantify a fuel factor for these items.

The last question in this section aimed to gauge opinions on how subcontractors should be compensated for fuel cost changes. Eight, six, and five states selected "not applicable, little fuel used," "add additional fuel use factors," and "use a percentage of cost method," respectively. The "Other" section netted 28 responses. The general theme of "that's between the prime and the sub" made up 15 of these 28 responses. Tennessee, Nevada, and Mississippi responded that the fuel adjustment is applied to the item of work and no distinction exists between primes and subs.

2.1.7 System Design

This section of the survey was designed to provide the study team with feedback on the particular elements that may be included in future deliverables such as a software tool.

FHWA Technical Advisory T5080.3 provides low, medium, and high values so adjustments can be applied to specific project conditions. These may include grade, terrain, altitude, soil type, and other variables. The majority of DOTs, 30 out of 46, said that this range of factors should not be included in the new system. Exhibit 2-14 provides the relevant comments provided on this question.

Exhibit 2-14. Comments regarding low, medium, and high values.

State	Response
Arizona	It is helpful to the DOT to know the range of applicable fuel factors.
Oklahoma	Could be helpful. Would need to review the results of the research to see if there would be any benefit.
Vermont	Keep it simple, if possible.
Nevada	Does not address regional issues.
Oregon	I would prefer one number with methods to adjust for individual states, regions, etc.
New York	Don't need them for unit priced work. Folks will tend to pick the middle number almost always.
Utah	The study should recommend ranges and each state or agency should have the freedom to take the recommendations and implement that which best fits their specific needs.
Idaho	Provided some guidance was given in how to apply the ranges.
Mississippi	Fuel factors need to either apply or not apply to specific items of work; the ranges would add too much subjectivity to the process.
Colorado	Maybe, CDOT would need to see the new system and test it to see how it applies to CDOT projects.

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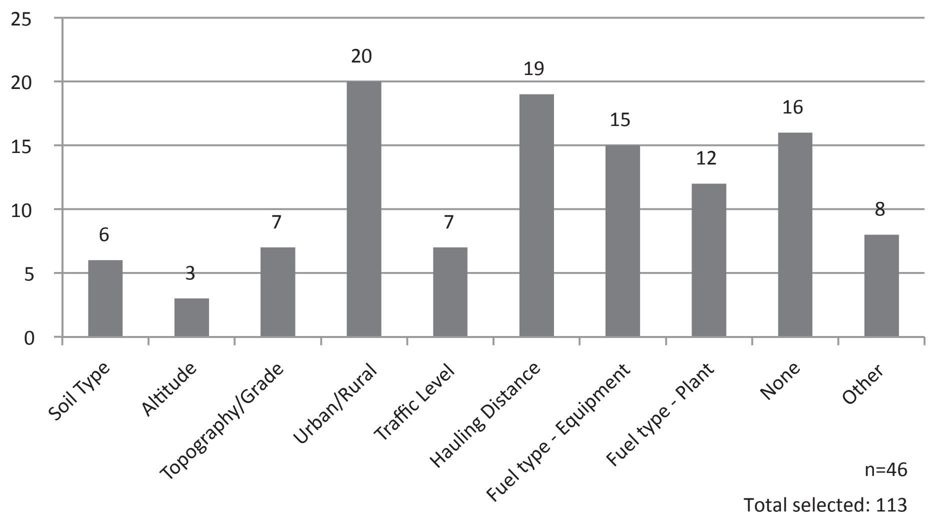
Exhibit 2-15. Preferences for variable inclusion.



Units of measure for pay items often vary from state to state. When asked if the ability to convert units would be a helpful component of the new system, 26 states said it would, while 20 said it would not. Only Pennsylvania and New Jersey mentioned having this capability with their existing systems. Nearly 30 percent of the responding states (13) would like both high-medium-low variables and conversion ability, while 17 would want neither.

The survey included a question that presented an assortment of variables that affect fuel factors for which a software system could account. The states were asked to select the ones they wanted to be included and were allowed to select multiple features. Exhibit 2-15 tabulates the 74 total options that were selected.

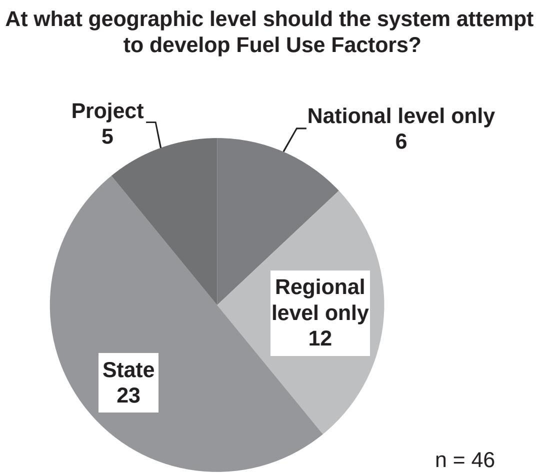
Urban/rural and hauling distance each received the support of 20 and 19 DOTs, respectively, more than 40 percent of the total participating. Differing hauling distances to and from construction sites will alter the relative contribution of fuel use in a project budget, making the effects of price fluctuations more noticeable. Variance in urban and rural construction characteristics, such as hauling distance, storage capability, and other factors, can likewise influence project fuel costs. Of the 46 responding states, 15 selected three or more variables. At the same time, 16 states did not want any variables to be included. Three respondents commented that such variables would incur added administrative and contractual burdens that might not justify their inclusion.

The survey also queried respondents as to whether fuel factor calculation should be responsive to varying levels of geography. Exhibit 2-16 provides the tabulation of the states' preferences for geographic level.

More than 75 percent of respondents prefer a state or regional level for their fuel factors. The two "extreme" options garnered only about 24 percent combined support. This might be due to concerns that national factors would not be attuned to local conditions, while a project-specific system might be too cumbersome to manage efficiently.

The survey also asked the DOTs how often fuel factors should be updated as well as how often they actually are updated. A cross-tabulation of these responses, which is presented in Exhibit 2-17, indicates consistency between how often factors are updated and how often DOTs want them updated. Only 6 of the 29 DOTs chose responses that were separated by more than one spot. This

Exhibit 2-16. Geographic preference.



may signal satisfaction with the current timing of fuel factor updates among the states, although it does not measure the qualitative aspects of their fuel factor programs. For those DOTs who answered "Unknown," three wanted the factors updated every 2–3 years, three preferred every 4–5 years, and two chose no less than every 10 years.

2.1.8 Future Plans

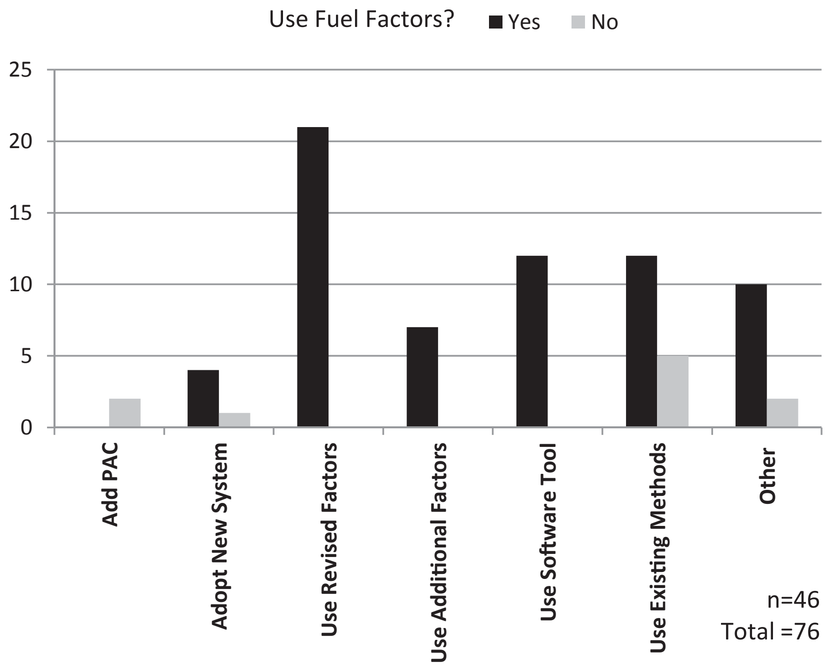
The state DOTs were asked what actions they would take if they had access to updated fuel factors and a software tool to reduce implementation costs. Exhibit 2-18 tabulates the 76 total responses selected by the 46 responding states.

Almost two thirds of the states surveyed (30 out of 46) would either create a fuel factor adjustment program or institute changes to their existing programs. This includes 4 of the 12 states without fuel factor adjustments. The other five non-factor states who responded (Michigan, Texas, Wyoming, Montana, and Hawaii) would not make any changes. A total of 12 states with existing programs would retain their current systems as well. Approximately 45 percent of those surveyed (21 out of 46) would update their factors with the revised factors. Under the "Other" category, 11 states commented that they would evaluate the delivered products and determine how they would be used based on their effectiveness. Of those 11, 3 said they would collaborate with the contracting industry in their evaluation process.

Exhibit 2-17. Last updates and timing of future updates.

How Often Should Fuel Usage Factors Be Updated?	How Often Fuel Usage Factors Are Updated				
	Within the Last Year	Within the Last 2-3 Years	Within the Last 4-5 Years	Within the Last 6-10 Years	Over 10 Years
Every Year	2				
Every 2-3 Years	1	3	3		1
Every 4-5 Years	1	4	2	1	4
Every 6-10 Years				1	4
No Less than 10 Years					1
Never					1

Exhibit 2-18. Anticipated actions with updated fuel factors and software tool.



Several DOTs offered recommendations on items for which they would be interested in new or updated fuel factors. Exhibit 2-19 provides these responses. Of note was interest in factors for guiderail and non-standard HMA mixes.

The survey concluded by querying respondents as to any concluding comments they might have. Exhibit 2-20 provides these comments. Responses were quite varied, recommending allowances for geographic adjustments, periodic updating, simplicity, and gathering input from contractor organizations.

2.1.9 Summary and Conclusions

A large majority of the states surveyed employ fuel factors in some form, but many states rely on antiquated sources for their factors and/or do not update their factors regularly. Of the 50 states that responded to the survey, 38 employ some form of fuel price adjustment using fuel factors on construction contracts. The 1980 data in FHWA Technical Advisory T5080.3 is the source of fuel factors for 21 of these states. A majority of 21 states employing fuel factors have not updated their factors within the last 6 years or do not know when their factors were last updated.

Exhibit 2-19. Preferred additions.

State	Response
Pennsylvania	Bituminous pavement milling
Vermont	The equipment is changing quickly and there needs to be some way to address new equipment, classes of equipment, or ranges of power plants.
New York	Guiderail
Colorado	Non-standard HMA mixes like warm mix, shingle mixes, etc.
New Jersey	Consider a fuel usage factor based on total contract cost and based on contract type.

Exhibit 2-20. Final comments.

State	Response
Oregon	The fuel factors that come from this study should have the capability to be adjusted for different areas of the country. They should also provide tools to update the fuel factors on a periodic basis.
Louisiana	Keep it as simple as possible: the more variables, the more mistakes. From an audit standpoint we spend more time recalculating and correcting adjustment errors in our fuel and asphalt adjustments than on the rest of the construction items in a contract.
Colorado	Highly recommend that this survey be provided to contractor associations for their feedback.
New Jersey	It is likely that fuel usage varies based on contractor. Analysis should look to normalize average usage among efficient contractors and not simply average in inefficient contractors.

The use of fuel factors in bridge/structure contracting is common, but several flaws act as a hindrance to their effectiveness. Fuels factors for bridges/structures were present in 20 states, 40 percent of the total surveyed. When asked to divulge perceived flaws in bridge/structure fuel factors, 28 out of 37 states responded with at least one criticism. Changes in construction methods and fuel intensity and differences in structure type, size, and complexity were perceived as the largest flaws, receiving 12 selections each.

Respondents had similar perceptions of the activities that were most fuel intensive. Asphalt paving and grading/excavation were the decisive top choices when ranking construction activities by fuel intensity, and shared all 48 first-place rankings between them. Recent fluctuations in fuel price affected the data/analytical needs of nine states.

Respondents had mixed opinions on whether they desired fuel factors for a broader spectrum of items. A total of 33 out of 47 states believe it is unnecessary to include fuel factors for additional pay items due to limited fuel use. Administrative burden was cited as justification for limiting the number of fuel factors by 16 states.

State DOTs had definite, although sometimes conflicting, ideas on the form fuel factors should take and how often they should be updated. The ability to convert units of measure in the new system received support from 26 states, while the inclusion of high-medium-low factor ranges would be useful for 16 states. Urban/rural and hauling distance were the most popular options when selecting additional variables for the system, receiving 20 and 19 selections, respectively, although 16 states would not want any additional variables. Seventy percent of states would like the system to be configured at the state (23) or regional (12) level. A majority of 34 states would like the factors to be updated every 5 years or less.

State DOTs shared a high level of interest in new research on fuel factors. For example, almost two-thirds of those responding (30 out of 46) would begin a fuel factor program or implement changes to their fuel factor adjustments if presented with revised factors and a software tool. Only 12 states with fuel factor programs would retain their existing methods, while 5 states that do not implement fuel factors would continue to refrain from utilizing them. Several states said they would evaluate the delivered products and consult with the contracting industry before moving forward.

2.2 Contractor Needs and Perceptions

The study team conducted a nationwide survey of contractors. Designed as a precursor to the more detailed Contractor Fuel Usage Survey, this survey explored the basic components of the fuel usage experiences and methodologies of construction firms. An additional goal was to determine methods to maximize the visibility and effectiveness of the later survey. The findings of the initial survey are presented in Section 2.2. Subsection 2.2.1 explains the survey methodology and response. The following five subsections, delineated by responses in each survey category, enumerate the survey findings. Subsection 2.2.7 summarizes the survey and offers conclusions.

2.2.1 Survey Methodology and Response

The study team provided the NCHRP study panel with a draft copy of the contractor survey on September 29, 2010. The study team reviewed the comments and suggestions of the panel members and made appropriate changes.

On October 11, 2010, the study team distributed invitations to 500 contractors to participate in the online survey. Contractors were selected through a random sample of bids in order to ensure a representative sample. This invitation requested that surveys be completed by October 25, 2010. Additional invitations were sent on October 25 and November 1, 2010. Additionally, the study team contacted several additional randomly selected contractors by phone in an effort to amplify participation.

These requests resulted in 63 survey responses. The response rate of 13 percent equals the response rate of the original 1980 fuel factor survey disseminated by the American Road and Transportation Builders Association (ARTBA) and the Associated General Contractors of America (AGC).

2.2.2 General Company Information

The 63 survey respondents include firm owners and presidents, vice presidents, chief estimators and engineers, and other high-ranking company officials. The responding firms vary widely in size and specialization. Firms with 100 to 200 employees represent the largest group of respondents, with 20 responses, nearly a third of the total. Firms with 200 to 500 employees followed with 18 responses. Small firms with 100 employees or less garnered 20 responses. Very large firms of over 500 employees accounted for five responses. Exhibit 2-21 displays the number of respondent firms by employment size class.

Exhibit 2-21. Firm size of survey respondents.

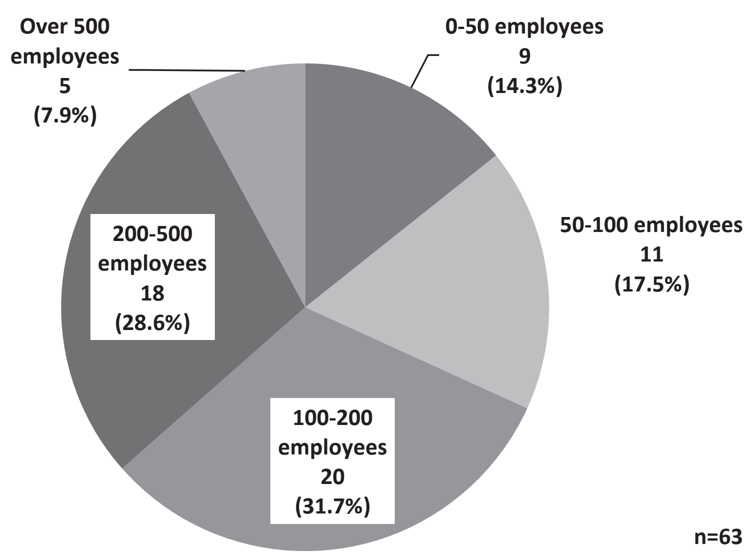


Exhibit 2-22. Areas of work.*

What type of work does your company primarily perform?				
Answer Options	**Primary**	**2nd Most**	**3rd Most**	**Response Count**
Asphalt Paving	32	3	3	38
Bridge	13	13	6	32
Grading	7	18	10	35
Storm Sewer/Drainage	0	9	13	22
Concrete Paving	3	4	1	8
Water/Sanitary Sewer	3	1	5	9
Misc. Concrete	0	6	3	9
Electrical/Signalization	2	0	1	3
Clearing/Demolition	0	1	1	2
Landscaping	0	0	2	2
Pavement Marking	0	0	1	1
Guardrail	0	0	1	1
Other (please specify)				13
				n=175

*Arranged by weighted ranking. "Primary" responses are worth three points, "2nd Most" responses are worth two points, and "3rd Most" responses are worth one point.

The questionnaire queried respondents as to the primary and secondary types of work their firms perform. The responding firms conduct varied operations. At least one response was registered for each of the 11 provided work categories. Asphalt paving received the most responses and is the primary area of operations for nearly half of the responding firms. More than half of the contractors selected the bridge and grading categories as well. Additional contracting areas enumerated under the "Other" category include general, civil, marine, and industrial contracting, building construction, base stones/aggregates, and research. Exhibit 2-22 displays the areas of work of responding firms.

The final question in this section asked contractors if the DOT in their primary state of operation uses fuel factors to determine price adjustments in construction contracts. More than 75 percent of contractors (50 total) replied in the affirmative. Exhibit 2-23 displays these results.

Exhibit 2-23. Presence of fuel factors in primary state.

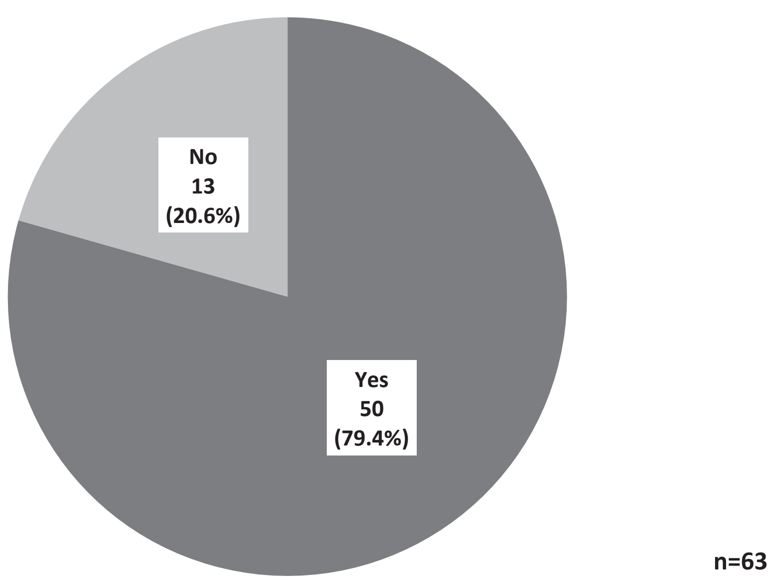
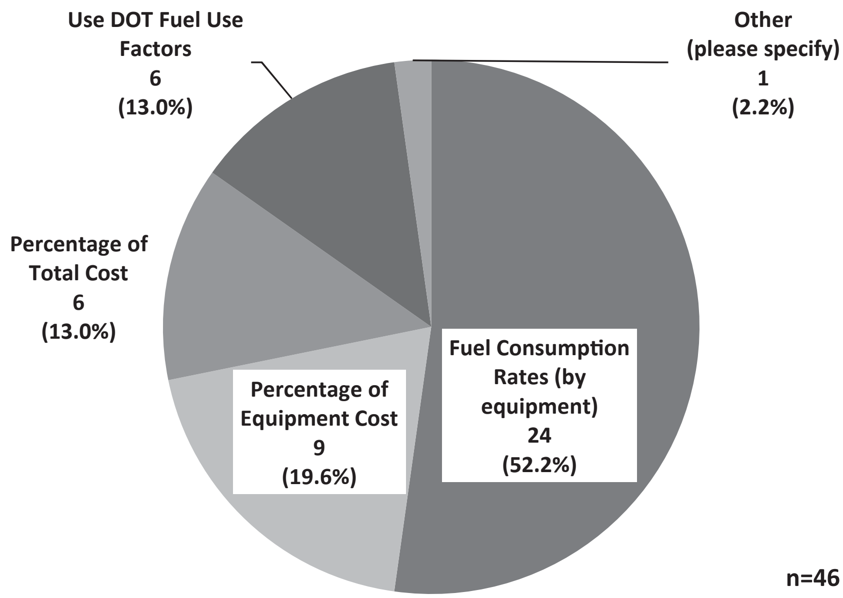


Exhibit 2-24. Fuel cost estimation methods.



2.2.3 Estimating Methods

This section of the contractor survey investigated the estimating methods used by contractors. The responding contractors utilize several different methods to calculate fuel cost. Fuel consumption rates by equipment type proved to be the most popular, garnering 24 of 46 responses, or slightly more than half of the total. Smaller numbers of contractors selected percentage of equipment cost (nine), percentage of total cost (six), and DOT supplied fuel factors (six). Exhibit 2-24 provides the estimation methods of responding firms.

The contractors surveyed employ a variety of sources for their fuel consumption rates. Internally developed rates received 24 responses. Equipment manufacturer's rates received 16 responses, while historical rates received 15 responses. One contractor uses gallons per second (GPS), while another respondent did not know the source of his firm's fuel consumption rates. Exhibit 2-25 displays the sources of contractors' fuel consumptions rates.

Exhibit 2-25. Sources of fuel consumption rates.

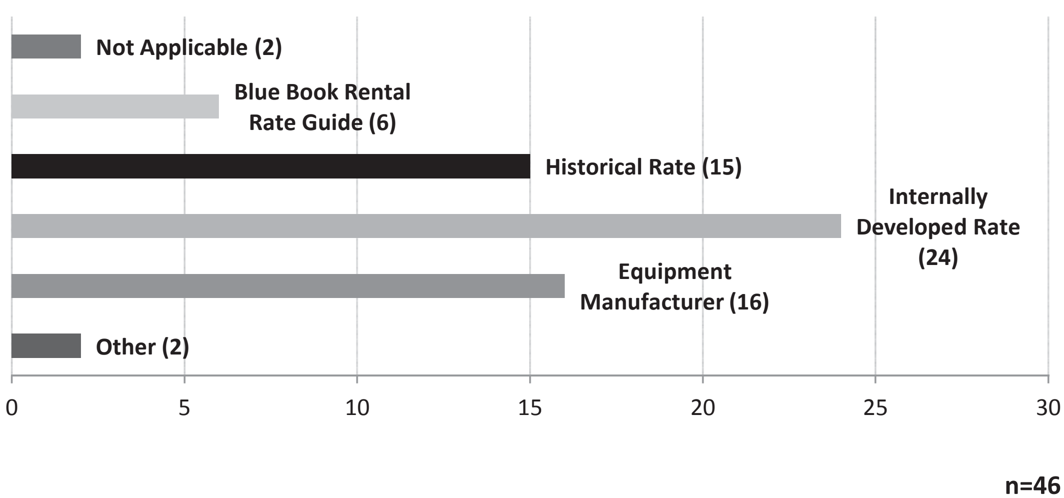
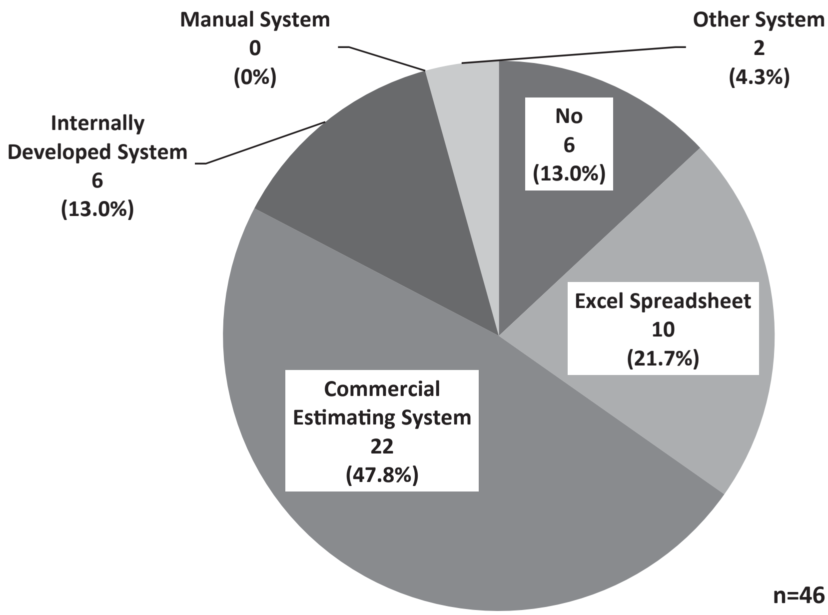


Exhibit 2-26. Use of estimating tools and software applications.



When asked when their fuel consumption rates or factors had last been updated, 23 out of 46 contractors indicated within the last year. Overall, 39 out of 46 respondents (more than 84 percent) have updated their factors within the last 3 years. Based on the relatively rapid updating of their factors, it appears that contractors have a strong incentive to keep their factors as current as possible in order to facilitate accurate estimation. Two contractors commented that they update the factors when new equipment is purchased.

Of the 46 responding contractors, 40 said that they use a tool or software application to prepare their estimates. The most popular method is using a commercial estimating system, which was selected by 22 respondents. An Excel spreadsheet application is used by 10 contractors, or slightly more than a fifth of those responding. Two contractors use programs developed by a construction estimating firm. Exhibit 2-26 displays contractor use of estimating tools and software applications.

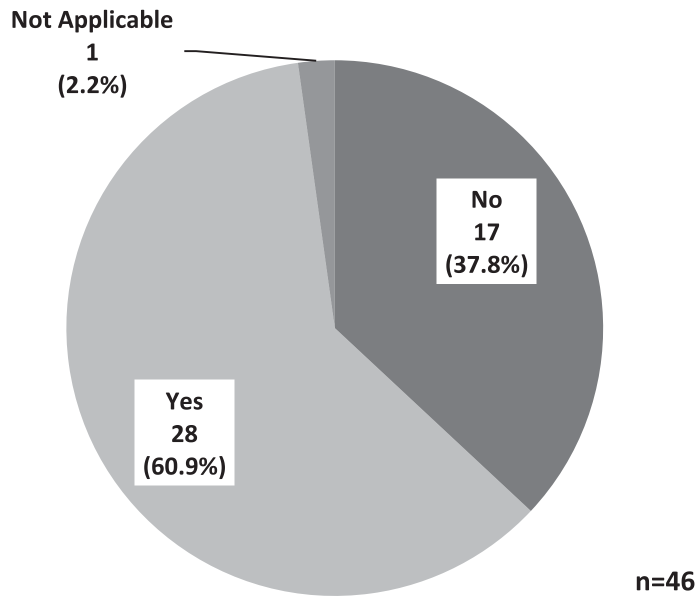
Sixty percent of contractors (28 out of 46) report that their applications have the capacity to calculate the quantity of fuel needed for a project, while 17 out of 46 do not. One contractor, presumably one of the six without a tool or application, chose “Not Applicable.” Only three contractors using commercial systems cannot calculate fuel quantities. Exhibit 2-27 displays contractor ability to calculate a project’s fuel quantity.

A cross-tabulation of the data by firm size reveals that smaller firms are less likely to have the ability to calculate fuel quantities used. Five of the six responding firms with less than 50 employees do not currently have this capability. More than 80 percent of firms with 200 to 500 employees and both firms with over 500 employees possess the capability to calculate fuel quantities.

2.2.4 Fuel Consumption Items

The contractors were asked to rank various construction activities in terms of fuel intensity. As was the case with the DOT survey, asphalt paving and grading/excavation were the clear top two choices, combining for 52 of 55 selections for the most fuel intensive activity. Grading/excavation is viewed as more fuel intensive than asphalt paving, receiving 34 top selections compared to 18 for asphalt paving. In comparison, asphalt paving received 25 first-place selections in the DOT survey,

Exhibit 2-27. Ability of estimating tools/software to calculate fuel quantities.



with grading/excavation receiving 23 first-place selections. Exhibit 2-28 displays relative fuel intensity perceptions.

The contractors identified eight other fuel intensive activities. Five of these activities involve asphalt and/or aggregates, and three relate to the handling and transportation of construction equipment and materials. Exhibit 2-29 provides additional comments regarding fuel intensive activities.

Nearly two-thirds of the responding contractors (35 out of 55) believe that recent fuel price fluctuations have not altered their analytical needs. Nineteen of the remaining contractors said that their needs had changed and offered explanations (one contractor responded "Yes (please explain)" to this question but put only a dash in the text box). Four respondents have increased their bids or included escalators/hedging as an attempt to control cost. Exhibit 2-30 provides these responses.

2.2.5 Perceptions

The responding contractors had varying opinions on how to account for fuel use in excluded pay items. Sixteen would prefer to add additional items through industry consultation and thirteen would add fuel factors to other items of work. However, 14 said that the fuel use for

Exhibit 2-28. Fuel intensity by construction activity.

Answer Options	Most	2nd Most	3rd Most	4th Most	5th Most	6th Most (Least)	Rating Average	DOT Rating Average
Grading/Excavation	34	14	7	0	0	0	1.51	1.75
Asphalt Paving	18	21	10	2	1	3	2.20	1.69
Base Stone/Aggregates	1	13	21	11	6	3	3.31	3.44
Concrete Paving	0	1	10	23	14	7	4.29	4.27
Drainage	1	4	3	18	22	7	4.40	4.73
Structures	1	2	4	1	12	35	5.29	5.13
								n=55

Exhibit 2-29. Additional contractor-identified fuel intensive activities.

Respondent	Comment
1	Materials transport trucking
2	Line utility work
3	Quarrying aggregates
4	On-highway commuting
5	Materials handling
6	Milling
7	Transportation of aggregates for asphalt by barge
8	Plant fuel use
9	Delivery of asphalt
10	Cold planing asphalt

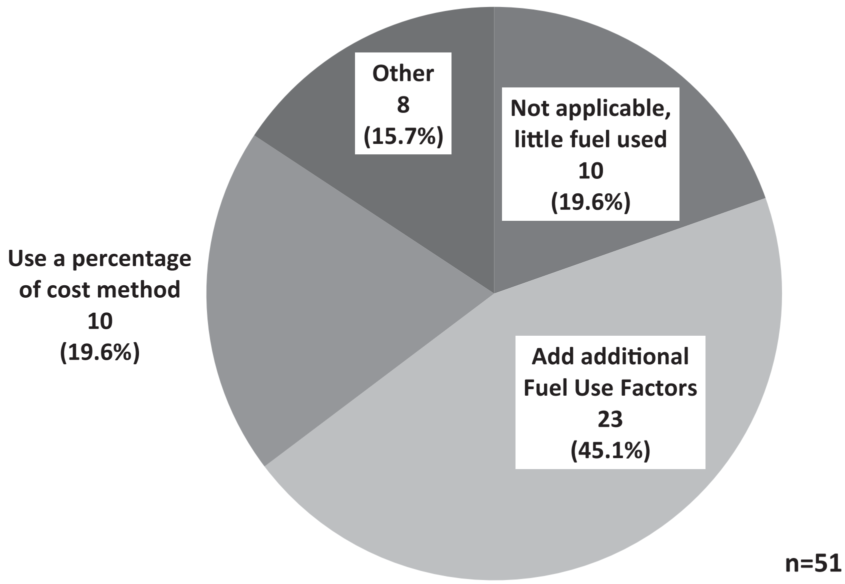
other pay items is limited and fuel factors should not be extended. Two contractors recommended eliminating fuel factors altogether, as follows:

- Eliminate fuel use factors and use a more equitable and accurate method of accounting for the risk of fuel cost escalations. Fuel use factors are not equitable even on the traditional items to which they are applied. Fuel use is very dependent on type of equipment owned, more so than what work is performed.
- Drop the use of fuel factors and use three lump sum items (grading, paving, and structures) to allow the contractor to place the fuel dollars he wishes to be indexed in the program. Due to timing and fuel pricing, the major work disciplines need to each have their own fuel item. On medium- and long-term projects, it is possible for the grading work to experience a significant windfall while the paving work can lose significant fuel dollars, and vice versa, and all due to timing of the work versus actual fuel prices.

Exhibit 2-30. Additional contractor comments on experiences with price fluctuations.

Respondent	Comment
1	We add a "fuel" factor as a lump sum to our bid based on the length of the project (for non-covered items like concrete)
2	Price per ton of asphalt
3	No analytical tool can predict what the fuel price will be when a project has no fuel adjustment
4	Need to be able to quickly analyze cost data
5	Can't rely as much on our historical information, have to make projections based on current info
6	We have to add enough for fuel so that it doesn't kill us to do the job. We overestimate the cost of fuel on purpose.
7	Productivity concerns on minimums needed to be competitive and fuel conscious
8	We track spot prices to purchase prices and purchase futures based on spot prices
9	Plan for worst case
10	When fuel was stable it was more like a fixed cost on the project with little or no variation. When it started having major fluctuations and with projects that extend over multiple months or years, the fuel became a major concern.
11	Seasonal pricing, futures, intensity of work, and timing of major activities, theft control
12	Only price
13	Much more attention is paid to actual fuel unit pricing and how it relates to the rates posted by the DOT
14	Had to attempt to bid in fuel escalators from suppliers
15	We now factor fuel in our bids
16	Petroleum-based material cost fluctuations
17	Fuel consumption and pricing are monitored much closer now than in the past
18	We look at fuel per piece of equipment annually, project drying cost and trucking fuel requirements for large jobs
19	Fuel cost is analyzed with every large bid and protected sometimes by hedging

Exhibit 2-31. Preferences for compensating subcontractors.



Approximately half of the responding contractors (25 out of 51) pass along fuel price adjustments to their subcontractors, while 14 do not. The remaining 12 utilize varying practices. Three contractors said it depends on the subcontractor's quote, two said that price adjustment clauses are negotiated, and two said that price adjustment inclusion can occur if the subcontractor requests it.

When asked to provide opinions on how to compensate subcontractors for increased fuel costs, 23 contractors approve of including additional fuel factors, while using a percentage of cost method and not extending fuel factors due to limited fuel use each received support from 10 contractors. Eight contractors selected the "Other" category and enumerated their preferences. Exhibits 2-31 and 2-32 display contractor preferences for reimbursing subcontractors and additional comments on the topic, respectively.

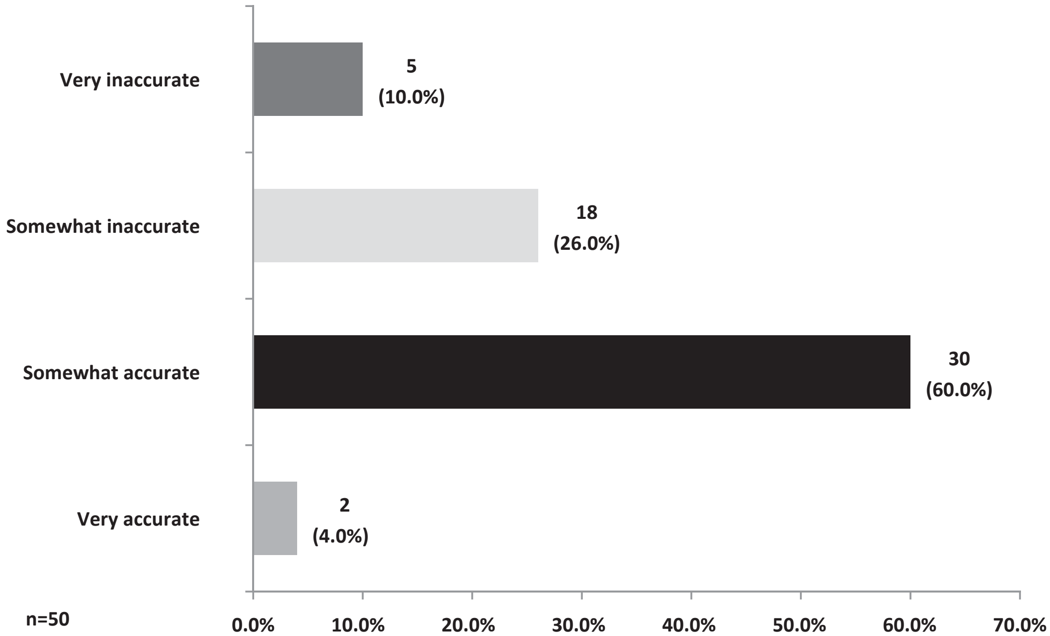
When asked what approximate percent of the contract dollars they received from the state DOTs were subcontracted, 86 percent (44 out of 51) selected an option of 30 percent or less. The selections "11–20 Percent" and "21–30 Percent" were chosen by 20 contractors each. Only two respondents selected "Over 40 Percent."

In a similar vein, contractors were asked what percentage of their DOT contract dollars were performed as a subcontractor. A substantial majority of 94 percent (48 out of 51) operate as

Exhibit 2-32. Additional contractor methods for subcontractor compensation.

Respondent	Comment
1	They should get the increase/decrease on the item they are doing
2	Grading and asphalt subs are compensated
3	Set up terms and conditions under subcontract by type of work and amounts of fuel being used
4	Generally negligible, but depends on which items of work are subcontracted
5	Negotiate adjustment factors with subs based on agreed-upon usage
6	WYDOT's method is a percentage of cost method, which we pass on to any sub that chooses to participate when we choose it on the prime contract
7	Non-factor unless the subcontractor states it in their quote
8	Allow the contractor to manage

Exhibit 2-33. Accuracy of fuel usage factors.



subcontractors for 40 percent or less of their DOT project dollars, and 31 out of 51 did so 20 percent of the time or less.

The final question of this survey was designed to gauge contractor satisfaction (or lack thereof) with their primary state DOT's fuel factors. Sixty percent (30 out of 50 respondents) believe that their fuel factors are somewhat accurate. Twenty-six percent (18 out of 50) stated that their factors are somewhat or very inaccurate. Exhibit 2-33 displays perceptions on fuel factor accuracy.

Several contractors offered additional comments. Two express general satisfaction with the current factors, one mentions the dualistic nature of price adjustment clauses, and another comments on the difficulty in creating and utilizing a single fuel factor. Exhibit 2-34 displays additional comments regarding fuel factor accuracy.

2.2.6 Future Plans

Seven contractors responded with pay items that they would like revised or for which they would favor the development of additional fuel factors. Four of the seven would like transportation

Exhibit 2-34. Contractor comments on fuel usage factor accuracy.

Respondent	Comment
1	Concrete paving, asphalt, and grading are the largest pay factors and they seem adequate
2	When the fuel decreases, it takes too much money away from the contractor, and when it increases, it gives too much money to the contractor
3	Fuel consumption rates vary as to haul lengths, method of work, type of materials, and grades—all these factors have major impacts to fuel consumption and make the use of a single fuel factor inaccurate from the beginning
4	Seems close
5	The paving diesel factor only covers about 50% of the fuel used

Exhibit 2-35. Contractor comments on additional or updated fuel usage factors.

Respondent	Comment
1	Bridge items
2	Grading and excavation, hauling (stone/earth/demo)
3	The production of hot mix asphalt mixes
4	Trucking
5	Storm drainage items, box culvert items, box bridge items, bridge items
6	Transportation costs (trucking/barge)
7	Item 502-01: There should be two separate diesel fuel indices calculated. Plant drying fuel should be separate from transportation and paving fuel usage. There should also be a factor for trucking and barging aggregate. Item 501-01: Should be eligible for the asphalt index for square yard patching items. The fuel usage factors should be re-evaluated for all pay items.

and hauling to be added. Two contractors support the addition of bridge/structure pay items. Exhibit 2-35 displays contractor comments regarding additional or updated fuel factors.

Two contractors provided comments for improving or refining the use of fuel factors. One recommended the automation of index price adjustments as a means of ensuring accuracy. The other suggested studying the system employed by the Wyoming DOT.

Six contractors provided advice on how the study team can maximize participation in the later fuel use survey. Several contractors suggested addressing the survey to estimators, project and equipment managers, and accountants. Another suggested working through the Associated General Contractors of America (AGC) and the National Asphalt Pavement Association (NAPA). Exhibit 2-36 displays these, and other, contractor suggestions.

2.2.7 Summary and Conclusions

Nearly 80 percent of the responding contractors operate primarily in states that use fuel factors. A sizable majority (39 out of 46) of responding contractors have updated their fuel consumption rates or factors within the last 3 years, while less than a third of state DOTs have done the same. Individual contractors would seem to have an incentive to update this information regularly as a means of increasing bid accuracy and eliminating uncertainty.

The most popular method of fuel cost estimation is fuel consumption rate by equipment type, which is used by 52 percent of responding contractors. Contractors most often utilize internally developed rates, although historical rates and rates supplied by equipment manufacturers are

Exhibit 2-36. Contractor suggestions for the fuel use survey distribution.

Respondent	Comment
1	Equipment managers and estimators
2	Work through AGC, NAPA, etc.
3	Contact the organization's estimators and project managers. They are the ones who deal with fuel adjustments on a regular basis and can provide the most input; DOT Road Builder Associations. Keep it short and sweet.
4	This topic has broad applicability to off-road emissions reduction targets. The more accurate and broad the dataset, the better we will be able to respond to U.S. EPA/California emissions mandates.
5	Address inquires to the accountants.
6	Paving contractors are primary users of fuel. This group should be main focus.

also popular. Eighty-seven percent of responding contractors employ a software application or estimating tool, with commercial estimating services being the most popular option. More than 60 percent of responding contractors report that their estimating tools are capable of calculating fuel use, although nearly 40 percent are not capable of doing so.

The contractors and DOTs are in broad agreement over the fuel intensity of various construction activities. Although the contractors believe that grading/excavation (rather than asphalt paving) is the most fuel intensive work type, the rankings of the remaining activities were the same in both surveys. About two-thirds of contractors replied that recent fuel price fluctuations had not affected their analytical needs. This percentage is lower than the 81 percent of state DOTs who believe similarly.

More contractors pass on price adjustments to their subcontractors than not. Slightly less than half of the responding contractors believe that additional fuel factors should be added to cover subcontractors' increasing costs. Large majorities of contractors subcontract between 11 and 30 percent of their DOT contract dollars and perform less than 40 percent of their DOT contract dollars as a subcontractor.

More than 60 percent of contractors believe that their state's fuel factors are somewhat or very accurate. The remaining 36 percent believe them to be somewhat or very inaccurate.

The results for the contractor survey illustrate several trends that may be ameliorated by updated fuel usage factors. Contractors update their fuel consumption rates or factors more often than state DOTs. Fluctuations in commodity pricing have a larger effect on contractors than DOTs, primarily due to smaller operating budgets. Contractors then have an incentive to update and maintain factors. While 60 percent of the responding contractors expressed satisfaction with the accuracy of their primary state's fuel factors, nearly 40 percent find them to be somewhat inaccurate at best. Inaccuracies can be compounded if a contractor's estimating tool cannot calculate the amount of fuel used on a project, which nearly 40 percent of respondents indicated.

2.3 Initial Engineering Estimation of Fuel Intensity

As part of the study team's three-pronged approach to addressing the research problem, the project team conducted an initial investigation to determine construction pay items that had high fuel intensity. An expert panel of professional estimators and contractors rated the fuel use of over 1,000 specific pay items. The ratings of individual estimators were averaged to create a composite ranking of fuel use. Reviewer D is a member of the research team and Reviewers A through C performed as consultants for the research team. Each member of the panel possesses at least 25 years of experience in the highway construction and/or cost estimation fields.

This analysis consisted of three parts, as follows:

- Creating a list of pay items to study by filtering unsuitable pay items,
- Creating a ranking system to apply to the pay items, and
- Performing the fuel use ranking of each pay item and pay item category.

2.3.1 The Expert Panel

The initial engineering estimation was conducted using a four-person expert engineering panel. Each member of the panel estimated the relative fuel intensity of over 1,000 specific pay items and 31 summary categories. The four panel members were

- Expert Panel Member A is a civil engineer and former district engineer and contracting officer in the U.S. Army Corps of Engineers. He has over 30 years of experience in the heavy/highway construction industry as an estimator, project manager, division manager, operations manager, and vice president.

- Expert Panel Member B has nearly 35 years of experience with the Georgia Department of Transportation, has estimated or supervised estimation for over 8,000 DOT projects, is a three-time chairperson of the Transportation Estimators Association, and has been elected to the FHWA's Peer Team Review.
- Expert Panel Member C is a veteran consulting estimator for the heavy construction industry with 30 years of experience.
- Expert Panel Member D has over 25 years of experience in the road building industry, is the creator and primary developer of the BidTabs Professional and ProEstimate line of estimating software, and assisted in the development of the FHWA Highway Construction Cost Index.

2.3.2 Pay Item Selection

The first part of this analysis was to develop criteria for filtering the list of pay items to eliminate unsuitable pay items. The source of the data was the BidTabs professional database development, which contains all pay item prices for all DOT contracts in 48 states (Alaska and Hawaii are not included). This database also divides items among 31 predefined categories of pay items that are assigned to every standard pay item in the database.

The first step in developing the database was to exclude older data. The decision was made to eliminate data prior to 2006. The second step was to eliminate data for bids that were not awarded, leaving the low bid only. The third step was to eliminate lump sum pay items and non-standard pay items. Since each of these bids was for a unique construction item, there is no basis for comparison amongst them. The final step was to eliminate pay items with a bid frequency of less than 100 bids during the selected time period. Items that are purchased so infrequently would not be useful for inclusion in the final fuel factor database. The results of the program generated a list of 1,176 pay items across all states and across all pay item categories.

2.3.3 Fuel Intensity Ranking

The project team developed a scale to use in the classification of pay items based on "fuel intensity." The scale ranges from one to five (1–5) with items marked as a 5 being "heavy use" and items marked as a 1 being "light use." To have a better understanding of the actual fuel use as a percentage of cost, the team identified two known very heavy use items: (1) on-road truck haul excavation and (2) off-road truck haul excavation. These tasks include only labor and equipment cost and heavy fuel consumption equipment. The team priced these items to determine the fuel cost as a percentage of the total cost and this value allowed the team to establish an upper end value for "high use" items. From this analysis, the team then established ranges to use in the fuel ranking. The fuel cost strictly as a percentage of the pay item cost (equipment, labor, etc.) was 22 percent and 28 percent. Adding 10 percent overhead and 10 percent profit to this pay item yielded a fuel cost percentage of 18 percent and 23 percent of the estimated bid price.

Using this range of values as the high end due to hauling being a very fuel intense activity, the project team used a value of over 15 percent as the top-end fuel ranking. Breaking this down into five categories, the project team set the fuel ranking system as follows:

1. Less than 1 percent,
2. From 1 to 5 percent,
3. From 6 to 10 percent,
4. From 11 to 15 percent, and
5. More than 15 percent.

These values provided a guide to the expert panel.

2.3.4 Ranking of Fuel Intensity

Once the pay item list was created and the ranking method determined, each member of the expert estimating panel assigned a value to each pay item. In addition, each team member assigned a ranking to each of the 31 summary pay items.

Exhibit 2-37 provides fuel use rankings at the 31 summary pay item level. The first four columns provide the ranking selected by the four reviewers at the 31 summary level. The fifth provides the average of the four rankings. The sixth column shows the range of the rankings as a measure of the variation. The final column provides the average of the values for the detailed pay items within each category.

2.3.5 Initial Recommendations

Historically, the most common categories of pay items used for fuel use factors are grading, asphalt, base stone, and concrete pavement. All four of these categories ranked high in both the summary and detailed analysis. Exhibit 2-38 breaks down the categories into three sections of high, medium, and low fuel use based on the rankings. The pay items are listed from highest to lowest fuel use within each column.

Exhibit 2-37. Fuel use rankings by category.*

Category	Reviewer				Average	High-Low	Detail Average
	A	B	C	D			
GRADING/EXCAVATION	5	5	5	5	5.00	-	4.67
CLEARING	5	3	4	5	4.25	2.00	3.24
MOBILIZATION	5	4	4	3	4.00	2.00	2.41
BASE STONE	3	4	4	4	3.75	1.00	2.85
MISC STONE/RIPRAP	5	3	3	3	3.50	2.00	3.00
CONCRETE-PAVEMENT	3	3	4	4	3.50	1.00	2.99
ASPHALT	2	4	4	4	3.50	2.00	2.83
EQUIPMENT/LABOR	3	4	3	3	3.25	1.00	4.25
UNDERDRAIN	5	1	3	3	3.00	4.00	3.08
BRIDGE	3	3	3	3	3.00	-	2.32
DRAINAGE-PIPE	3	2	3	3	2.75	1.00	3.01
DRAINAGE-INLETS/CATCH BASINS	3	1	4	3	2.75	3.00	2.30
CONCRETE-MISC	3	1	4	3	2.75	3.00	2.12
EROSION CONTROL	4	1	4	2	2.75	3.00	2.01
UTILITY-WATER	3	2	3	2	2.50	1.00	2.63
UTILITY-GAS	3	2	3	2	2.50	1.00	2.63
UTILITY-SEWER	3	2	3	2	2.50	1.00	2.63
RETAINING WALL	3	2	3	2	2.50	1.00	2.50
CONCRETE-CULVERTS	3	1	3	3	2.50	2.00	2.30
TRAFFIC CONTROL	4	2	2	2	2.50	2.00	2.02
GRASSING	3	2	2	1	2.00	2.00	2.51
GUARD RAIL	3	1	2	2	2.00	2.00	2.20
FENCING	3	1	2	2	2.00	2.00	2.17
MISC ELECTRICAL	3	1	3	1	2.00	2.00	1.77
ROADWAY LIGHTING/ELECTICAL	3	1	3	1	2.00	2.00	1.77
STRIPING/PAVEMENT MARKING	3	1	2	2	2.00	2.00	1.75
SIGNALIZATION	3	1	2	2	2.00	2.00	1.57
SIGNS-PERMANENT	3	1	2	2	2.00	2.00	1.50
BUILDINGS/MISC STRUCTURES	3	1	3	1	2.00	2.00	1.31
PAINTING STRUCTURES	2	1	2	1	1.50	1.00	1.75
ALTERNATES/BONUS/TIME	1	1	1	1	1.00	-	1.63

*Fuel intensity is estimated on a 1 to 5 scale with 1 being the least intense.

Exhibit 2-38. Ranking of pay item categories by fuel use.

High	Medium	Low
Grading/Excavation	Drainage – Pipe	Grassing
Clearing	Drainage – Inlet	Guardrail
Mobilization	Concrete – Misc	Fencing
Base Stone	Erosion Control	Misc. Electrical
Misc Stone/Riprap	Utility – Water	Roadway Lighting
Concrete – Pavement	Utility – Gas	Striping/Pavement Mark
Asphalt	Utility – Sewer	Signalization
Equipment/Labor	Retaining Walls	Signs – Perm.
Underdrain	Concrete – Culverts	Buildings/Misc. Structures
Bridge	Traffic Control	Painting
		Alternates/Time

Several pay item categories in the high group have been removed from this list. These categories and the reasons for their exclusion are presented in Exhibit 2-39.

2.4 Initial Statistical Analysis of Fuel Intensity

This report section documents the development of the BidTabs database that the study team analyzed as part of this project. In this initial effort, the objective was to examine which pay item prices are sensitive to changes in fuel prices in order to develop a list of items for which to develop fuel use factors. The thesis was that if there is no association between fuel prices and pay item prices, it would not be necessary to provide a price adjustment clause for those pay items.

The initial statistical analysis consisted of three steps. The first step was to tabulate unit prices for pay items over time. The second step was to develop price indices for fuel. The third step was to conduct the initial BidTabs statistical analysis.

2.4.1 Selecting Pay Items for the Development of New Fuel Usage Factors

The study team designed the database so that it would contain prices over 3 to 5 years. The study team selected a start date of January 1, 2006, and an end date of September 1, 2010. In total, data are available in the Oman Systems BidTabs Database for 335,564 separate pay items. For these pay items, there are almost 3.6 million low bids. Note that low bids are the unit price bid for the pay item in the winning low bid as opposed to the lowest bid for that pay item. Exhibit 2-40 summarizes the process of filtering the pay items used for analysis.

To prepare the database, the study team excluded records that were not suitable for the analysis. The first step was to exclude non-standard pay items. Non-standard pay items are items that do

Exhibit 2-39. Excluded pay item categories.

Pay Item Category	Justification for Exclusion
Equipment/Labor	This category consists of equipment rental or labor hour pay items and is used only by a very limited number of states and is rarely used by those states.
Clearing	This category is typically bid utilizing lump sum pay items.
Mobilization	This category is typically bid utilizing lump sum pay items.

Exhibit 2-40. Number of pay items and bid lettings from 1/1/2006 to 9/1/2010.

Options	Number of Pay Items	Number of Bids
Low Bids Only	335,564	3,597,517
Also Exclude Non-Standard Pay Items	171,381	3,289,606
Also Exclude Lump Sum Pay Items	157,407	2,973,784
Also Exclude Pay Items Bid Less than 100 Times	6,338	1,799,740
Also Exclude Pay Items with Less than 3 Years of Data	5,965	1,723,059

not have the same definition or units from one project/bid to another. Therefore, there is no price per unit of work. There is no ability for the analysis to compare unit price across projects or over time. There is no ability for the analysis to regress unit price against fuel prices to assess the existence of a relationship or correlation. Note from Exhibit 2-40 that the exclusion of non-standard pay items from the sample does not have a large impact on the total number of records included in the study. Although the number of pay items excluded is a large percentage of the total number of pay items, these items were bid much less frequently than standard pay items, resulting in a much smaller percentage drop in the number of records included in the study.

The second step was to exclude lump sum pay items. Lump sum pay items are items for which the bid quantity is essentially equal to one. For example, build one bridge or pave one section of road. In this case, there is once again no price per unit of work and therefore no ability for the analysis to compare unit price across projects or over time. There is no ability for the analysis to regress unit price against fuel prices to assess the existence of a relationship or correlation. The exclusion of non-standard items only reduces the number of pay items by about 14,000, but again reduces the number of bids by only about 10 percent.

The third step was to exclude pay items that the issuing state DOT did not put out for bid with much frequency. In this case, the analysis excluded pay items if there were less than 100 lettings of that item over the examination period, or approximately 22 bids per year. The research team determined that this average of 22 observations per year provided sufficient data to determine both means and variability in each year. The purpose of excluding pay items with very few bids is that the small sample size may hamper the ability to accurately assess the existence of a relationship or correlation. The exclusion of these pay items reduces the number of pay items drastically to about 2 percent of the original number of pay items, but reduces the number of bids to only about half of the original number of pay items. Note that the average number of records for the pay items excluded from the analysis was only 7.8 over the examination period.

The fourth step was to exclude pay items that were not used during the critical 2008 time period when fuel prices were fluctuating. The analysis examined the first bid date and the last bid date for each pay item to remove all pay items with less than a 3-year range of data. This action removed less than 400 pay items.

The final database contained approximately 1.8 million records providing data on 5,965 pay items. The mean number of bids per pay item was approximately 284. The database included state, pay item number, pay item description, unit, quantity, amount (in dollars per unit), a category identifier developed by Oman Systems, and the bid date.

2.4.2 Tabulation of Diesel Fuel Price Index

The second step was to tabulate price indices over the same period. Highway construction projects are known to use large amounts of diesel fuel for equipment use. Diesel fuel prices also serve as a surrogate for the price of other petroleum-product-based inputs to highway construction such as asphalt, paint, and sealers. In addition, many other inputs to highway construction such as concrete and steel have high fuel-use input requirements and high transportation costs to the work site.

The available data indicate that fuel costs have become a more important component of construction costs in general. For example, in 1998, the Bureau of Economic Analysis (BEA) national input-output matrix had a total input requirement coefficient of 0.029 (2.9 cents per dollar output) for petroleum and coal-based products used by the construction industry as a whole. By 2008, total input requirement of petroleum and coal-based products had increased by almost a factor of three to 0.083 (8.3 cents per dollar output). Given the reduction in fuel costs since 2008, it is likely that the 2010 BEA benchmark revision will have a smaller coefficient. Fuel is an important input to highway construction activities, and petroleum products represent a relatively larger proportion of the total costs of production than for the construction industry in general.

Although fuel and petroleum-based products are important components of production costs for the construction industry, when viewed on a total requirements basis, the direct input requirement of fuel and petroleum-based products is somewhat smaller (2.2 cents per dollar output in 1998 and 6.1 cents per dollar output in 2008). The lower level of direct costs is due to the relatively large embodied energy content of other input materials such as concrete and steel. Given these figures, and applying an extra factor of two to account for the fact that highway construction is more fuel-intensive than construction in general, suggests that the direct cost of fuel and petroleum-based products represented somewhere between 2 percent and 5 percent of production costs for highway construction in 1998, rising perhaps to a range from 6 percent to 12 percent in 2008, and falling since then to somewhere below 10 percent of production costs. To put these costs in perspective, employee compensation costs in the construction industry rose from 30 cents per dollar output to 35 cents per dollar output between 1998 and 2008.

Despite the relatively small (10 percent) share of direct fuel costs per dollar output, diesel fuel prices have ranged both up and down by over a factor of three from 2004 to 2010. It is reasonable to expect that this large variation in diesel fuel price and other petroleum-based product prices has had a measurable impact on the bid prices received for highway construction projects. The statistical analysis attempted to find empirical evidence of this relationship.

The daily U.S. No. 2 diesel fuel price (cents per gallon) was calculated as the arithmetic average of three regional price indices published by the U.S. Department of Energy. The three regional price series represent daily market closing prices in the New York area (New York Harbor No. 2 Diesel Low Sulfur Spot Price FOB), the Gulf Coast (U.S. Gulf Coast No. 2 Diesel Low Sulfur Spot Price FOB), and Los Angeles (Los Angeles, California, No. 2 Diesel Spot Price FOB). The published data do not include prices for weekends or U.S. oil market trading holidays. The research team imputed the last available price in these instances. For example, prices on a Monday holiday would match the last available spot prices from the previous Friday.

2.4.3 Assessment of BidTabs Data

The highway construction bid database includes over 3 million records with information on bids submitted in the 48 states. Each pay item has a unique definition within each state and is provided in terms of specific units. Variables in the bid price database include the quantity and unit bid prices, and the bid date for each pay item. Dates range from January 1, 2006, to September 1, 2010. Since the project was interested in the impact of the large diesel fuel price swings, the first bid date and the last bid date for each pay item were examined to remove all pay items with less than a 3-year range of data. The 3-year requirement ensures that the range of

Exhibit 2-41. Ten largest mean partial correlation coefficients by category and significance level.

Rank	Category	Mean Correlation
1	Concrete - Culverts	0.099
2	Roadway Lighting/Electrical	0.092
3	Signalization	0.078
4	Retaining Wall	0.069
5	Bridge	0.062
6	Guard Rail	0.058
7	Drainage - Pipe	0.052
8	Underdrain	0.050
9	Concrete – Misc.	0.045
10	Buildings/Misc. Structures	0.045

bid dates for the pay item includes the critical 2008 time period. Pay items receiving less than 100 bids were also removed.

The resulting database included 5,965 pay items. The pay items were categorized into 29 summary categories used in the BidTabs database. A partial correlation analysis was run for each pay item within each category. The partial correlation of the bid price with the diesel fuel price and the significance level of the estimated partial correlation coefficient were then summarized by category. The categories with the 10 largest mean partial correlations coefficients are displayed in Exhibit 2-41.

The overall conclusion of the initial statistical analysis is that there is a positive relationship between fuel prices and bid prices. The positive relationship is strongest where the significance of the correlation is strongest. However, there is a large amount of variation in the results for individual pay items within the categories of construction. The negative coefficients indicate the fuel price is not always an important factor for determining bid prices for many types of purchases. Further analysis is needed to determine why this is the case. It may be concluded that fuel consumption is significant in most types of highway construction, but perhaps is not limited to only certain construction activities, as previous studies have suggested.

A major goal of the initial analysis was to identify construction tasks that consume large amounts of fuel and are fuel intensive. These items would be obvious candidates for newly calculated fuel factors. The initial statistical analysis indicated that a larger number of activities than previously envisioned are heavy users of fuel and/or are fuel intensive. Many heavy construction tasks, such as asphalt paving and grading, were confirmed as being heavy users of fuel. However, additional items appear to be more fuel intensive than anticipated. For example, the roadway lighting/electrical and signalization categories ranked second and third in the initial statistical analysis. Those categories did not rank within the top 10 of the other initial methodologies.

2.5 The Three-Pronged Research Methodology

The first phase of the study examined three strategies for developing fuel usage factors. The study team examined the strengths and weaknesses of each approach in preparation for the second data collection phase of the project. This report section describes observations and lessons learned during the first phase, assesses the strengths and weaknesses of each approach, and outlines the research approach that was ultimately used in collecting the data and developing the fuel usage factors.

2.5.1 Issues in Developing Fuel Usage Factors

This subsection discusses several issues that the study team encountered during the first phase of the project. The first is a discussion of the economic production function of construction activities and how it relates to the observed fuel intensity rankings. The following section addresses the number of updated and additional fuel factors. The last section discusses fuel factors for bridges and structures.

Understanding the Production Function

An underlying assumption in the literature and in the application of fuel factors by state DOTs is that certain construction activities, such as grading and paving, are more fuel intensive than many other activities. Both state DOT officials and contractors share this perception, as indicated by the mutual preference for selecting grading/excavation and asphalt pavement as the most fuel intensive activities.

However, the statistical analysis performed during the analysis of the BidTabs database indicated that a larger variety of activities might have significant fuel use. In fact, the statistical analysis found significant correlations between bid price and fuel prices for a large variety of construction activities.

Exhibit 2-42 displays the fuel intensity rankings determined by each research method. It also displays the fuel percent of cost rankings from Attachment 3 of the original Technical Advisory T5080.3. Note that several work categories that rank in the top 10 for 3 of the research efforts and the Attachment 3 rankings (notably grading/excavation, asphalt paving, and base stone/aggregates) do not appear in the BidTabs statistical analysis rankings, while the BidTabs statistical analysis contains items that have historically been thought of as less fuel intensive.

A potential reason for this apparent contradiction is that the focus is often on total fuel use and the dichotomy between heavy and light construction activities. An alternative is to focus on the full economic production function.

In economics, factors of production (or productive inputs or resources) are any commodities or services used to produce goods and services. "Factors of production" may also refer specifically to the primary factors, which are stocks including land, labor (the ability to work), and capital goods applied to production. For example, in productivity analysis, the U.S. Bureau of Labor Statistics defines the production function as the combination of capital (K), labor (L), energy (E), materials (M), and purchased business services (S) inputs, or KLEMS inputs.

Exhibit 2-42. Rankings of fuel use by activity.

Rank	Attachment 3 from TA5080.3	Research Method			
		DOT Survey	Contractor Survey	Estimating Analysis	BidTabs Statistical Analysis
1	Grading/Excavation	Asphalt Paving	Grading/Excavation	Grading/Excavation	**Concrete - Culverts**
2	Asphalt Paving	Grading/Excavation	Asphalt Paving	Clearing	**Roadway Lighting/Electrical**
3	Base Stone/Aggregates	Base Stone/Aggregates	Base Stone/Aggregates	Mobilization	**Signalization**
4	Concrete Paving	Concrete Paving	Concrete Paving	Base Stone/Aggregates	**Retaining Wall**
5	Bridges/Structures	Drainage - General	Drainage - General	Misc. Stone/Riprap	**Bridges/Structures**
6	Landscaping	Bridges/Structures	Bridges/Structures	Concrete Paving	**Guard Rail**
7	Roadway Lighting/Electrical			Asphalt Paving	**Drainage - Pipe**
8	Deck Repair/Minor Widening			Equipment/Labor	**Underdrain**
9	Striping/Pavement Mark			Underdrain	**Concrete - Misc.**
10				Bridges/Structures	**Buildings/Misc. Structures**

For example, most observers would characterize asphalt paving as a fuel intensive activity and pavement marking as a non-fuel intensive activity. In the case of asphalt paving, the equipment used is much heavier and has a higher fuel consumption rate. However, when examining the whole production function, asphalt paving also requires more capital, labor, and materials. In particular, although liquid asphalt is a petroleum product, it is not fuel and its consumption is not part of the fuel factor.

In the case of pavement marking, the equipment may only be one light vehicle with a low fuel consumption rate. However, if there is only one driver and very little material cost, fuel cost as a percentage of total cost may actually rival or exceed the fuel cost percentage for asphalt paving.

Pay Item Flexibility

The flexibility to alter the list of items or add new items varies considerably among the three study methodologies. Including a lengthy list of items in the contractor survey would reduce response rates and increase processing time and costs. Once a survey is distributed, it becomes infeasible to add new or additional items. In contrast, changes or additions to the list of items considered in the engineering or statistical analyses can be accomplished with relative ease. For this reason, the proposed methodology for the survey included a flexible additional factor survey section. Contractors were allowed to write in non-traditional items that they believed to be fuel intensive.

An important consideration was the analytical needs of the ultimate users. Different users have different priorities and preferences. For example, while only five state DOTs stated that they would prefer additional fuel use factors, nearly 57 percent of the contractors in the initial survey recommended either adding additional fuel factors or consulting with the construction industry to select new fuel factors. Accordingly, the methodology envisioned two levels of detail in the final fuel factors. The basic product is a hard copy table containing a limited number of fuel factors, including the items commonly used by state DOTs in price escalation clauses. The more detailed Excel spreadsheet tool allows the user to access additional, and more detailed, fuel factors.

Structures

Fuel factors for structures presented a particular concern because the current factors are on a unit consumption per $1,000 of work basis. Therefore, as fuel and other input prices vary, the measure can become unreliable, especially over time. The study team envisioned two methodological alternatives to address this problem. The first option was to include links and information regarding price indices within the software tool. These indices allow the user to update the fuel factors to address the effects of cost inflation. The second option was to tabulate fuel factors on a gallons per unit basis. The study team ultimately included both of these options.

2.5.2 Assessment of the Survey Approach

As part of the first phase of the study, the team conducted an initial survey of contractors to assess their ability and willingness to provide data on fuel usage estimates for bid items. In addition to questions concerning fuel factor administration and fuel intensity perceptions, the initial survey invited suggestions for improving the response rate for the more comprehensive survey in the second project phase.

Strengths of the Survey Approach

The survey approach relied on information gathered directly from the contractors who perform construction activities. The original fuel factors research was also conducted in this manner. Contractor survey results are easily understood among a non-technical audience.

Shortcomings of the Survey Approach

Similar to the engineering estimation approach, a contractor survey has the potential to be influenced by responder biases. Contractors may allow their own experiences with fuel factors and fuel costs, whether they are positive or negative, to influence their responses. The legitimacy of data obtained using this method is dependent on a satisfactory response rate as well as a representative sample. A full contractor survey is also an expensive undertaking.

Recommendations, Modifications, and Final Methodology

The study team estimated fuel usage directly from a survey of contractors. In the first project phase, the team conducted an initial survey of contractors to assess their ability and willingness to provide data on fuel usage estimates for bid items. Based on the findings and lessons learned from that task, the study team developed a survey of fuel usage. Oman Systems maintains a Contact Management System that collects information on all of the firms bidding highway projects. The study team utilized this database to develop a list of firms to survey.

A stated goal for this project was to exceed the 13 percent response rate achieved in the original contractor survey, the results of which were published in Technical Advisory T5080.3. The initial Task 6 contractor survey matched this response rate. However, this required substantial follow-up efforts such as phone calls. For the larger second phase survey, the study team made a concerted, multi-pronged effort to maximize the response rate. As suggested by several contractors in the initial survey, the study team targeted estimators and other personnel with knowledge of their firm's construction costs. Additionally, the study team attempted to design a survey that was as brief as possible while still being able to capture the needed data. The study team also contacted key industry associations to elicit their support.

2.5.3 Assessment of the Engineering Estimating Approach

For the initial engineering estimating analysis, an expert panel of four construction professionals rated the fuel consumption of 31 work categories and over 1,000 individual pay items. The data used for this effort came from Oman Systems' BidTabs database. In order to create a reasonable number of items for analysis, the research team created several parameters for exclusion, including discarding lump-sum and non-standard pay items, pay items that were bid less than 100 times, and pay items lacking sufficient data for the targeted 4.5-year time period. These efforts resulted in a data set comprising 1,176 unique pay items from states nationwide. The expert panel then created a 1 to 5 fuel use scale with a "5" ranking indicating heavy fuel use. Each of the 1,176 pay items and 31 work categories was then issued a fuel use ranking informed by this scale.

Strengths of the Engineering Estimating Approach

The engineering estimating approach employed a methodology that is transparent to the user. The methods of the ranking of fuel use are clearly described and easily understood. The process of developing estimates of fuel use, which was based on types of equipment, consumption rates and work rates, is also a method that laypeople and engineers will readily understand. Items can be added relatively quickly and inexpensively.

Shortcomings of the Engineering Estimating Approach

The relative ranking of fuel use can be a subjective exercise. As witnessed in the first phase, equally qualified estimators assigned different rankings for the same pay item. For example, out of the 31 summary work categories, the four members of the estimating team assigned identical rankings for only three categories (grading/excavation, bridge, and alternates/bonus/time). The engineering estimation of fuel use was also subject to this limitation. Updating the entire set of engineering estimates requires new estimates of equipment consumption rates and work rates, a medium cost activity that is also relatively time consuming.

Recommendations, Modifications, and Final Methodology

In consultation with the NCHRP project panel, it was agreed that the research team would estimate fuel usage using engineering cost estimation software. This would require the collection of fuel consumption factors for specific pieces of equipment, the assigning of crews (composed of labor, equipment, material), and crew production rates.

2.5.4 Assessment of the Statistical Approach

The initial statistical analysis of the BidTabs database examined the relationship between fuel prices and bid prices. Pay items whose prices correlate with fluctuating fuel prices would be likely to be fuel intensive and could be considered for inclusion in a price adjustment clause program. The BidTabs analysis used the same parameters for exclusion as the estimating analysis, as well as the additional caveat that price information must have been available for the periods of rapid fuel price fluctuation in 2008.

Strengths of the Statistical Approach

The BidTabs statistical analysis had several potential strengths. One strength was that the analysis uses an objective assessment of the correlation between fuel prices and bid prices based on historical data. The analysis did not rely on subjective judgment to select items. This method also had the advantage that the analysis could be replicated in future years to update results. Since this method was based on data that is collected on an ongoing basis, it would preclude the need for future surveys or data collection.

Shortcomings of the Statistical Approach

Statistical analysis is a complex tool that is often difficult to explain to the layperson. Statistical analysis may not always provide the expected result in every case. In some instances, analyses may be subject to problems such as multicollinearity, where several important variables are also correlated so that only one can be included in the analysis. The analyses could also be subject to confounding variables and could produce unexpected results. The initial statistical analysis did not clearly illustrate whether or not a statistical analysis could produce direct estimation of fuel use.

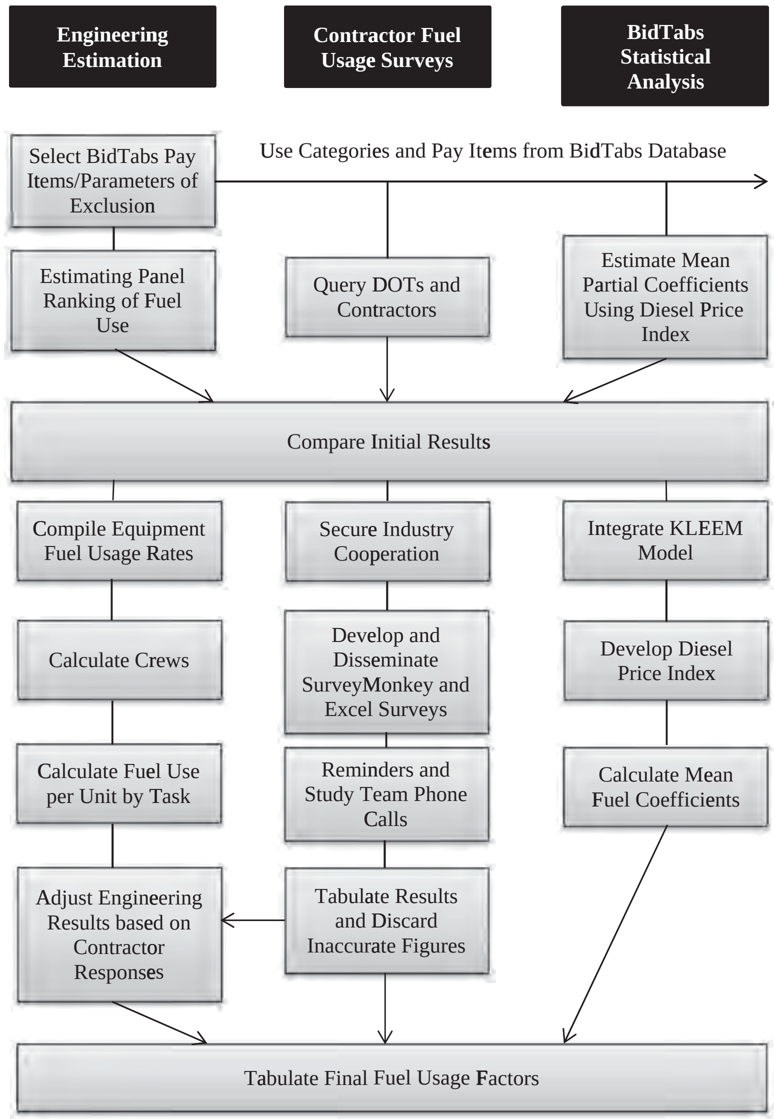
Recommendations, Modifications, and Final Methodology

In consultation with the study panel, the study team decided to include the statistical analysis in the data collection phase. This included a specification of the model, testing of different combinations and forms of the variables, exploration of lagged variables, evaluation of residuals and error terms, and exploration of different combinations of pay items both within and across states. The study team integrated the KLEMS model into the analysis. The final analysis was designed to produce correlation coefficients that would indicate fuel use.

2.5.5 Overview of the Final Research Approach

Exhibit 2-43 presents the final methodology utilized in the project from the initial scoping efforts to the development of the final fuel usage factors. This methodology is presented in flow chart form and indicates the sequential steps undertaken for each of the three methodologies,

Exhibit 2-43. Project methodology flow chart.



as well as areas where the methodologies intersected with, and complemented, each other. The survey approach provided much of the data used in formulating the new factors. The engineering approach confirmed the survey data and provided additional detail when the survey approach did not garner sufficient observations for particular work items. More particular details regarding the step-by-step process employed for each methodology may be found in Chapter 3, Findings and Applications, and Chapter 4, Conclusions, Recommendations, and Future Research.

CHAPTER 3

Findings and Applications

Chapter 3 presents the processes and results of the data collection phase. This phase involves the application of the three research methodologies: the engineering analysis, the contractor fuel usage survey, and the BidTabs statistical analysis. The study team designed each of these approaches to provide independent calculations of fuel use for highway construction activities. Each section of this chapter provides a sequential description of the research process undertaken and the results for each work item examined.

3.1 Contractor Fuel Usage Surveys

This report section details the project team's efforts to collect fuel use consumption information from the highway contracting community. This effort aided in the identification of heavy fuel use activities and allowed the project team to establish current levels of fuel use across a variety of construction activities and project conditions. The project team utilized several surveys, including an Excel spreadsheet tool and several industry-segment-specific SurveyMonkey surveys, to elicit contractor responses. In order to maximize contractor participation, the project team strived to ensure the cooperation of several industry organizations.

This section contains four subsections. The first subsection describes the survey effort methodology, including survey design and dissemination, as well as the industry collaboration process. The second subsection displays respondent biographical information. The third subsection presents the acquired survey data. The fourth subsection summarizes the chapter and offers conclusions.

3.1.1 Survey Methodology

This section describes the methodology employed by the study team to design and disseminate the contractor fuel usage survey. It describes industry cooperation, survey design, survey review and approval, initial survey dissemination, and efforts to improve the survey response rate.

Initial Industry Cooperation

This survey effort benefitted from the support of several industry organizations. Soliciting support from industry organizations was a tactic that was strongly recommended by both the project review panel and several contractors during the initial survey effort. The American Road & Transportation Builders Association (ARTBA), the Associated General Contractors of America (AGC), the National Asphalt Pavement Association (NAPA), and the American Concrete Pavement Association (ACPA) each agreed to cooperate with the project team and aid in survey review and dissemination. Exhibit 3-1 displays the contacts within each organization, their titles, contact information, and statements of support for the project.

Exhibit 3-1. Initial industry contacts and commitments.

Organization	Liaison Title	Statement of Support
AGC	Senior Director, Highway and Transportation Division	"AGC believes the Fuel Usage Factors Survey is a very worthwhile project that will provide useful information for the construction industry as well as state departments of transportation. AGC is willing to disseminate the survey to our contractors involved in highway, bridge, transit, and other transportation infrastructure construction. Once the results are received, AGC is equally committed to disseminating the results to our state chapters and contractor members."
ARTBA	Vice President of Policy and Senior Economist	Verbal commitment
NAPA	Vice President of Legislative and Regulatory Affairs	"NAPA will be happy to help in any way possible to help ensure the success of this project including assistance with reaching the industry during the survey process."
ACPA	Vice President of Highway and Federal Affairs	"We appreciate the opportunity to provide input to this important effort."

The project team also contacted two other organizations whose contact information was provided by a member of the NCHRP project panel. These organizations are the National Association of Minority Contractors (NAMC) and the Associated Minority Contractors of America (AMCA). The executive director of NAMC responded that the NAMC membership would likely not respond in large enough numbers to be statistically significant and declined to participate. The project team attempted to contact AMCA several times but did not receive a response.

Survey Design

The project team originally planned to conduct the contractor survey of fuel usage using SurveyMonkey. However, the survey design envisioned by the project team was found to be impracticable using this tool. The survey design necessitated sorting pay items by the contractor's primary state of operation as well as major areas of work, adding a level of complexity to the survey design. SurveyMonkey could only handle this complexity if respondents manually entered work item information, fuel consumption quantities, and units. The survey returns would then have to be manually compiled by the project team.

This realization led the project team to a new survey template. The survey, constructed in a user-friendly Excel format and entitled the Contractor Fuel Usage Survey (CFUS), contained the following features:

- An introductory page;
- A contact page;
- A page for background information (name of firm, state, areas of work, etc.);
- A fuel consumption information page; and
- A submission page.

The introductory page provided a brief description of the project's goals and background. It also provided a link to the official project description on the TRB website. The project team took special care to emphasize that individual firms will remain anonymous in all publicly available research products.

The contact page contained contact information for a member of the project team (subject matter questions) and the NCHRP Project Officer (study background, legitimacy, and other concerns).

The background information page was designed to collect information similar to the initial contractor survey. This page inquired about the respondent's name, position, firm name, state, size, and whether a firm works in urban, suburban, or rural areas, among other data points. The respondent's selections of work category(s) determined the work items available on the fuel consumption page.

The next page in the survey was the fuel consumption information page. Based on the work category(s) selected, the respondent was able to supply fuel consumption information for particular work items. Respondents were able to provide fuel consumption information on as many items as they wish. Units of measure were fixed, although the respondent had the option to fill in an alternative unit of measure. Exhibit 3-2 provides a screenshot of a portion of the fuel consumption information page of the survey. The darker areas were locked and could not be altered. The lighter areas allowed the respondents latitude in their responses. A "Notes" column was present to the right of the "Gallons of Fuel Use per Unit" column.

The final page was the submission page. This page thanked the respondents for their time and effort. It also provided instructions for submitting the completed survey. Respondents were then asked to save their completed survey and email it to an email address dedicated to this survey collection effort. The project team was able to download survey responses from this email and organize them into a more manageable Excel database.

Draft Survey Review and Approval

The project team submitted a draft of the Contractor of Fuel Usage Survey (CFUS) and an accompanying memorandum to the NCHRP project officer on May 27, 2011. The project officer set the deadline for comments as June 20, 2011. The panel provided two comments. In response to a comment regarding bridge demolition work items, the study team renamed the bridge work category "Bridge Construction and Demolition" and added two additional work items: complete structure demolition and deck removal. The other comment was an inquiry of a technical nature regarding how to properly use the survey tool, which was resolved shortly thereafter.

ARTBA reviewed the survey, provided an email sharing approval, and offered to distribute the final version to ARTBA members. An email sent to the project team dated June 20, 2011, read in part, ". . . I think that looks good and we are happy to help out. Just let us know about distribution when the time comes—I am happy to forward this to our contractor members."

Exhibit 3-2. Fuel use consumption screenshot.

	Work Item Description	Unit of Measure	Alternative Unit of Measure (if different)	Gallons of Fuel Use per Unit
Clearing	Clearing - heavy	Acres		
	Clearing - medium	Acres		
	Clearing - light	Acres		
	Structure demolition	Acres		
	Pipe removal	Each		
	Pavement Removal	Linear feet		

AGC likewise reviewed the survey, provided an email indicating their support, and offered to distribute the survey to AGC members. An email to the project team dated June 20, 2011, read in part, ". . . I think the survey is fine and will forward to our members when finalized."

The study team also worked with NAPA and several of their member contractors to improve the survey form. Specifically, NAPA input led the study team to split the asphalt work category into two separate production and hauling/placing work categories. The study team also utilized NAPA members to conduct a test of the survey.

As suggested by NAPA, the project team also contacted the American Concrete Pavement Association (ACPA). The ACPA signaled their support of the project effort and committed to distributing the survey to ACPA members.

Initial Survey Dissemination

The final survey form was distributed through the Oman Systems contact database and the above industry associations on July 11, 2011, with a deadline for submission of July 29, 2011. The study team subsequently extended the submission deadline to August 15, 2011, in an effort to increase the number of survey returns. Unfortunately, this effort resulted in only 16 survey returns.

In an effort to elicit a greater number of survey responses, the study team then acquired the ARTBA official membership list on August 23, 2011. This list contains over 2,600 members. The project team devoted significant staff resources to calling as many ARTBA members as practicable. Between September 12, 2011, and September 30, 2011, calls to more than half of the ARTBA membership resulted in eight additional survey returns. In total, the initial dissemination effort and subsequent phone drive effort yielded a total of only 24 survey returns.

Subsequent Efforts to Improve Response Rate

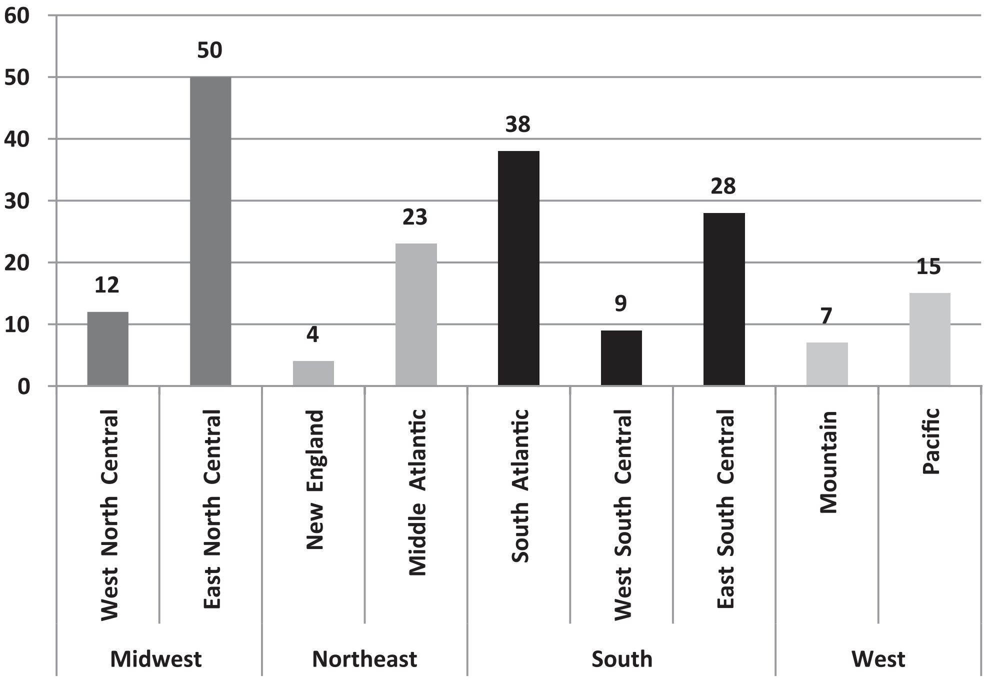
In a further effort to increase survey participation, project staff consulted with officials from NAPA. The project team and NAPA decided to test a simplified survey directed toward a single industry segment employing SurveyMonkey. Both the project team and NAPA felt that an industry-specific survey would remove the need for a more sophisticated design, such as in the Excel version of the survey, by significantly limiting the number of work categories and items. The project team submitted an asphalt-specific SurveyMonkey survey to NAPA on November 9, 2011. The NAPA survey was distributed on November 15, 2011, and garnered 89 responses within 3 days of release and 151 responses by January 9, 2012.

With the encouraging results from the NAPA survey in mind, the project team reached out to ARTBA, ACPA, and the National Ready Mixed Concrete Association (NRMCA) to inquire if they would release similar SurveyMonkey surveys. Although NRMCA did not believe that their members would respond in large numbers, they did provide the project team with internally conducted survey data regarding concrete hauling and delivery fuel use. This information contains responses from 84 concrete contractors. ARTBA and ACPA committed to disseminating SurveyMonkey surveys. Like the Excel survey, the ARTBA SurveyMonkey survey contained each work item. The work categories and items were listed sequentially. ARTBA and ACPA disseminated their versions of the survey on January 9, 2012, and January 19, 2012, respectively.

3.1.2 Respondent Company Information

A total of 186 contractors replied to the Excel and SurveyMonkey solicitations conducted for this effort, in addition to the 84 NRMCA respondents. In addition to inquiring about their task-specific fuel usage, these two survey forms also allowed respondents to provide information about their companies. This section presents relevant company metrics, including region, size, whether they are located in urban or rural locations, and methods of fuel use calculation.

Exhibit 3-3. Regional and subregional locations of contractors.



The survey of fuel usage was advertised to contractors across the country. The respondents hail from 37 states. When sorted by the U.S. Census Bureau's official regional designations, the group of respondents includes 75 contractors from the South, 62 from the Midwest, 27 from the Northeast, and 22 from the West. Exhibit 3-3 displays regional and subregional locations of responding contractors.

Participating firms vary widely in size from 50 or fewer employees to over 500 employees. Exhibit 3-4 displays the number of employees for the responding firms. More than two-thirds of respondents report company sizes between 50 and 500 employees.

Exhibit 3-4. Size of responding construction firms.

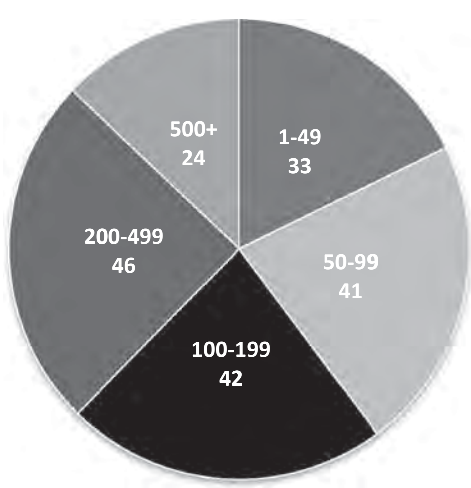
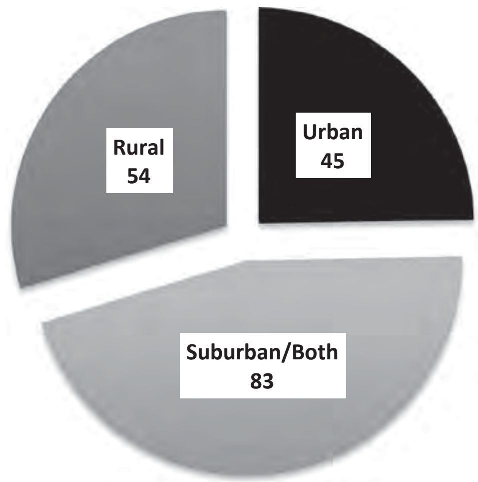


Exhibit 3-5. Typical project locations for responding contractors.



The responding contractors perform work in a variety of terrain types. Exhibit 3-5 displays how many contractors perform in urban or rural areas, or both. Nearly half of the respondents (83) perform work in suburban areas or a mix of urban and rural environments.

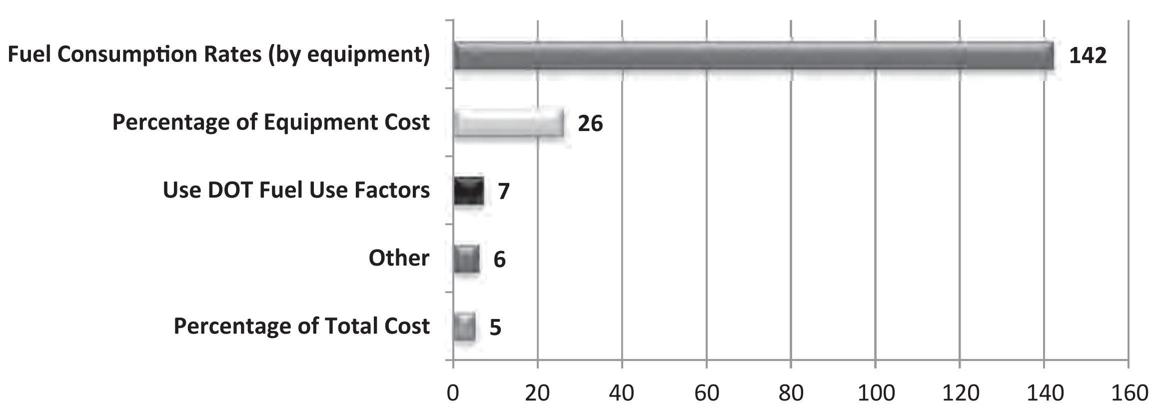
Respondents also provided information on how they calculate fuel costs during the estimation process. More than three-quarters of the respondents (142 out of 186) calculate costs using equipment-specific consumption rates. Exhibit 3-6 displays contractor methods for calculating fuel costs.

3.1.3 Fuel Consumption Data Collected

This section presents an overview of the data collected from all of the survey efforts and survey instruments. In total, respondents provided fuel consumption information for over 40 different activities. As stipulated in the outreach efforts to highway construction contractors and organizations, this report provides results as an average of the valid responses for each activity and does not provide information reported by individual respondents.

The fuel consumption estimates represent the simple mean (average) of all of the responses that met two criteria. The first criterion was that the respondent provided the estimate in either the

Exhibit 3-6. Contractor methods for calculating fuel costs.



default unit suggested in the survey or an alternative unit that the project team could convert to the base unit with a conversion factor. For example, for most activities, a subset of respondents reported results in terms of gallons consumed per hour. Conversion of these estimates to gallons per unit of work was not possible without assuming a production rate.

The second criterion was that each individual response included in the estimate had to be within a range that the engineering staff judged to be reasonable. In some instances, respondents provided estimates that varied from the majority of estimates by a factor of 10 or more. For example, one respondent provided fuel consumption per unit estimates for the six types of milling that ranged from 8.8 to 9.5 times greater than the mean estimate for all of the respondents. In each case, this respondent's estimate was at least 6.6 times higher than any other estimate. These out-of-range estimates were not included in the calculation of mean values.

Exhibit 3-7 provides the summary of the mean quantities of fuel reported per unit of activity. The first column of the exhibit describes the general category of work, such as clearing, grading, milling, and asphalt or concrete paving. The second column describes the specific item, such as grading items that vary according to on-road and off-road, short and long haul, and soil type and milling items that vary according to depth and haul length. The third column presents the mean estimate of gallons of fuel consumption, while the forth column lists unit of measurement, such as gallons per cubic yard. The final column provides the number of observations in the survey sample. In total, survey respondents provided over 500 individual fuel usage observations.

Comparisons of fuel usage across activities were difficult because the units are not comparable. For example, the estimate for clearing was 183.33 gallons per acre while the estimate for pipe removal was 1.75 gallons per linear foot. Since the two estimates were in different units (acres and linear feet), the gallons of fuel use were not directly comparable and, therefore, the exhibit did not rate one as more fuel intensive than the other.

However, some comparisons within categories were possible and, in general, the observable differences followed expected patterns. For example, grading in rocky conditions is generally more fuel intensive than grading sandy or dirt soils. Milling to greater depths and using longer hauls is more fuel intensive. Warm mix asphalt requires less fuel than hot mix. Therefore, one may conclude that the survey results were internally consistent as fuel intensities, where comparable, followed expected patterns.

3.1.4 Conclusion

This chapter presents the efforts of the research team to engage the contracting community and ascertain their fuel usage for highway and bridge construction activities. In total, the research team invited over 10,000 contractors to participate. Further efforts to maximize participation include collaborating with several contractor organizations, creating multiple versions of the survey form, and directly calling over 1,000 highway contractors. The contractors that responded to these efforts specialize in heavy construction activities and encompass a wide variety of locations, working conditions, and firm sizes.

In studying the results of the surveys it became clear to the team that certain types of information are easier to collect than other types. The response rates for general questions that can be answered with little or no additional effort were very high. However, the more detailed questions that required additional analysis resulted in a low response rate.

Based on the examination of the comments and discussions with selected respondents, the study team concluded that the reason for lower-than-expected response rates on these questions generally related to the type of data collected by the contractors. The survey questions were

Exhibit 3-7. Survey-based estimates of mean quantities of fuel per unit of activity.

Category	Item	Gallons of Fuel Consumption	Unit	Number of Observations
Clearing	Clearing (all types)	183.333	Acre	10
	Pipe Removal	1.750	L.F.	3
	Pavement Removal	2.675	S.Y.	3
Grading	Off-Road Short (Dirt)	0.382	C.Y.	8
	On-Road Short (Dirt)	0.306	C.Y.	7
	Off-Road Long (Dirt)	0.305	C.Y.	9
	On-Road Long (Dirt)	0.372	C.Y.	8
	Off-Road Short (Rock)	0.352	C.Y.	9
	On-Road Short (Rock)	0.411	C.Y.	7
	Off-Road Long (Rock)	0.440	C.Y.	8
	On-Road Long (Rock)	0.492	C.Y.	7
	Borrow (Rock)	0.690	C.Y.	5
	Strip Topsoil (Dirt)	0.442	C.Y.	7
	Respread Topsoil (Dirt)	0.418	C.Y.	7
	Roadway Finishing (Dirt)	0.192	S.Y.	9
Milling	0-1" (0-5 mile haul)	0.028	S.Y.	9
	0-1" (6-15 mile haul)	0.036	S.Y.	9
	0-1" (>15 mile haul)	0.046	S.Y.	9
	2-4" (0-5 mile haul)	0.052	S.Y.	12
	2-4" (6-15 mile haul)	0.074	S.Y.	9
	2-4" (>15 mile haul)	0.098	S.Y.	9
Storm Pipe	Small Pipe Crew	1.600	L.F.	5
	Medium Pipe Crew	2.332	L.F.	6
	Large Pipe Crew	3.308	L.F.	5
Asphalt	Hot Mix Structural (Place and Compact)	0.970	Ton	27
	Hot Mix Surface (Place and Compact)	0.989	Ton	25
	Hot Mix Leveling (Place and Compact)	1.026	Ton	25
	Warm Mix (Place and Compact)	0.772	Ton	20
	Hauling	0.375	Ton	16
	Prime and Tack	0.094	Ton	17
	Plant (Diesel)	1.984	Ton	14
	Plant (Natural Gas - BTU)	268806.308	BTU	15
	Plant (Support Equipment)	0.111	Ton	13
Concrete Paving	Concrete Paving	0.300	C.Y.	7
	Concrete Hauling	1.140	C.Y.	84
	Concrete Hauling	2.900	Vehicle Hour	63
Structural Concrete	Structural Concrete	6.530	C.Y.	10
Total Observations				**516**

designed to capture "fuel use per unit of work." A large percentage of contractors collect internal data based on equipment usage (gallons per hour), but they do not calculate or retain data based on units of work (per ton or per cubic yard). This made it difficult for respondents to supply meaningful data to the more general question of "fuel use per unit of work," since they look at each project (and tasks within each project) with the specific set of requirements for that project.

The number of observations was sufficient to constitute a valid sample for most work items. With the exception of several outlying responses that would have skewed the calculated averages, the fuel usage estimates provided by the contracting community were within a reasonable range of accuracy as determined by the research team's engineering experts. Results within categories demonstrated consistency as well. The survey results provided utility throughout the remainder of the project, especially as a means to complement and verify the engineering results.

3.2 Engineering Analysis of Fuel Usage

The objective of the engineering analysis was to estimate the fuel usage of construction activities using engineering cost estimating techniques. The results of this effort, in conjunction with the statistical analysis and CFUS, allowed the project team to formulate new and updated fuel usage factors.

Building on the results from the initial engineering analysis, which aimed to identify high fuel use activities, the project team extended the analysis to calculate the fuel use per unit for each work task. Using the initial phase calculations as well as estimated quantities of work for a typical project, the project team was able to estimate a fuel usage factor for each work task.

This report section is divided into six subsections. The first subsection describes the expert panel used to develop data elements throughout this effort. The second subsection describes the creation of the list of typical construction equipment and the tabulation of equipment-specific fuel consumption rates. The third subsection describes the creation of the list of construction tasks for which fuel use was estimated. The fourth subsection describes the process of assigning equipment and crew production rates for each work task. The fifth subsection describes the process of calculating per unit fuel usage rates and presents the results. The sixth and final subsection provides conclusions and next steps.

3.2.1 The Expert Panel

As in the initial engineering analysis, the study team utilized an expert panel of four construction engineers and estimators. Each panel member employed their industry expertise to compile a list of construction activities, assign equipment and crews to work tasks, and calculate production rates. Panel members A, B, and C each independently calculated fuel use per unit for each work task. Panel member D acted as a mediator during this effort and investigated discrepancies, resolved differences in calculations, and compiled the results.

3.2.2 Equipment Fuel Use

The first step in the data development process was the compilation of fuel use by equipment type. For this step, the study team first created a general list of construction equipment commonly used in highway construction. Key data sources for this effort include the 40th edition of the Caterpillar Performance Handbook, which estimates the performance of a wide variety of construction equipment, and historical contractor data. Fuel usage estimates for other equipment were developed using the expert panel. The fuel consumption rates are listed in "gallons per hour" and are for "average" working conditions. These values are derived from manufacturers' operating handbooks for the major pieces of equipment as well as estimator experience for the minor equipment.

The equipment list is based on typical construction practices. The list of equipment that is available to a contractor can have an impact on the crew makeup, production rates, and the ultimate cost of a work activity. The project team created a list of equipment that is generally used within the heavy construction industry and avoided specialty equipment where possible. Exhibit 3-8 displays the items of equipment, fuel types, and fuel consumption in gallons per

Exhibit 3-8. Construction equipment and fuel consumption rates.

Equipment Description	Fuel Type	Fuel Consumption (GPH)	Source
Dozer D-10	Diesel	23.0	A
Dozer D-10 STANDBY	Diesel	0.0	A
Dozer D-3	Diesel	2.2	A
Dozer D-5	Diesel	4.0	A
Dozer D-6	Diesel	5.0	A
Dozer D-6 RENTAL	Diesel	5.0	A
Dozer D-7	Diesel	9.0	A
Dozer D-8	Diesel	12.0	A
Dozer D-8 RENTAL	Diesel	12.0	A
Dozer D-9	Diesel	16.0	A
Dozer D-9 RENTAL	Diesel	16.0	A
Dozer D-9 Push Tractor	Diesel	16.0	A
Excavator Cat 315	Diesel	5.0	A
Excavator Cat 324	Diesel	7.0	A
Excavator Cat 336	Diesel	11.0	A
Excavator Cat 345	Diesel	15.0	A
Excavator Cat 345 SPARE	Diesel	0.0	A
Excavator R/T Cat 316	Diesel	5.0	A
Excavator W/ Hoeram	Diesel	11.0	A
Excavator/Front Shovel Cat 5130	Diesel	40.0	A
Generator Cat 150 kw	Diesel	6.0	A
Generator Cat 35 kw	Diesel	3.0	A
Haul Truck Articulated 25 Ton	Diesel	7.0	A
Haul Truck Articulated 30 Ton	Diesel	8.0	A
Haul Truck Articulated 40 Ton	Diesel	11.0	A
Haul Truck Rigid 100 Ton	Diesel	23.0	A
Haul Truck Rigid 50 Ton	Diesel	12.0	A
Haul Truck Rigid 70 Ton	Diesel	16.0	A
Loader R/T 938	Diesel	4.0	A
Loader R/T Cat 914	Diesel	3.0	A
Loader R/T Cat 980	Diesel	8.0	A
Loader R/T Cat 992C	Diesel	31.0	A
Loader R/T Cat 950	Diesel	4.0	A
Loader Skid/Steer	Diesel	3.0	A
Loader Track Cat 953	Diesel	7.0	A
Loader Track Cat 973	Diesel	13.0	A
Loader Track Cat 973 RENTAL	Diesel	13.0	A
Loader/Backhoe Cat 416	Diesel	3.0	A
Loader/Backhoe Cat 430	Diesel	5.0	A
Loader/Tool Carrier Cat IT38	Diesel	4.0	A
Motor Grader Cat 12	Diesel	6.0	A
Motor Grader Cat 14 w/GPS	Diesel	9.0	A
Motor Grader Cat 16	Diesel	11.0	A
Roller 815 Soil Compactor	Diesel	7.0	A
Roller Asphalt (Breakdown)	Diesel	4.0	A
Roller Asphalt (Finish)	Diesel	4.0	A
Roller Asphalt (Rubber Tire)	Diesel	4.0	A
Roller Cat 825 Soil Compactor	Diesel	10.5	A
Scraper (Twin) 627	Diesel	24.0	A
Scraper (Twin) 637	Diesel	30.0	A
Scraper (Twin) 657	Diesel	41.0	A
Scraper 613 Water Wagon	Diesel	8.5	A
Scraper 621	Diesel	14.0	A
Scraper 621 RENTAL	Diesel	14.0	A
Scraper 631	Diesel	18.0	A
Scraper 631 RENTAL	Diesel	18.0	A
Generator Small	Gas	0.5	B
9 Passenger Van	Gas	2.0	B
Air Curtain Burner	Diesel	3.0	B
Asphalt Plant	Diesel	15.0	B
Base Stone Shoulder Spreader	Diesel	5.0	B
Base Stone Spreader Box	No Fuel	0.0	B
BlawKnox PF3200 Asphalt Paver	Diesel	7.0	B

Exhibit 3-8. (Continued).

Bridge Inspection Truck	Diesel	1.0	B
Broom	Diesel	3.0	B
Car Sedan	Gas	2.0	B
Compressor 800	Diesel	6.0	B
Compressor 85-185	Diesel	1.5	B
Concrete Bridge Deck Finisher	Diesel	2.0	B
Concrete Saw	Gas	1.0	B
Concrete Slipform Paver	Diesel	7.0	B
Crane 100 Ton Crawler	Diesel	10.0	B
Crane 100 Ton Crawler RENTAL	Diesel	5.0	B
Crane 12 Ton Truck	Diesel	3.0	B
Crane 15-18 Ton Hydraulic	Diesel	3.0	B
Crane 25 Ton Crawler	Diesel	3.5	B
Crane 30 Ton Hydraulic	Diesel	6.0	B
Crane 40 Ton Hydraulic	Diesel	6.5	B
Crane 45 Ton Motor	Diesel	5.0	B
Crane 50 Ton Crawler	Diesel	5.0	B
Crane 50 Ton Hydraulic	Diesel	7.0	B
Crane 75 Ton Crawler	Diesel	8.0	B
Forklift	Diesel	1.1	B
Gradall 880	Diesel	5.0	B
JLG 600S Manlift	Diesel	1.0	B
Light Plant 6kw	Gas	1.0	B
Pile Hammer (Diesel)	Diesel	1.0	B
Pile Hammer, Sheet (Hydraulic) RENTAL	No Fuel	0.0	B
Power Curber 5700B	Diesel	4.0	B
Pump 10"	Diesel	2.0	B
Pump 2"	Gas	0.2	B
Pump 4"	Gas	0.5	B
Pump 6"	Diesel	1.5	B
RoadTec Shuttle Buggy	Diesel	10.0	B
Roller IR SP54 Vib	Diesel	6.5	B
Roller IR SP60 Vib	Diesel	6.0	B
Roller Ram Max Trench	Diesel	1.5	B
Roller Tampo 12 Ton Vib	Diesel	4.0	B
Roller Tampo 25-35 Ton	Diesel	3.0	B
Roller Vibrating Plate Compact	Gas	0.2	B
Screening/Crushing Plant (Portable)	Diesel	10.0	B
SUV 4X4	Gas	2.0	B
Track Drill ECM370	Diesel	4.5	B
Track Drill ECM590 (2006)	Diesel	5.3	B
Track Drill ECM729	Diesel	6.5	B
Tractor with Bush Hog	Diesel	2.0	B
Traffic Control Utility Trailer	No Fuel	0.0	B
Trencher Vermeer T-555	Diesel	10.5	B
Truck 1/2 Ton	Gas	2.0	B
Truck 1 Ton	TxDiesel*	3.0	B
Truck 1 Ton Powder	TxDiesel	3.0	B
Truck 2 Ton Flatbed	TxDiesel	3.5	B
Truck 3/4 Ton	TxDiesel	2.5	B
Truck 4x4 Utility Vehicle	Gas	2.0	B
Truck Distributor	TxDiesel	2.0	B
Truck Dump 14 CY	TxDiesel	5.5	B
Truck Fuel	TxDiesel	4.0	B
Truck Service/Mechanic	TxDiesel	4.0	B
Truck Water	TxDiesel	5.0	B
Truck Tractor & Lowboy Trailer	TxDiesel	6.0	B
Volvo MT2000 Milling Machine	Diesel	10.0	B
Welder 200 Amp	Diesel	1.5	B

A: CAT Performance Handbook (Ed. 40)
B: Other (Historical Contractor Data)
*TxDiesel is taxed diesel fuel. Tax is applied to construction equipment that travels on roads, primarily dump trucks.

hour, as well as the data source for each item's fuel consumption rates. In total, fuel consumption rates are provided for 122 different pieces of equipment. The top fuel consumer is a twin scraper, which consumes 41 gallons of diesel fuel per hour.

3.2.3 Work Tasks

The four members of the expert panel worked collaboratively to compile a list of construction work tasks. This list includes work tasks that would be common across geographic areas as well as topographic conditions. Unlike the analysis of specific pay item data in previous efforts, this list contains specific work tasks not always unique to a pay item; there may be multiple work tasks within a single pay item on a project. For example, the excavation pay item on a project may include short- and long-haul dirt as well as rock excavation and stripping topsoil. In other cases, work tasks may relate to many different pay items. For example, there may be hundreds of pay items related to storm water structures, but only one work task for these pay items. The difference between each storm water structure is mostly due to the design of the structure and the materials used in its construction. Because this effort focused on the equipment needed to accomplish the work task, the different material or structure design would not have any effect on fuel consumption. Exhibit 3-9 displays the 66 work tasks compiled by the project team and the units used to measure the work tasks. Note that several additional work tasks were compiled following an analysis of the statistical analysis and contractor survey. These additional items are introduced and explained in Chapter 4. Nine distinct units are used to measure quantities.

3.2.4 Equipment and Production Rates

The panel of estimators then used their construction experience and expertise to create a list of equipment needed to accomplish each work task. Because there are varying possible combinations of equipment used and production rates, each member of the expert panel assembled a crew that they believed would be the most efficient to accomplish the task based on the above equipment list.

Assigning production rates to each task can be a subjective exercise when dealing with non-project-specific, generic activities. Each panel member utilized their own experience to establish the average production rates based on the equipment selected for the task. As with the development of fuel consumption factors, the goal in this effort is to establish production rates for average conditions that apply across many different project scenarios.

The selected production rate used for each task is an average of the estimators' evaluations. In some cases there was some relatively large variance between the estimators' equipment choices and selected production rates. Further consultation and discussion between the estimating panel and the moderator (Reviewer D) resulted in modifications to equipment selections and production rates. Factors that affected the different production rates and were considered in establishing the agreed production rates were equipment type, average topography, hauling distances, soil conditions, and industry standards.

Listed below are the major categories of work items. A chapter subsection is dedicated to each of these categories and includes a discussion of the project conditions and equipment, as well as a table listing the work task, required equipment, unit of measure, and production rate. The major categories of work items are

- Clearing and removal,
- Grading,
- Base stone,

Exhibit 3-9. Highway construction work tasks.

Task Description	Unit
Base Stone	Ton
Clearing - Light	Acre
Clearing - Medium	Acre
Clearing - Heavy	Acre
Concrete Median Barrier	L.F. (linear foot)
Concrete Pavement (</= 6" Thick)	S.Y. (square yard)
Concrete Pavement (> 6" Thick)	S.Y.
Curb and Gutter	L.F.
Drainage Structures	C.Y. (cubic yard)
Fence Gates	Each
Fencing (Over 6' Height)	L.F.
Fencing (Up to 6' Height)	L.F.
Grading - Dirt - Off Road - Long Haul	C.Y.
Grading - Dirt - Off Road - Short Haul	C.Y.
Grading - Dirt - On Road - Long Haul	C.Y.
Grading - Dirt - On Road - Short Haul	C.Y.
Grading - Rock - Off Road - Long Haul	C.Y.
Grading - Rock - Off Road - Short Haul	C.Y.
Grading - Rock - On Road - Long Haul	C.Y.
Grading - Rock - On Road - Short Haul	C.Y.
Grassing (Hydro Seeding)	Acre
Guardrail Posts	Each
Hot Mix Asphalt - Leveling Course (0-5 Mile Haul)	Ton
Hot Mix Asphalt - Leveling Course (5-15 Mile Haul)	Ton
Hot Mix Asphalt - Leveling Course (Over 15 Mile Haul)	Ton
Hot Mix Asphalt - Structural Course (0-5 Mile Haul)	Ton
Hot Mix Asphalt - Structural Course (5-15 Mile Haul)	Ton
Hot Mix Asphalt - Structural Course (Over 15 Mile Haul)	Ton
Hot Mix Asphalt - Surface Course (0-5 Mile Haul)	Ton
Hot Mix Asphalt - Surface Course (5-15 Mile Haul)	Ton
Hot Mix Asphalt - Surface Course (Over 15 Mile Haul)	Ton
Intersection Signalization (2 Lane)	Each
Intersection Signalization (4 Lane)	Each
Large Pipe Crew (> 36" Pipe)	L.F.
Medium Pipe Crew (> 18" to 36" Pipe)	L.F.
Milling (<2") (0-5 Mile Haul)	S.Y.
Milling (<2") (5-15 Mile Haul)	S.Y.
Milling (<2") (Over 15 Mile Haul)	S.Y.
Milling (2-4") (0-5 Mile Haul)	S.Y.
Milling (2-4") (5-15 Mile Haul)	S.Y.
Milling (2-4") (Over 15 Mile Haul)	S.Y.
Pavement Removal – Asphalt	C.Y.
Pavement Removal – Concrete	C.Y.
Pipe Removal - All Sizes	L.F.
Reinforcing Steel	L.B. (pound)
Retaining Wall	S.F.
Roadbed Finishing	S.Y.
Rock Drilling and Blasting (Only) (No Haul)	C.Y.
Seedbed Preparation	Acre
Sewer Line (Over 4' Depth)	L.F.
Sewer Line (Up to 4' Depth)	L.F.
Sidewalk	L.F.
Skip Pavement Marking	L.M. (linear meter)
Small Pipe Crew (</= 18" Pipe)	L.F.
Solid Pavement Marking	L.M.
Solid Sodding	S.Y.
Steel Beams	L.F.
Steel Guardrail	L.F.
Strip Topsoil	C.Y.
Structure Demolition	Each
Substructure Concrete	C.Y.
Super Structure Concrete	C.Y.
Water Line (Over 4' Depth)	L.F.
Water Line (Up to 4' Depth)	L.F.
Water/Sewer Manholes	Each
Wire/Cable Guardrail	L.F.

- Asphalt,
- Milling,
- Structures,
- Miscellaneous concrete/concrete pavement/retaining wall,
- Drainage pipe and structures/water/sewer, and
- Specialty items (fencing/guardrail/landscaping/pavement marking/signalization).

Clearing and Removal

Clearing and removal activities can vary widely from project to project. The general assumptions to develop the equipment and production rates for these tasks relate to the density and type of materials to be removed from the site. Exhibit 3-10 presents the selected work tasks, units of measure, production rates, and production rate units of measure for the clearing and removal work tasks.

Clearing (Light) would be in areas that have only a minimal growth of trees and brush. This would generally be related to projects that are widening or where existing roads are being reconstructed. In addition, light clearing areas would contain little or no general clearing items such as fence rows or other debris.

Clearing (Medium) would be in areas where the trees and brush are only moderately dense. An example of these areas would be in residential areas where trees and open areas are mixed.

Exhibit 3-10. Clearing and removal summary table.

Work Task	Unit of Measure	Production Rate	Production Rate Unit of Measure
Clearing – Light	**Acre**	**0.225**	**Acre/Hour**
Truck 1/2 Ton (1)			
Dozer D-5 (1)			
Excavator Cat 336 (1)			
Tub Grinder (1)			
Clearing - Medium	**Acre**	**0.175**	**Acre/Hour**
Truck 1/2 Ton (1)			
Dozer D-6 (1)			
Excavator Cat 336 (1)			
Tub Grinder (1)			
Clearing - Heavy	**Acre**	**0.15**	**Acre/Hour**
Truck 1/2 Ton (1)			
Dozer D-5 (1)			
Dozer D-8 (1)			
Excavator Cat 336 (1)			
Tub Grinder (1)			
Structure Demolition	**Each**	**1.00**	**Each/Hour**
Truck 1/2 Ton (1)			
Truck Dump 14 CY (3)			
Loader R/T Cat 980 (1)			
Excavator Cat 336 (1)			
Pipe Removal - All Sizes	**L.F.**	**24.00**	**L.F./Hour**
Truck 1/2 Ton (1)			
Truck Dump 14 CY (1)			
Dozer D-3 (1)			
Excavator Cat 336 (1)			
Pavement Removal - Asphalt	**C.Y.**	**50.00**	**C.Y./Hour**
Truck 1/2 Ton (1)			
Truck Dump 14 CY (4)			
Volvo Milling Machine (1)			
Broom (1)			
Pavement Removal - Concrete	**C.Y.**	**66.00**	**C.Y./Hour**
Truck 1/2 Ton (1)			
Truck Dump 14 CY (3)			
Loader R/T Cat 950 (1)			
Excavator W/ Hoeram (1)			

Clearing (Heavy) would be in areas that are densely populated with trees and brush and in more virgin area projects where there are no current roads.

Removal Items. The largest cost related to most removal items relates to the distance required to haul the debris. Removal items are not generally "production" type items and cycle times are not calculated in the same way grading items are calculated. The assumption is that the crew will include sufficient trucks to cycle within a 10-mile radius of the project site. Note also that the asphalt pavement removal item is separate from the major work category milling that is described later in this section.

Structure Demolition includes the demolition and removal of buildings, homes, or small-to-medium-sized bridges. The range of possible time for removal and hauling of structures is much wider than for most of the other items in the study.

Grading and Excavation

The largest on-site consumers of fuel on highway projects are the grading items. These items are also the most variable from project to project and even within a project. The equipment utilized to perform the grading activities can also vary from contractor to contractor depending on the techniques employed by the contractor and the equipment that is available. Exhibit 3-11 presents the selected work tasks, units of measure, production rates, and production rate units of measure for the grading work tasks.

The grading activities have been separated into tasks that would require different equipment and production rates. Within a single project, one or more of these tasks may be used in the development of the excavation pay item.

Based on each estimator's experience and background, they each developed different equipment lists and production rates to accomplish each task. The end result, however, was that the fuel consumption rates for each activity were very consistent for each activity.

Exhibit 3-11. Grading and excavation summary table.

Work Task	Unit of Measure	Production Rate	Production Rate Unit of Measure
Grading - Dirt - Off Road - Short Haul	**C.Y.**	**215.32**	**C.Y./Hour**
Truck 1/2 Ton (1)			
Truck Water (0.5)			
Dozer D-7 (1)			
Haul Truck Articulated 25 Ton (2)			
Excavator Cat 345 (1)			
Motor Grader Cat 12 (0.5)			
Roller 815 Soil Compactor (1)			
Grading - Dirt - On Road - Short Haul	**C.Y.**	**233.38**	**C.Y./Hour**
Truck 1/2 Ton (1)			
Truck Dump 14 CY (6)			
Truck Water (0.5)			
Dozer D-8 (1)			
Excavator Cat 345 (1)			
Motor Grader Cat 12 (0.5)			
Roller 815 Soil Compactor (1)			
Grading - Dirt - Off Road - Long Haul	**C.Y.**	**285.60**	**C.Y./Hour**
Truck 1/2 Ton (1)			
Truck Water (1)			
Dozer D-8 (1)			
Haul Truck Rigid 50 Ton (3)			
Excavator Cat 345 (1)			
Motor Grader Cat 16 (1)			
Roller Cat 825 Soil Compactor (1)			

(continued on next page)

Exhibit 3-11. (Continued).

Work Task	Unit of Measure	Production Rate	Production Rate Unit of Measure
Grading - Dirt - On Road - Long Haul	**C.Y.**	**233.38**	**C.Y./Hour**
Truck 1/2 Ton (1)			
Truck Dump 14 CY (18)			
Truck Water (0.5)			
Dozer D-8 (2)			
Excavator Cat 345 (1)			
Motor Grader Cat 16 (1)			
Roller 815 Soil Compactor (1)			
Grading -Rock - Off Road - Short Haul	**C.Y.**	**215.32**	**C.Y./Hour**
Truck 1/2 Ton (1)			
Truck 1 Ton Powder (1)			
Truck Water (0.5)			
Dozer D-7 (1)			
Haul Truck Articulated 25 Ton (3)			
Loader R/T Cat 980 (1)			
Motor Grader Cat 12 (1)			
Track Drill ECM590 (2006) (1)			
Grading - Rock - On Road - Short Haul	**C.Y.**	**140.00**	**C.Y./Hour**
Truck 1/2 Ton (1)			
Truck 1 Ton Powder (1)			
Truck Dump 14 CY (4)			
Truck Water (0.5)			
Dozer D-7 (1)			
Loader R/T Cat 980 (1)			
Motor Grader Cat 12 (1)			
Track Drill ECM590 (2006) (1)			
Grading - Rock - Off Road - Long Haul	**C.Y.**	**240.00**	**C.Y./Hour**
Truck 1/2 Ton (1)			
Truck 1 Ton Powder (1)			
Truck Water (0.5)			
Dozer D-7 (1)			
Haul Truck Rigid 70 Ton (3)			
Loader R/T Cat 980 (1)			
Motor Grader Cat 12 (1)			
Track Drill ECM590 (2006) (1)			
Grading - Rock - On Road - Long Haul	**C.Y.**	**140.00**	**C.Y./Hour**
Truck 1/2 Ton (1)			
Truck 1 Ton Powder (1)			
Truck Dump 14 CY (11)			
Truck Water (0.5)			
Dozer D-7 (1)			
Loader R/T Cat 980 (1)			
Motor Grader Cat 12 (1)			
Track Drill ECM590 (2006) (1)			
Rock Drilling & Blasting (Only) (No Haul)	**C.Y.**	**250.00**	**C.Y./Hour**
Truck 1/2 Ton (1)			
Truck 1 Ton Powder (1)			
Loader/Backhoe Cat 416 (1)			
Track Drill ECM590 (2006) (1)			
Strip Topsoil	**C.Y.**	**120.00**	**C.Y./Hour**
Truck 1/2 Ton (1)			
Dozer D-5 (1)			
Scraper 621 (1)			
Roadbed Finishing	**S.Y.**	**400.00**	**S.Y./Hour**
Truck 1/2 Ton (1)			
Dozer D-5 (1)			
Scraper 621 (1)			
Motor Grader Cat 14 w/GPS (1)			

Base Stone

Unlike clearing and grading items, the base stone category will have a more standard crew. The largest variable in the base stone task is the haul distance from the quarry to the project site, which can vary widely from project to project and state to state. In this study we have assumed a moderate haul distance of 10 to 15 miles. The equipment used for placing and compacting the stone is much more consistent from project to project. Exhibit 3-12 presents the selected work task, units of measure, production rate, and production rate unit of measure for the base stone work task.

Asphalt

The equipment list for the asphalt category is relatively standard from contractor to contractor. The specific types of pavers, rollers, and other support equipment vary from contractor to contractor, but the overall fuel consumption would not vary significantly. The two main variables in asphalt activities relate to the project conditions and the haul distance from the plant to the project site. Exhibit 3-13 presents the selected work tasks, units of measure, production rates, and production rate units of measure for the asphalt work tasks.

The primary project conditions that can affect production rates for lay down operations are traffic conditions, pavement depth, pavement width, and lengths of runs. In this exercise, the project team assumed "general" conditions for each of these factors. Projects with long uninterrupted runs will exceed the listed production rates and projects with high traffic interference and many intersections will fall short of the listed production rates.

The most variable cost of asphalt operations is the haul distance from the plant to the project. In order to minimize this effect on the fuel use, the project team broke down each of the three main asphalt activities (structural, surface, and leveling courses) into three haul distance ranges. Each of the three haul distances (0-5 miles, 5-15 miles, and over 15 miles) increases the number of trucks required to service the lay down crew and increases the amount of fuel consumed.

Leveling course asphalt has the lowest production rate of the three types of asphalt operations. This task typically involves smaller quantities and larger areas, resulting in slower lay down operations. Structural course asphalt has the highest production rate and is typically completed with larger quantities and thicker courses than the other mixes. Surface course asphalt requires more attention to the finished surface and is typically done with thinner courses (1″–2″) and consequently is slower to place than structural courses.

Milling

The milling category will have the most standardized crew among the work categories examined. Although there are different sizes of milling machines and the production rates can vary based on the material being milled, all the equipment lists and production rates were similar across all estimators. The largest variable in calculating the production rate for a milling item is the haul

Exhibit 3-12. Base stone summary table.

Work Task	Unit of Measure	Production Rate	Production Rate Unit of Measure
Base Stone	**Ton**	**217.00**	**Ton/Hour**
Truck 1/2 Ton (1)			
Truck Dump 14 CY (10)			
Truck Water (1)			
Dozer D-5 w/Spreader Box (1)			
Motor Grader Cat 14 w/GPS (1)			
Roller Tampo 25-35 Ton (1)			
Screening/Crushing Plant (Portable) (1)			

Exhibit 3-13. Asphalt summary table.

Work Task	Unit of Measure	Production Rate	Production Rate Unit of Measure
Hot Mix Asphalt - Structural Course (0-5 mile haul)	**Ton**	**200.06**	**Ton/Hour**
Truck 1/2 Ton (1)			
Truck Distributor (1)			
Truck Dump 14 CY (6)			
Truck Water (1)			
Roller Asphalt (Breakdown) (1)			
Roller Asphalt (Finish) (1)			
Roller Asphalt (Rubber Tire) (1)			
BlawKnox PF3200 Asphalt Paver (1)			
RoadTec Shuttle Buggy (1)			
Asphalt Plant (1)			
Hot Mix Asphalt - Surface Course (0-5 mile haul)	**Ton**	**150.00**	**Ton/Hour**
Truck 1/2 Ton (1)			
Truck Distributor (1)			
Truck Dump 14 CY (6)			
Truck Water (1)			
Roller Asphalt (Breakdown) (1)			
Roller Asphalt (Finish) (1)			
Roller Asphalt (Rubber Tire) (1)			
BlawKnox PF3200 Asphalt Paver (1)			
RoadTec Shuttle Buggy (1)			
Asphalt Plant (1)			
Hot Mix Asphalt - Leveling Course (0-5 mile haul)	**Ton**	**130.00**	**Ton/Hour**
Truck 1/2 Ton (1)			
Truck Distributor (1)			
Truck Dump 14 CY (6)			
Truck Water (1)			
Roller Asphalt (Breakdown) (1)			
Roller Asphalt (Finish) (1)			
Roller Asphalt (Rubber Tire) (1)			
BlawKnox PF3200 Asphalt Paver (1)			
RoadTec Shuttle Buggy (1)			
Asphalt Plant (1)			
Hot Mix Asphalt - Structural Course (5-15 mile haul)	**Ton**	**200.00**	**Ton/Hour**
Truck 1/2 Ton (1)			
Truck Distributor (1)			
Truck Dump 14 CY (11)			
Truck Water (1)			
Roller Asphalt (Breakdown) (1)			
Roller Asphalt (Finish) (1)			
Roller Asphalt (Rubber Tire) (1)			
BlawKnox PF3200 Asphalt Paver (1)			
RoadTec Shuttle Buggy (1)			
Asphalt Plant (1)			
Hot Mix Asphalt - Surface Course (5-15 mile haul)	**Ton**	**150.00**	**Ton/Hour**
Truck 1/2 Ton (1)			
Truck Distributor (1)			
Truck Dump 14 CY (8)			
Truck Water (1)			
Roller Asphalt (Breakdown) (1)			
Roller Asphalt (Finish) (1)			
Roller Asphalt (Rubber Tire) (1)			
BlawKnox PF3200 Asphalt Paver (1)			
RoadTec Shuttle Buggy (1)			
Asphalt Plant (1)			
Hot Mix Asphalt - Leveling Course (5-15 mile haul)	**Ton**	**130.00**	**Ton/Hour**
Truck 1/2 Ton (1)			
Truck Distributor (1)			
Truck Dump 14 CY (8)			
Truck Water (1)			
Roller Asphalt (Breakdown) (1)			
Roller Asphalt (Finish) (1)			
Roller Asphalt (Rubber Tire) (1)			
BlawKnox PF3200 Asphalt Paver (1)			
RoadTec Shuttle Buggy (1)			
Asphalt Plant (1)			

Exhibit 3-13. (Continued).

Work Task	Unit of Measure	Production Rate	Production Rate Unit of Measure
Hot Mix Asphalt - Structural Course (Over 15 mile haul)	**Ton**	**200.00**	**Ton/Hour**
Truck 1/2 Ton (1)			
Truck Distributor (1)			
Truck Dump 14 CY (12)			
Truck Water (1)			
Roller Asphalt (Breakdown) (1)			
Roller Asphalt (Finish) (1)			
Roller Asphalt (Rubber Tire) (1)			
BlawKnox PF3200 Asphalt Paver (1)			
RoadTec Shuttle Buggy (1)			
Asphalt Plant (1)			
Hot Mix Asphalt - Surface Course (Over 15 mile haul)	**Ton**	**150.00**	**Ton/Hour**
Truck 1/2 Ton (1)			
Truck Distributor (1)			
Truck Dump 14 CY (12)			
Truck Water (1)			
Roller Asphalt (Breakdown) (1)			
Roller Asphalt (Finish) (1)			
Roller Asphalt (Rubber Tire) (1)			
BlawKnox PF3200 Asphalt Paver (1)			
RoadTec Shuttle Buggy (1)			
Asphalt Plant (1)			
Hot Mix Asphalt - Leveling Course (Over 15 mile haul)	**Ton**	**130.00**	**Ton/Hour**
Truck 1/2 Ton (1)			
Truck Distributor (1)			
Truck Dump 14 CY (7)			
Truck Water (1)			
Roller Asphalt (Breakdown) (1)			
Roller Asphalt (Finish) (1)			
Roller Asphalt (Rubber Tire) (1)			
BlawKnox PF3200 Asphalt Paver (1)			
RoadTec Shuttle Buggy (1)			
Asphalt Plant (1)			

distance from the project site to the disposal site. As mentioned previously, these distances can vary dramatically from project to project and state to state. In this study the researchers assumed a moderate haul distance of 10 to 15 miles. The equipment used for milling and hauling is consistent from project to project. Other factors that affect the production rates for milling activities relate to specific project conditions related to length of runs, number of turnouts, width of pavement, and traffic conditions. This exercise assumed an average of all these factors. Exhibit 3-14 presents the selected work tasks, units of measure, production rates, and production rate units of measure for the milling work tasks.

Structures

Activities related to structures vary widely from project to project and state to state. The project team identified four main activities that are common to many structures. The estimating panel then identified the equipment needed to perform each activity. The equipment lists were fairly consistent among the estimators. The largest difference in equipment is the size of the crane that each estimator used in the calculation. There is also a large variance in the cranes that would be used by different contractors.

The largest variance in the estimates is the production rates for each item. This is consistent with the idea that each structure on each project would also be unique to that project. There are many factors that can have an impact on the productivity for each of these work items. These factors include location, size, design, height, width, span, and type. The production rates used are also average productivity across the duration of the task. The concrete structure items are based

Exhibit 3-14. Milling summary table.

Work Task	Unit of Measure	Production Rate	Production Rate Unit of Measure
Milling (<2") (0 - 5 Mile Haul)	**S.Y.**	**6,250.00**	**S.Y./Hour**
Truck 1/2 Ton (1)			
Truck Dump 14 CY (3)			
Truck Water (1)			
Dozer D-5 (1)			
Volvo MT2000 Milling Machine (1)			
Broom (1)			
Milling (<2") (5 - 15 Mile Haul)	**S.Y.**	**6,250.00**	**S.Y./Hour**
Truck 1/2 Ton (1)			
Truck Dump 14 CY (4)			
Truck Water (1)			
Dozer D-5 (1)			
Volvo MT2000 Milling Machine (1)			
Broom (1)			
Milling (<2") (Over 15 Mile Haul)	**S.Y.**	**6,250.00**	**S.Y./Hour**
Truck 1/2 Ton (1)			
Truck Dump 14 CY (7)			
Truck Water (1)			
Dozer D-5 (1)			
Volvo MT2000 Milling Machine (1)			
Broom (1)			
Milling (2-4") (0 - 5 Mile Haul)	**S.Y.**	**6,250.00**	**S.Y./Hour**
Truck 1/2 Ton (1)			
Truck Dump 14 CY (3)			
Truck Water (1)			
Dozer D-5 (1)			
Volvo MT2000 Milling Machine (1)			
Broom (1)			
Milling (2-4") (5 - 15 Mile Haul)	**S.Y.**	**6,250.00**	**S.Y./Hour**
Truck 1/2 Ton (1)			
Truck Dump 14 CY (11)			
Truck Water (1)			
Dozer D-5 (1)			
Volvo MT2000 Milling Machine (1)			
Broom (1)			
Milling (2-4”)(Over 15 Mile Haul)	**S.Y.**	**6,250.00**	**S.Y./Hour**
Truck 1/2 Ton (1)			
Truck Dump 14 CY (20)			
Truck Water (1)			
Dozer D-5 (1)			
Volvo MT2000 Milling Machine (1)			
Broom (1)			

on the cubic yards of concrete poured. Although the actual pouring of the concrete takes place relatively quickly, the production rate accounts for the preparation, forming, pouring, wrecking, and finishing of the concrete. Exhibit 3-15 presents the work tasks, units of measure, production rates, and production rate units of measure for the structures' work tasks.

Miscellaneous Concrete/Concrete Pavement/Retaining Wall

The items that make up this work category are relatively standard and the estimators were in general agreement on the necessary equipment and production rates for this section. Although concrete curb specifications can vary from state to state, the equipment required and production rates are relatively consistent. Another factor that can have an impact on the equipment used, as well as the production rate, is the ability to use a machine to slip-form the item. Some projects can have unique circumstances that require hand forming and pouring of the concrete instead of using a paver. This exercise assumed the use of pavers to perform the majority of the work. Exhibit 3-16 presents the selected work tasks, units of measure, production rates, and production rate units of measure for the miscellaneous concrete, concrete paving, and retaining wall work tasks.

Exhibit 3-15. Structures summary table.

Work Task	Unit of Measure	Production Rate	Production Rate Unit of Measure
Substructure Concrete	**C.Y.**	**10.00**	**C.Y./Hour**
Truck 1/2 Ton (1)			
Ready-Mix Truck (6)			
Loader/Backhoe Cat 430 (1)			
Excavator R/T Cat 316 (1)			
Crane 100 Ton Crawler (1)			
Pump 4 (1)"			
Generator Small (1)			
Superstructure Concrete	**C.Y.**	**10.00**	**C.Y./Hour**
Truck 1/2 Ton (1)			
Ready-Mix Truck (5)			
Loader/Backhoe Cat 416 (1)			
Crane 100 Ton Crawler (1)			
Compressor 85-185 (1)			
Generator Small (1)			
Concrete Bridge Deck Finisher (1)			
Reinforcing Steel	**L.B.**	**2,000.00**	**L.B./Hour**
Truck 1/2 Ton (1)			
Crane 30 Ton Hydraulic (1)			
Steel Beams	**L.F.**	**100.00**	**L.F./Hour**
Truck 1/2 Ton (1)			
TruckTractor & Lowboy Trailer (1)			
Crane 100 Ton Crawler (1)			

Exhibit 3-16. Miscellaneous concrete/concrete pavement/retaining wall summary table.

Work Task	Unit of Measure	Production Rate	Production Rate Unit of Measure
Concrete Pavement (</= 6 Thick)	**S.Y.**	**60.00**	**S.Y./Hour**
Truck 1/2 Ton (1)			
Ready-Mix Truck (6)			
Loader/Backhoe Cat 416 (1)			
Concrete Slipform Paver (1)			
Concrete Pavement (>6 Thick)	**S.Y.**	**45.00**	**S.Y./Hour**
Truck 1/2 Ton (1)			
Ready-Mix Truck (6)			
Loader/Backhoe Cat 416 (1)			
Concrete Slipform Paver (1)			
Curb & Gutter	**L.F.**	**100.00**	**L.F./Hour**
Truck 1/2 Ton (1)			
Ready-Mix Truck (1)			
Loader Skid Steer (1)			
Gomaco Commander GT3200 Curber (1)			
Concrete Median Barrier	**L.F.**	**70.80**	**L.F./Hour**
Truck 1/2 Ton (1)			
Ready-Mix Truck (6)			
Loader Skid Steer (1)			
Power Curber 5700B (1)			
Sidewalk	**L.F.**	**100.00**	**L.F./Hour**
Truck 1/2 Ton (1)			
Ready-Mix Truck (6)			
Loader Skid Steer (1)			
Power Curber 5700B (1)			
Retaining Wall	**S.F.**	**24.00**	**S.F./Hour**
Truck 1/2 Ton (1)			
Ready-Mix Truck (1)			
Loader Backhoe Cat 430 (1)			
Crane 30 Ton Hydraulic (1)			

Storm Drainage/Water/Sewer

Pipe crews are generally consistent from project to project and generally vary by pipe size and depth. The estimating panel produced generally consistent equipment lists and production rates. This exercise assumed standard open conditions with standard specification depths for pipe. These production rates would not be for urban areas where site conditions limit the work area and for unusual depth requirements. Exhibit 3-17 presents the selected work tasks, units of measure, production rates, and production rate units of measure for the storm drainage, water, and sewer work tasks.

Specialty Items

The equipment lists for most of the specialty items are much shorter than for many of the previous items. Labor and material costs make up a much larger percentage of the cost for these items. In addition, most of these items are performed by companies that specialize in the items listed and are not performed by the average highway contractor. Although the equipment lists are generally used, the production rates for many of these items can vary for each subcontractor depending on a number of project-specific factors. For example, signalization installations can vary from one intersection to the next within the same project. The estimating team relied on information from specialty subcontractors for much of the information in this section. Exhibit 3-18 presents the selected work tasks, units of measure, production rates, and production rate units of measure for the specialty item work tasks.

3.2.5 Calculation of Per Unit Fuel Use

The last step in this process was the calculation of the "Fuel Use Factor" for each task. Each estimator created an estimated task quantity for each task. For example, a quantity of 1,000 L.F. of pipe was assigned for each of the pipe items. Using an estimated quantity for each crew, a total time for completing the task was established. Total fuel consumption was then calculated by factoring in the total time for the crew and the required equipment for each crew. Creating a sample quantity for each task eliminated rounding errors that occur when entering the calculations for large production rates. In addition, using larger quantities allows the estimator to better visualize the results. Exhibit 3-19 displays a sample computation for a small pipe crew.

Exhibits 3-20 through 3-28 display the final per unit fuel use for the selected work tasks. The results are presented by category in order to group similar tasks.

Under the clearing and removal category, the heavy clearing work task uses more fuel than light and medium clearing. Asphalt pavement removal (1.397 gallons per cubic yard) is nearly three times more fuel intense than concrete pavement removal (0.562 gallons per cubic yard). Exhibit 3-20 displays fuel use per unit among the clearing and removal work tasks.

Exhibit 3-21 displays the fuel use per unit for the grading work tasks. The work tasks within dirt and rock do not demonstrably differ in fuel intensity, with the one exception of the work task involving dirt and rock with a short on-road haul. Rock takes longer to load, and the loading operation will be a larger percentage of the cost with shorter hauls.

Exhibit 3-22 displays the fuel use per unit for the base stone work task. This is the only work task under the base stone category. The base stone task is estimated to use 0.406 gallons of fuel per ton of base stone.

Exhibit 3-23 displays the fuel use per unit for the work tasks under the asphalt category. The leveling course work tasks have the highest average fuel use per unit, and the over 15-mile leveling course is the most fuel intensive work task.

Exhibit 3-17. Storm drainage/water/sewer summary table.

Work Task	Unit of Measure	Production Rate	Production Rate Unit of Measure
Small Pipe Crew (</= 18" Pipe)	**L.F.**	**24.00**	**L.F./Hour**
Truck 1/2 Ton (1)			
Dozer D-3 (1)			
Loader R/T 938 (1)			
Excavator Cat 336 (1)			
Roller Vibrating Plate Compact (1)			
Roller Ram Max Trench (1)			
Medium Pipe Crew (>18" to 36" Pipe)	**L.F.**	**16.00**	**L.F./Hour**
Truck 1/2 Ton (1)			
Dozer D-3 (1)			
Loader R/T 938 (1)			
Excavator Cat 336 (1)			
Roller Vibrating Plate Compact (1)			
Roller Ram Max Trench (1)			
Large Pipe Crew (> 36" Pipe)	**L.F.**	**8.00**	**L.F./Hour**
Truck 1/2 Ton (1)			
Dozer D-6 (1)			
Loader R/T 938 (1)			
Excavator Cat 345 (1)			
Roller 815 Soil Compactor			
Roller Vibrating Plate Compact (1)			
Roller Ram Max Trench (1)			
Drainage Structures	**Each**	**2.00**	**Each/Hour**
Truck 1/2 Ton (1)			
Truck 2 Ton Flatbed (1)			
Ready Mix Truck (0.1)			
Loader/Backhoe Cat 416 (1)			
Excavator Cat 324 (1)			
Roller Ram Max Trench (1)			
Water Line (up to 4' depth)	**L.F.**	**20.00**	**L.F./Hour**
Truck 1/2 Ton (1)			
Dozer D-3 (1)			
Loader R/T 938 (1)			
Excavator Cat 336 (1)			
Roller Vibrating Plate Compact (1)			
Roller Ram Max Trench			
Roller Ram Max Trench (1)			
Water Line (over 4' depth)	**L.F.**	**10.00**	**L.F./Hour**
Truck 1/2 Ton (1)			
Dozer D-3 (1)			
Loader R/T 938 (1)			
Excavator Cat 336 (1)			
Roller Vibrating Plate Compact (1)			
Roller Ram Max Trench (1)			
Sewer Line (up to 4' depth)	**L.F.**	**20.00**	**L.F./Hour**
Truck 1/2 Ton (1)			
Dozer D-3 (1)			
Loader R/T 938 (1)			
Excavator Cat 336 (1)			
Roller Vibrating Plate Compact (1)			
Roller Ram Max Trench (1)			
Sewer Line (over 4' depth)	**L.F.**	**10.00**	**L.F./Hour**
Truck 1/2 Ton (1)			
Dozer D-3 (1)			
Loader R/T 938 (1)			
Excavator Cat 336 (1)			
Roller Vibrating Plate Compact (1)			
Roller Ram Max Trench (1)			
Water/Sewer Manholes	**Each**	**2.00**	**Each/Hour**
Truck 1/2 Ton (1)			
Truck 2 Ton Flatbed (1)			
Loader/Backhoe Cat 416 (1)			
Roller Ram Max Trench			

Exhibit 3-18. Specialty items summary table.

Work Task	Unit of Measure	Production Rate	Production Rate Unit of Measure
Fencing (up to 6' height)	**L.F.**	**200.00**	**L.F./Hour**
Truck 1/2 Ton (1)			
Truck 2 Ton Flatbed (1)			
Loader Skid/Steer (1)			
Fencing (over 6' height)	**L.F.**	**200.00**	**L.F./Hour**
Truck 1/2 Ton (1)			
Truck 2 Ton Flatbed (1)			
Loader Skid/Steer (1)			
Fence Gates	**Each**	**2.00**	**Each/Hour**
Truck 1/2 Ton (1)			
Truck 2 Ton Flatbed (1)			
Loader Skid/Steer (1)			
Steel Guardrail	**L.F.**	**300.00**	**L.F./Hour**
Truck 1/2 Ton (1)			
Truck 2 Ton Flatbed (1)			
Truck Guardrail Install (1)			
Generator Small (1)			
Wire/Cable Guardrail	**L.F.**	**100.00**	**L.F./Hour**
Truck 1/2 Ton (1)			
Truck 2 Ton Flatbed (1)			
Truck Guardrail Install (1)			
Guardrail Posts	**Each**	**25.00**	**Each/Hour**
Truck 1/2 Ton (1)			
Truck 2 Ton Flatbed (1)			
Guardrail Install Truck (1)			
Solid Sodding	**S.Y.**	**500.00**	**S.Y./Hour**
Truck 1/2 Ton (1)			
Truck 2 Ton Flatbed (1)			
Loader Skid/Steer (1)			
Hydro Seeding	**Acre**	**3.00**	**Acre/Hour**
Truck 1/2 Ton (1)			
Truck 2 Ton Flatbed (1)			
Truck Hydroseeder (1)			
Seedbed Preparation	**Acre**	**0.50**	**Acre/Hour**
Truck 1/2 Ton (1)			
Tractor w/Disk (1)			
Solid Pavement Marking	**L.M.**	**2.00**	**L.M./Hour**
Truck 1/2 Ton (2)			
Truck, Thermoplastic Paint (1)			
Skip Pavement Marking	**L.M.**	**2.00**	**L.M./Hour**
Truck 1/2 Ton (2)			
Truck, Thermoplastic Paint (1)			
Intersection Signalization (2 Lane)	**Each**	**0.50**	**Each/Hour**
Truck 1/2 Ton (1)			
Truck 2 Ton Flatbed (1)			
Crane 12 Ton Truck (1)			
Intersection Signalization (4 Lane)	**Each**	**0.25**	**Each/Hour**
Truck 1/2 Ton (1)			
Truck 2 Ton Flatbed (1)			
Crane 12 Ton Truck (1)			

Exhibit 3-19. Sample computation for small pipe crew.

Estimated Quantity:	1,000 L.F.	
Estimated Production Rate:	24 L.F./Hour	
Estimated Crew Time:	41.67 Hours (1,000 L.F./24 L.F./Hour)	
Equipment Fuel:		
Truck ½ Ton	41.67 x 2.0 Gallons/Hour =	83.34
Dozer D-3	41.67 x 2.2 Gallons/Hour =	91.67
Loader R/T 938	41.67 x 4.0 Gallons/Hour =	166.68
Excavator Cat 336	41.67 x 11.0 Gallons/Hour =	458.37
Roller Vibrating Plate	41.67 x 0.2 Gallons/Hour =	8.34
Roller Ram Max Trench	41.67 x 0.5 Gallons/Hour =	20.84
Total Fuel Consumption:		**829.24 Gallons**
Fuel Use Factor:	829.24 Gallons/ 1,000 L.F. =	**0.829 Gallons/L.F.**

Exhibit 3-20. Clearing and removal fuel use per unit.

Task Description	Fuel Use Per Unit	Units
Clearing - Light	128.876	Gallons/Acre
Clearing - Medium	171.459	Gallons/Acre
Clearing - Heavy	273.347	Gallons/Acre
Pavement Removal - Asphalt	1.397	Gallons/C.Y.
Pavement Removal - Concrete	0.562	Gallons/C.Y.
Pipe Removal - All Sizes	0.863	Gallons/L.F.
Structure Demolition (House/Building)	375.000	Gallons/Each
Structure (Bridge per S.F. of Deck)	0.626	Gallons/S.F.

Exhibit 3-21. Grading fuel use per unit.

Task Description	Fuel Use Per Unit	Units
Grading - Dirt - Off Road - Long Haul	0.320	Gallons/C.Y.
Grading - Dirt - Off Road - Short Haul	0.263	Gallons/C.Y.
Grading - Dirt - On Road - Long Haul	0.687	Gallons/C.Y.
Grading - Dirt - On Road - Short Haul	0.319	Gallons/C.Y.
Grading - Rock - Off Road - Long Haul	0.349	Gallons/C.Y.
Grading - Rock - Off Road - Short Haul	0.258	Gallons/C.Y.
Grading - Rock - On Road - Long Haul	0.687	Gallons/C.Y.
Grading - Rock - On Road - Short Haul	0.412	Gallons/C.Y.
Roadbed Finishing	0.073	Gallons/S.Y.
Rock Drilling and Blasting (Only) (No Haul)	0.053	Gallons/C.Y.

Exhibit 3-22. Base stone fuel use per unit.

Task Description	Fuel Use Per Unit	Units
Base Stone	0.406	Gallons/Ton

Exhibit 3-23. Asphalt fuel use per unit.

Task Description	Fuel Use Per Unit	Units
Hot Mix Asphalt - Leveling Course (0-5 Mile Haul)	0.892	Gallons/Ton
Hot Mix Asphalt - Leveling Course (5-15 Mile Haul)	0.977	Gallons/Ton
Hot Mix Asphalt - Leveling Course (Over 15 Mile Haul)	1.061	Gallons/Ton
Hot Mix Asphalt - Structural Course (0-5 Mile Haul)	0.580	Gallons/Ton
Hot Mix Asphalt - Structural Course (5-15 Mile Haul)	0.718	Gallons/Ton
Hot Mix Asphalt - Structural Course (Over 15 Mile Haul)	0.745	Gallons/Ton
Hot Mix Asphalt - Surface Course (0-5 Mile Haul)	0.770	Gallons/Ton
Hot Mix Asphalt - Surface Course (5-15 Mile Haul)	0.847	Gallons/Ton
Hot Mix Asphalt - Surface Course (Over 15 Mile Haul)	0.994	Gallons/Ton

Exhibit 3-24 displays the fuel use per unit for the work tasks under the milling category. The 2- to 4-inch milling tasks have higher fuel use than the corresponding 0- to 1-inch tasks, and the difference is exacerbated as hauling distances increase.

Exhibit 3-25 displays the fuel use per unit for the structure work tasks. Substructure concrete and superstructure concrete are particularly fuel intensive tasks, requiring 4.70 and 4.15 gallons per cubic yard, respectively.

Exhibit 3-26 displays the fuel use per unit for the miscellaneous concrete, concrete paving, and retaining wall work tasks. Heavy fuel usage tasks include concrete median barrier (0.508 gallons of fuel per linear foot), concrete pavement more than 6 inches thick (0.867 gallons per square yard), and retaining wall (0.729 gallons per square foot).

Exhibit 3-27 displays the fuel use per unit for the storm drainage, water, and sewer work tasks. Fuel use increases depending on pipe size and sewer and water line depth. Drainage for structures requires the most fuel per unit at 8.725 gallons of fuel per cubic yard. Large pipe requires three times as much fuel per linear foot as medium pipe.

Exhibit 3-24. Milling fuel use per unit.

Task Description	Fuel Use Per Unit	Units
Milling (<2") (0-5 Mile Haul)	0.010	Gallons/S.Y.
Milling (<2") (5-15 Mile Haul)	0.011	Gallons/S.Y.
Milling (<2") (Over 15 Mile Haul)	0.014	Gallons/S.Y.
Milling (2-4") (0-5 Mile Haul)	0.013	Gallons/S.Y.
Milling (2-4") (5-15 Mile Haul)	0.018	Gallons/S.Y.
Milling (2-4") (Over 15 Mile Haul)	0.025	Gallons/S.Y.

Exhibit 3-25. Structures fuel use per unit.

Task Description	Fuel Use Per Unit	Units
Reinforcing Steel	0.004	Gallons/L.B.
Steel Beams	0.180	Gallons/L.F.
Substructure Concrete	4.700	Gallons/C.Y.
Superstructure Concrete	4.150	Gallons/C.Y.

Exhibit 3-26. Miscellaneous concrete/concrete paving/retaining wall fuel use per unit.

Task Description	Fuel Use Per Unit	Units
Concrete Median Barrier	0.508	Gallons/L.F.
Concrete Pavement (</= 6 Thick)	0.650	Gallons/S.Y.
Concrete Pavement (>6 Thick)	0.867	Gallons/S.Y.
Curb & Gutter	0.152	Gallons/L.F.
Retaining Wall	0.729	Gallons/S.F.
Sidewalk	0.360	Gallons/S.F.

Exhibit 3-27. Storm drainage/water/sewer fuel use per unit.

Task Description	Fuel Use Per Unit	Units
Drainage Structures	8.725	Gallons/C.Y.
Large Pipe Crew (> 36" Pipe)	4.338	Gallons/L.F.
Medium Pipe Crew (>18" to 36" Pipe)	1.481	Gallons/L.F.
Sewer Line (Over 4' Depth)	2.090	Gallons/L.F.
Sewer Line (Up to 4' Depth)	1.045	Gallons/L.F.
Small Pipe Crew (</= 18" Pipe)	0.829	Gallons/L.F.
Water Line (Over 4' Depth)	2.090	Gallons/L.F.
Water Line (Up to 4' Depth)	1.045	Gallons/L.F.
Water/Sewer Manholes	5.000	Gallons/Each

Exhibit 3-28. Specialty items fuel use per unit.

Task Description	Fuel Use Per Unit	Units
Fence Gates	4.250	Gallons/Each
Fencing (Over 6' Height)	0.043	Gallons/L.F.
Fencing (Up to 6' Height)	0.043	Gallons/L.F.
Grassing (Hydro Seeding)	3.497	Gallons/Acre
Guardrail Posts	0.042	Gallons/Each
Intersection Signalization (2 Lane)	170.000	Gallons/Each
Intersection Signalization (4 Lane)	340.000	Gallons/Each
Seedbed Preparation	10.000	Gallons/Acre
Skip Pavement Marking	4.500	Gallons/L.M.
Solid Pavement Marking	4.500	Gallons/L.M.
Solid Sodding	0.017	Gallons/S.Y.
Steel Guardrail	0.037	Gallons/L.F.
Strip Topsoil	0.167	Gallons/C.Y.
Wire/Cable Guardrail	0.105	Gallons/L.F.

Exhibit 3-28 displays the fuel use per unit for specialty items that do not belong to the above work categories. Some heavy fuel use work tasks include skip and solid pavement marking at 4.5 gallons per linear meter each. An average four-lane intersection signalization would require 340 gallons of fuel.

3.2.6 Conclusion

The professional engineering estimation described in this chapter was one of three methodologies considered in the effort to tabulate new and updated fuel usage factors. The fuel use calculations, arrived at through a consensus-building process among the expert engineering panel, provide accurate average fuel use specifications for a variety of work tasks prevalent in the highway construction industry. Although any given estimator might choose approaches and equipment that differ slightly from those presented, the fuel use calculations enumerated above represent realistic baseline numbers for a detailed set of average work tasks.

3.3 Statistical Analysis of Fuel Usage

The objective of the BidTabs statistical analysis was to estimate the fuel usage of construction activities using a statistical model that incorporates changing fuel prices and bid prices. This included specification of the model, testing of different combinations and forms of the variables, exploration of lagged variables, evaluation of residuals and error terms, and exploration of different combinations of pay items both within and across states.

There are six subsections in this chapter section. The first subsection discusses the development of a database of unit prices for pay items and BidTabs over time. The second subsection introduces the KLEEM model, which is used to determine the fuel usage of construction activities. The third subsection provides an example of a one-variable application of the KLEEM model. The fourth subsection discusses the development of the variables used in the model estimation. The fifth subsection presents the results of the two-variable KLEEM model. The sixth subsection provides conclusions and next steps.

3.3.1 Development of the Database

The goal of this effort is to determine the fuel usage from construction activities in order to develop updated fuel usage factors. For this purpose, the project methodology included a statistical analysis of state highway construction bid data. The first step in the methodology was

Exhibit 3-29. Number of pay items and bid lettings from 1/1/2006 to 12/31/2010 (5 years).

Options	Number of Pay Items	Number of Records (Bids)
Low Bids Only	363,137	4,127,808
Also Exclude Non-Standard Pay Items	185,846	3,774,921
Also Exclude Lump Sum Pay Items	170,735	3,411,684
Also Exclude Items Bid Fewer than 100 Times	6,835	2,106,926

to tabulate unit prices for pay items over time. This required the development of a database of unit costs.

The original methodology envisioned that the database would contain prices over 3 to 5 years. The study team selected a start date of 1/1/2006 and a database containing 5 years of data. Exhibit 3-29 provides a summary of the number of pay items and the number of bids that were in the database for the selected period. In total, 363,137 separate pay items are available in the Oman Systems BidTabs database. For these pay items, there were more than 4.1 million low bids. Note that low bids are the unit price bid for the item in the winning low bid as opposed to the lowest bid for that item.

To prepare the database, the study team excluded records that were not suitable for the analysis. The first step was to exclude non-standard pay items. Non-standard pay items are items that do not have the same definition or units from one project/bid to another. Therefore, for these items, there is no price per unit of work. This means that a comparison of unit price across projects or over time it not possible. Similarly, without a price per unit of work, it is not possible to regress unit price on fuel prices in order to assess the existence of a relationship or correlation between the two prices. Exclusion of these non-standard items reduces the number of pay items by roughly half, but only reduces the number of bids by about 8.5 percent.

The second step was to exclude lump sum pay items. Lump sum bid items are items for which the bid quantity is essentially equal to one. For example, a lump sum bid item would be building one bridge or paving one section of road. As with non-standard pay items, there is no price per unit of work for lump sum bid items. Therefore it is not possible to compare unit price across projects or over time. Nor is it possible to regress unit price on fuel prices to assess the existence of a relationship or correlation. The exclusion of non-standard items only reduces the number of pay items by about 15,000, but again only reduces the number of bids by about 8 percent.

The third step was to exclude pay items that the issuing state DOT did not put out for bid with much frequency. In this case, the analysis excluded pay items if there were fewer than 100 lettings of that item over the 5-year period or fewer than 20 bids per year. The purpose of excluding bid items with very few bids is that the small sample size may hamper the ability to accurately assess the existence of a relationship or correlation. The exclusion of these non-standard items reduces the number of pay items drastically to about 2 percent of the original number of bid items, but only reduces the number of bids to about half of the original number of bid items. Note that there was only an average of eight bids per pay item for the pay items that were excluded from the analysis.

The compiled database has approximately 2.1 million records providing data on 6,835 bid items. There are approximately 308 bids per pay item, on average. Exhibit 3-30 provides a sample of 50 records. The database includes state, pay item number, pay item description, unit, quantity, amount (in dollars per unit), a category identifier developed by Oman Systems, and the bid date.

Exhibit 3-30. Fifty sample records from the custom BidTabs data base.

STATE	PAY ITEM #	PAY ITEM DESCRIPTION	UNIT	QUANTITY	UNIT PRICE	CATEGORY	BID DATE
WV	502001-012	12 INCH PORTLAND CEMENT CONCRETE APPROACH SLAB	S.Y.	290.00	205.00	26 (concrete pavement)	10/21/08
WV	502001-012	12 INCH PORTLAND CEMENT CONCRETE APPROACH SLAB	S.Y.	144.60	209.00	26 (concrete pavement)	10/21/08
WV	502001-012	12 INCH PORTLAND CEMENT CONCRETE APPROACH SLAB	S.Y.	161.00	205.00	26 (concrete pavement)	10/21/08
WV	502001-012	12 INCH PORTLAND CEMENT CONCRETE APPROACH SLAB	S.Y.	284.00	300.00	26 (concrete pavement)	10/21/08
WV	502001-012	12 INCH PORTLAND CEMENT CONCRETE APPROACH SLAB	S.Y.	453.00	218.00	26 (concrete pavement)	12/02/08
WV	502001-012	12 INCH PORTLAND CEMENT CONCRETE APPROACH SLAB	S.Y.	350.00	300.00	26 (concrete pavement)	12/02/08
WV	502001-012	12 INCH PORTLAND CEMENT CONCRETE APPROACH SLAB	S.Y.	113.00	270.00	26 (concrete pavement)	12/02/08
WV	502001-012	12 INCH PORTLAND CEMENT CONCRETE APPROACH SLAB	S.Y.	200.00	230.00	26 (concrete pavement)	12/02/08
WV	502001-012	12 INCH PORTLAND CEMENT CONCRETE APPROACH SLAB	S.Y.	364.00	280.00	26 (concrete pavement)	12/09/08
WV	502001-012	12 INCH PORTLAND CEMENT CONCRETE APPROACH SLAB	S.Y.	1707.87	183.95	26 (concrete pavement)	12/09/08
WV	502001-012	12 INCH PORTLAND CEMENT CONCRETE APPROACH SLAB	S.Y.	145.00	275.00	26 (concrete pavement)	12/09/08
WV	502001-012	12 INCH PORTLAND CEMENT CONCRETE APPROACH SLAB	S.Y.	708.00	175.00	26 (concrete pavement)	12/02/08
WV	502001-012	12 INCH PORTLAND CEMENT CONCRETE APPROACH SLAB	S.Y.	152.00	260.00	26 (concrete pavement)	02/10/09
WV	502001-012	12 INCH PORTLAND CEMENT CONCRETE APPROACH SLAB	S.Y.	126.00	93.00	26 (concrete pavement)	02/24/09
WV	502001-012	12 INCH PORTLAND CEMENT CONCRETE APPROACH SLAB	S.Y.	579.00	205.00	26 (concrete pavement)	04/16/09
WV	502001-012	12 INCH PORTLAND CEMENT CONCRETE APPROACH SLAB	S.Y.	136.00	225.00	26 (concrete pavement)	04/21/09
WV	502001-012	12 INCH PORTLAND CEMENT CONCRETE APPROACH SLAB	S.Y.	174.00	210.00	26 (concrete pavement)	04/21/09
WV	502001-012	12 INCH PORTLAND CEMENT CONCRETE APPROACH SLAB	S.Y.	98.00	225.00	26 (concrete pavement)	04/30/09
WV	502001-012	12 INCH PORTLAND CEMENT CONCRETE APPROACH SLAB	S.Y.	178.00	200.00	26 (concrete pavement)	06/02/09
WV	502001-012	12 INCH PORTLAND CEMENT CONCRETE APPROACH SLAB	S.Y.	163.00	182.00	26 (concrete pavement)	06/25/09
WV	502001-012	12 INCH PORTLAND CEMENT CONCRETE APPROACH SLAB	S.Y.	120.00	335.00	26 (concrete pavement)	06/18/09
WV	502001-012	12 INCH PORTLAND CEMENT CONCRETE APPROACH SLAB	S.Y.	682.91	162.06	26 (concrete pavement)	06/18/09
WV	502001-012	12 INCH PORTLAND CEMENT CONCRETE APPROACH SLAB	S.Y.	132.00	258.28	26 (concrete pavement)	07/07/09
WV	502001-012	12 INCH PORTLAND CEMENT CONCRETE APPROACH SLAB	S.Y.	294.00	240.00	26 (concrete pavement)	07/14/09
WV	502001-012	12 INCH PORTLAND CEMENT CONCRETE APPROACH SLAB	S.Y.	103.00	250.00	26 (concrete pavement)	07/14/09
WV	502001-012	12 INCH PORTLAND CEMENT CONCRETE APPROACH SLAB	S.Y.	400.00	231.00	26 (concrete pavement)	07/23/09
WV	502001-012	12 INCH PORTLAND CEMENT CONCRETE APPROACH SLAB	S.Y.	518.00	195.00	26 (concrete pavement)	08/13/09
WV	502001-012	12 INCH PORTLAND CEMENT CONCRETE APPROACH SLAB	S.Y.	178.00	190.00	26 (concrete pavement)	08/18/09
WV	502001-012	12 INCH PORTLAND CEMENT CONCRETE APPROACH SLAB	S.Y.	143.00	200.00	26 (concrete pavement)	08/18/09
WV	502001-012	12 INCH PORTLAND CEMENT CONCRETE APPROACH SLAB	S.Y.	111.00	220.00	26 (concrete pavement)	09/15/09
WV	502001-012	12 INCH PORTLAND CEMENT CONCRETE APPROACH SLAB	S.Y.	428.00	205.00	26 (concrete pavement)	09/15/09
WV	502001-012	12 INCH PORTLAND CEMENT CONCRETE APPROACH SLAB	S.Y.	237.00	188.00	26 (concrete pavement)	10/27/09
WV	502001-012	12 INCH PORTLAND CEMENT CONCRETE APPROACH SLAB	S.Y.	377.00	200.38	26 (concrete pavement)	07/21/09
WV	502001-012	12 INCH PORTLAND CEMENT CONCRETE APPROACH SLAB	S.Y.	98.00	210.00	26 (concrete pavement)	07/21/09
WV	502001-012	12 INCH PORTLAND CEMENT CONCRETE APPROACH SLAB	S.Y.	251.00	180.40	26 (concrete pavement)	11/17/09
WV	502001-012	12 INCH PORTLAND CEMENT CONCRETE APPROACH SLAB	S.Y.	124.00	200.00	26 (concrete pavement)	12/08/09
WV	502001-012	12 INCH PORTLAND CEMENT CONCRETE APPROACH SLAB	S.Y.	124.00	200.00	26 (concrete pavement)	12/08/09
WV	502001-012	12 INCH PORTLAND CEMENT CONCRETE APPROACH SLAB	S.Y.	166.00	275.00	26 (concrete pavement)	01/20/10
WV	502001-012	12 INCH PORTLAND CEMENT CONCRETE APPROACH SLAB	S.Y.	187.00	195.00	26 (concrete pavement)	01/20/10
WV	502001-012	12 INCH PORTLAND CEMENT CONCRETE APPROACH SLAB	S.Y.	204.00	205.00	26 (concrete pavement)	02/09/10
WV	502001-012	12 INCH PORTLAND CEMENT CONCRETE APPROACH SLAB	S.Y.	1125.00	150.00	26 (concrete pavement)	02/09/10
WV	502001-012	12 INCH PORTLAND CEMENT CONCRETE APPROACH SLAB	S.Y.	156.00	200.00	26 (concrete pavement)	02/23/10
WV	502001-012	12 INCH PORTLAND CEMENT CONCRETE APPROACH SLAB	S.Y.	131.00	234.00	26 (concrete pavement)	06/29/10
WV	502001-012	12 INCH PORTLAND CEMENT CONCRETE APPROACH SLAB	S.Y.	118.00	250.00	26 (concrete pavement)	06/29/10
WV	502001-012	12 INCH PORTLAND CEMENT CONCRETE APPROACH SLAB	S.Y.	242.00	200.00	26 (concrete pavement)	06/29/10
WV	502001-012	12 INCH PORTLAND CEMENT CONCRETE APPROACH SLAB	S.Y.	153.00	210.00	26 (concrete pavement)	06/29/10
WV	502001-012	12 INCH PORTLAND CEMENT CONCRETE APPROACH SLAB	S.Y.	142.00	215.00	26 (concrete pavement)	07/13/10
WV	502001-012	12 INCH PORTLAND CEMENT CONCRETE APPROACH SLAB	S.Y.	140.00	235.00	26 (concrete pavement)	07/13/10
WV	502001-012	12 INCH PORTLAND CEMENT CONCRETE APPROACH SLAB	S.Y.	98.00	225.00	26 (concrete pavement)	07/13/10
WV	502001-012	12 INCH PORTLAND CEMENT CONCRETE APPROACH SLAB	S.Y.	208.00	200.00	26 (concrete pavement)	07/27/10

3.3.2 KLEEM Model of Fuel Usage

After completing the tabulation of the unit prices for pay items over the 5-year period, the team used the diesel fuel price index from the initial statistical analysis from the first phase as a surrogate for other fuel types. With the individual price items and fuel prices over time, the team proceeded to integrate the KLEEM model into the statistical model. An overview of the modified KLEEM model and the analysis follows.

The cost of producing a unit of output is a function of the cost of the inputs required to produce a unit of output. The inputs to the construction industry can generally be classified into five types of inputs: capital (K), labor (L), energy (En), equipment (Eq), and materials and other intermediate inputs (M). The acronym KLEEM is used in reference to the classic KLEM input-output model. The traditional KLEM model includes four factors of production: capital (K), labor (L), energy (E), and materials and other intermediate inputs (M). In the KLEM model, equipment is included in capital costs. The KLEEM model provides separate accounting for equipment (Eq), which may be purchased or leased equipment. The input-output model is primarily used to determine the economic impacts due to a change in final demand. In this application, the input-output model framework is used to estimate the quantity of fuel required to produce a unit of output based on observed prices of the inputs and outputs.

The total cost to produce a unit of output in each year is the sum over all inputs of the input price per unit in that year times the quantity of the input required to produce a unit of output. It is assumed that the input quantities required per unit output are constant over time (i.e., change very slowly when compared to the frequency of price changes over the 5-year time period). Then the cost of producing a unit at times t = 1, . . . , T is

$$c(t)=\sum_{i=1}^{I} p_i(t)q_i.$$

Here c(t) represents the cost of producing a unit of output at time t and the $p_i(t)$ terms represent the price of input i = 1, . . . , I. In this application, I = 5 for the inputs K, L, En, Eq, and M. The q_i terms represent quantity of input i required per unit output.

In matrix form, let the column vectors $\underline{C}$ and $\underline{Q}$ and the matrix **P** be defined as

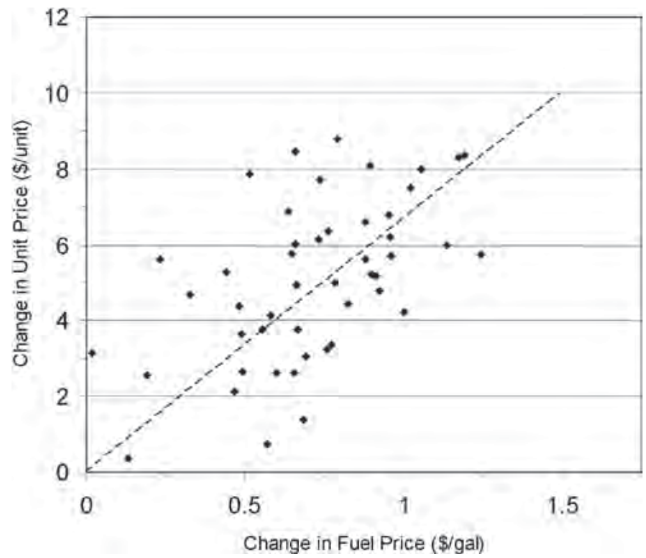
$$\underline{C}=\begin{bmatrix} c(1) \\ c(2) \\ \vdots \\ c(T) \end{bmatrix}, \mathbf{P}=\begin{bmatrix} p_1(1) & p_2(1) & \cdots & p_1(1) \\ p_1(2) & p_2(2) & \cdots & p_1(2) \\ \vdots & \vdots & & \vdots \\ p_1(T) & p_2(T) & \cdots & p_1(T) \end{bmatrix}, \text{and } \underline{Q}=\begin{bmatrix} q_1 \\ q_2 \\ \vdots \\ q_1 \end{bmatrix}.$$

Then the matrix equation $\underline{C} = \mathbf{P}\underline{Q}$ is a linear regression model that expresses the cost per unit output at each time as a linear function of the unknown input quantity vector $\underline{Q}$. If $T \geq I$ and no two columns of **P** are collinear, the least squares estimate of the input quantity vector $\underline{Q}$ is $\hat{\underline{Q}} = [\mathbf{P'P}]^{-1}\,\mathbf{P'}\underline{C}$ where **P′** denotes the transpose of the matrix **P**.

3.3.3 One-Variable Model of Fuel Usage

The KLEEM model defined above includes five classes of inputs. The regression model includes five coefficients, one representing each class of input. However, not all classes of input are especially variable over the 5-year period. For example, capital, labor, and equipment costs vary slowly, for the most part, over such a short period. Fuel price, on the other hand, is highly volatile. Much of the variation in the cost of a unit of output may be due to the change in the price of fuel alone.

Exhibit 3-31. Trend line estimate of fuel usage for one-variable model (Slope = ($/Unit)/($/Gallon) = Gallon/Unit).



In this way, the model can be simplified to one variable: fuel. In the one-variable model, the quantities and prices of all other inputs are considered fixed. Consider the following example.

A unit of output costs $10 to complete. The price of fuel at that time was $2.50 per gallon. In another period, the same unit of output costs $12.50 to complete. In this second period, the price of fuel was $5 per gallon. In a one-variable framework, fuel price is the only input that varies. It is assumed that the price of all other inputs remained unchanged and the quantity of fuel required to produce the unit of output was constant. The unknown in this example is the quantity of fuel required to produce the unit of output. Recall that the quantity of fuel that is required to produce one unit of output remains constant, regardless of the price of fuel. In this example, it can be determined that one gallon of fuel is required to produce the unit of output and the cost of all other inputs is $7.50.

In this simple example, where the bid price and the price of fuel are known, and the prices of all other inputs remain fixed, the amount of fuel required per unit can be calculated. Exhibit 3-31 presents a hypothetical example of the KLEEM model with one variable input: the price of fuel. The graph shows a scatter plot of the change in unit cost ($/Unit) versus the change in fuel price ($/Gallon) for a series of observations of unit output prices and fuel input prices. The slope of the regression line is an estimate of the quantity of fuel required to produce a unit of output. The slope has the dimensions of ($/Unit)/($/Gallon) = (Gallon/Unit).

3.3.4 Development of Independent Variables

The original KLEEM model utilizes five variables in determining fuel use per unit of output. Running the five-variable model with the available data, however, revealed a high degree of cross-correlations and unexpected signs that did not fit with the assumptions of the model variables. The two-variable model, which uses fuel and labor costs, gave reasonable results and was selected for this regression.

The energy prices for the model are monthly averages of the U.S. average daily Low-Sulfur No. 2 diesel fuel prices ($/Gallon) from the U.S. Department of Energy. The construction employment

Exhibit 3-32. U.S. construction employment cost index.

cost index is provided in Exhibit 3-32. The labor prices for the construction industry were calculated as a 50-day moving average of the quarterly construction wages price series (December 2005 = 100) obtained from the Bureau of Labor Statistics. The 50-day moving average is a standard technical indicator used in the analysis of day-to-day price movements of commodities and stocks. The moving average serves to smooth the data, reducing the effect of shocks, in this case fuel price shocks, and identifies the underlying trends in the data. Exhibit 3-33 shows the time series plot of the average daily U.S. No. 2 Diesel Fuel price and its 50-day moving average from November 2004.

3.3.5 Analysis of the Two-Variable KLEEM Model

The analysis proceeded in several stages, with a significant degree of data aggregation required at each stage to generate useful results. The data were first screened to eliminate any bids from

Exhibit 3-33. U.S. distillate fuel price with 50-day moving average.

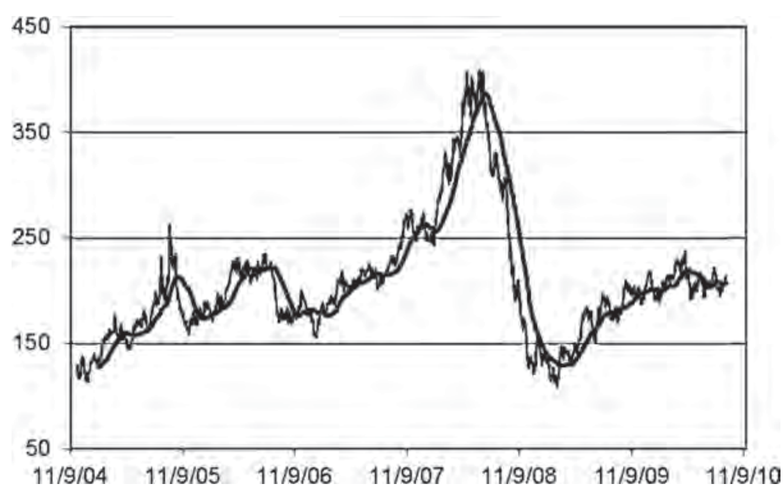


Exhibit 3-34. Pay item categories.

Category	Description
1	GRADING/EXCAVATION
2	BRIDGE
3	ASPHALT
4	BASE STONE
5	DRAINAGE-PIPE
6	DRAINAGE-INLETS/CATCH BASINS
7	CONCRETE-CULVERTS
8	CONCRETE-MISC
9	TRAFFIC CONTROL
10	GUARDRAIL
11	FENCING
12	GRASSING
13	CLEARING
14	EROSION CONTROL
15	RETAINING WALL
16	SIGNALIZATION
17	SIGNS-PERMANENT
18	STRIPING/PAVEMENT MARKING
19	PAINTING STRUCTURES
20	UTILITY-WATER
21	UTILITY-GAS
22	UTILITY-SEWER
23	LIGHTING
24	BUILDINGS/MISC STRUCTURES
25	MOBILIZATION
26	CONCRETE PAVEMENT
27	MISC STONE/RIPRAP
28	ROADWAY LIGHTING/ELECTRICAL
29	UNDERDRAIN
30	EQUIPMENT/LABOR
31	ALTERNATES/BONUS/TIME

pay items with a range of less than 3 years of data. This step was required to ensure that the prices reflect a wide range of the changes in input prices that occurred over the 5-year time period covered by this study. Approximately 600,000 bids were eliminated in this stage.

In the second stage, the pay items in each state were aggregated to pay item groups within each state. The groups were based on the categories shown in Exhibit 3-34. A consistent definition of the unit of production is required for the KLEEM model. However, each category contained bids for pay items expressed in various units.

An example of the pay items included in each category/unit grouping for bridges in Ohio is presented in Exhibit 3-35. The group of pay items for bridges with units of cubic yards (C.Y.) includes mainly concrete shapes, while the group for bridges in pounds (Lbs.) includes only bridge steel items and the square yard (S.Y.) category includes mainly organic surface coating. The fourth grouping is linear feet (L.F.) and shows more diversity in the listed pay items, indicating that the category/unit grouping within a state does not always result in a homogeneous group of pay items. Some lack of homogeneity within the groupings is an inevitable result of the aggregation process.

Exhibit 3-36 defines the work categories and items and presents the sample sizes for each. These items were obtained by selecting the most common units of measure for each pay item category in Exhibit 3-34. Separate tables were prepared for each state with the average quantities and weighted-average unit prices by month of pay items within each selected group shown in bold in Exhibit 3-36. The pay items selected for the state tables were screened to eliminate many bid records with very small or unusually large values of quantity or price from the calculation of the state means. The number of retained records in the second stage generally exceeded 100 per month within each grouping in each state.

Exhibit 3-35. Pay item grouping for bridge category in Ohio.

Category	Unit	Item
Bridge	C.Y.	'CLASS C CONCRETE
		'CLASS C CONCRETE RETAINING WALL/WINGWALL ABOVE FOOTING'
		'CLASS HP CONCRETE
		'CLASS HP CONC
		'CONCRETE
		'POLYMER MODIFIED ASPH EXP JNT SYSTEM'
		'QC/QA CONCRETE
	L.F.	'STEEL PILES HP10X42
		'STEEL PILES HP12X53
		'12" CIP REINFORCED CONCRETE
		'12" CIP REINFORCED CONCRETE PILES
		'CONC RPR BY EPOXY INJ'
		'STRUC EXP JT INCL ELAST STRIP'
		'STRUC CXP JT INC ELAST
		'SEMI-INTEGRAL ABUT EXP JOINT SEAL
		'JOINT SEALER
		'SAWING & SEALING BIT CONC JTS'
		'POLYMER MOD ASPH EXP JT SYSTEM'
		'RAILING (TWIN STEEL TUBE)'
		'STEEL DRIP STRIP'
	LBS	'EPOXY COATED REINFORCING STEEL
		'REINFORCING STEEL
		'STRC STEEL MEM
	S.Y.	'SLG OF CONC SURF (NON-EPOXY)'
		'SLG OF CONC SURF (EPOXY-URETHANE)
		'SEALING CONC BRIDGE DECKS W/HMWM RESIN'
		'TREATING OF CONCRETE BRIDGE DECK W/SRS'
		'TYPE 2 WATERPROOFING'
		'TYPE 3 WATERPROOFING'
		'TRTING CONC DECKS W/GRAVITY FED RESIN'
		'PTCHNG CONC DECK-TYPE B'
		'PTCHNG CONC DECK TYPE C'
		'APPROACH SLABS (T=15")
		'TIED CONCRETE BLOCK MAT
		'QC/QA CONCRETE

Exhibit 3-36. Number of records in pay item groups selected for analysis.

Units	EACH	L.F.	S.Y.	C.Y.	TON	S.F.	LBS	TON-G	GAL	ACRE	MILE	L.M.
ASPHALT	X	X	45,659	X	76,888	X	X	26,044	23,039	-	X	X
BASE STONE	X	X	X	13,055	15,554	-	-	X	-	-	X	-
BRIDGE	X	23,330	20,107	22,754	X	X	19,638	-	X	-	-	-
CLEARING	X	30,168	20,607	X	X	X	-	-	-	X	-	X
CONCRETE PAVEMENT	X	6,107	11,551	X	X	-	X	X	X	-	X	X
CONCRETE-CULVERTS	X	1,098	X	X	-	X	X	-	-	-	-	-
CONCRETE-MISC	X	20,749	18,218	11,765	X	X	X	-	-	-	-	-
DRAINAGE-INLETS\ CATCH BASINS	55,242	5,471	X	X	-	X	X	-	-	-	-	-
DRAINAGE-PIPE	X	38,769	X	X	-	-	-	-	-	-	-	-
EROSION CONTROL	X	42,561	23,347	X	X	X	X	X	-	X	-	-
FENCING	X	5,112	X	-	-	-	-	-	-	-	-	-
GRADING\EXCAVATION	X	X	10,582	87,727	X	X	-	X	-	X	X	X
GRASSING	X	X	23,678	X	X	X	22,649	X	X	22,904	-	X
GUARDRAIL	58,026	38,912	X	-	-	-	-	-	-	-	-	-
MISC STONE\RIPRAP	X	X	X	16,257	X	-	-	X	-	-	-	-
MOBILIZATION	19,168	1,633	-	X	X	-	-	-	-	X	-	X
PAINTING STRUCTURES	-	X	X	X	-	2,642	-	-	-	-	-	-
RETAINING WALL	-	X	-	758	-	X	X	-	-	-	-	-
ROADWAY LIGHTING\ ELECTRICAL	17,021	23,021	-	X	-	X	-	X	-	-	-	-
SIGNALIZATION	38,371	27,873	-	X	-	-	-	-	-	-	-	-
SIGNS-PERMANENT	36,762	X	X	X	-	29,892	X	-	-	-	-	-
STRIPING PAVEMENT MARKING	85,065	152,255	X	-	-	X	-	-	X	-	9,777	10,679
TRAFFIC CONTROL	91,788	41,377	X	X	X	19,716	-	X	-	-	X	X
UNDERDRAIN	4,071	12,146	X	X	-	-	-	-	-	-	-	-
UTILITY-SEWER	619	514	-	-	-	-	-	-	-	-	-	-
UTILITY-WATER	4,654	497	-	-	-	-	X	-	-	-	-	-

X Positive number of records, generally smaller than those shown for each pay item, but not selected for analysis.
\- No bid records available.

In the third stage, two-variable KLEEM model regressions were estimated for each pay item grouping in each state using the change in weighted-average price per unit as a function of the changes in the mean fuel price and labor cost. In this stage, regressions were estimated for approximately 330 state/pay item groupings. Each regression included at most 60 monthly data points, although fewer than 60 months of data were available in most states. The changes in the independent and dependent variables were calculated by subtracting the minimum value of the mean for each variable over the 60-month period from the mean value in each month. This transformation defines a multivariate origin for the regression where zero is equal to the minimum value of each variable. The origin transformation does not affect the scale or units of the data.

In the final stage of aggregation, the regression coefficients for fuel and labor for each pay item group were averaged across all states. Only states with regression coefficients with plausible significance ($p < 0.50$) were retained for the calculation of the mean fuel coefficient in each pay item group.

3.3.6 Results of the Two-Variable KLEEM Model

The two-variable KLEEM model assumes fixed prices and quantities for capital, materials, and equipment, while labor and fuel prices are permitted to vary. The mean fuel coefficient estimated for each pay item group is shown in Exhibit 3-37. Since the cost of labor is expressed as an index, the coefficients estimated for this input are not meaningful.

The regression results in Exhibit 3-37 show some degree of consistency. The fuel required for a ton of asphalt is (by a factor of approximately 10) higher than for a ton of base stone. The fuel required for asphalt per square yard is slightly smaller than the fuel required for the pay item grouping of bridges per square yard (mainly organic surface coatings) as described above. Drainage pipe has a higher fuel requirement per linear foot than fencing, which in turn has a higher requirement than erosion control. Guardrails require only slightly more fuel input per linear foot than roadway lighting/electrical.

On the other hand, however, several of the estimates generated by this analysis clearly do not appear to represent actual fuel usage. For example, the statistical estimate of fuel usage for grading on a cubic yard basis differs from the engineering and contractor survey estimates by a large factor of magnitude.

Despite the high level of aggregation, the number of states is small for many pay item groups. For example, in Exhibit 3-37, seven pay items rely on data for only one state, while 15 more rely on data from only two or three states. State-defined pay items are at a finer level of detail than the pay item groups shown in Exhibit 3-37. As a result, the estimates for these groupings are not as robust as those for pay items that are common to many states.

3.3.7 Conclusion

The statistical analysis of bid data described in this section was one of three methodologies under consideration in the effort to tabulate new and updated fuel usage factors. The statistical analysis demonstrated that most highway construction activities consume large amounts of fuel and are fuel intensive. However, the approach does not appear to have generated estimates of fuel usage that would be accurate enough to contribute to the development of the final fuel usage factors. However, in developing these fuel factors, the results of the statistical analysis were considered where it was felt that they might be useful.

Exhibit 3-37. Regression-based fuel use coefficients (gallons per unit output).

Pay Item Group [Unit]	Estimated Gallons/Unit	Number of States
Asphalt [Gal]	0.38	6
Asphalt [S.Y.]	5.61	6
Asphalt [Ton]	21.32	10
Asphalt [Ton-G]	19.51	6
Base Stone [C.Y.]	1.77	1
Base Stone [Ton]	2.56	2
Bridge [C.Y.]	68.95	3
Bridge [L.F.]	15.85	3
Bridge [Lbs.]	0.34	3
Bridge [S.Y.]	7.68	3
Clearing [L.F.]	22.28	5
Clearing [S.Y.]	168.98	3
Concrete-Misc. [C.Y.]	26.38	1
Concrete-Misc. [L.F.]	2.19	2
Concrete-Misc. [S.Y.]	14.44	3
Concrete Pavement [L.F.]	1.53	1
Concrete Pavement [S.Y.]	13.33	2
Drainage-Inlets/Catch Basins [Each]	328.56	10
Drainage-Inlets/Catch Basins [L.F.]	76.54	1
Drainage-Pipe [L.F.]	11.51	7
Erosion Control [L.F.]	1.45	9
Erosion Control [S.Y.]	93.88	5
Fencing [L.F.]	5.95	1
Grading/Excavation [C.Y.]	367.67	16
Grading/Excavation [S.Y.]	0.09	1
Grassing [Acre]	192.58	6
Grassing [Lbs.]	4.49	2
Grassing [S.Y.]	0.70	3
Guardrail [Each]	259.36	12
Guardrail [L.F.]	2.65	6
Misc. Stone/Riprap [C.Y.]	42.24	3
Painting Structures [S.F.]	4.17	1
Roadway Lighting/Electrical [Each]	190.92	4
Roadway Lighting/Electrical [L.F.]	2.17	4
Signalization [Each]	712.95	7
Signalization [L.F.]	4.40	7
Signs-Permanent [Each]	150.28	8
Signs-Permanent [S.F.]	2.44	5
Striping/Pavement Marking [Each]	14.54	14
Striping/Pavement Marking [L.F.]	0.24	21
Striping/Pavement Marking [L.M.]	79.83	3
Striping/Pavement Marking [Mile]	410.86	3
Traffic Control [Each]	341.07	15
Traffic Control [L.F.]	1.93	4
Traffic Control [S.F.]	0.76	5
Underdrain [L.F.]	5.40	2

CHAPTER 4

Conclusions, Recommendations, and Future Research

Chapter 4 of this report contains two sections. The first section compares the results of the three research methodologies, describes and justifies any modifications, and recommends the final fuel usage factors. The second section presents additional applications of the new fuel usage factors outside of the highway construction industry.

4.1 Comparison of Fuel Usage Estimates

This section combines the three different methods of calculating fuel use factors and recommends factors for each of the categories of work described in previous sections. Comparing the various methods of calculating factors allows the study team to develop factors that represent a broad range of methods while also expanding the scope of the factors outlined in the original Technical Advisory T5080.3.

This section compares and contrasts estimates of fuel use factors that are available from the various study sources and methodologies. This analysis is performed by major category of work. The major categories of work items are as follows:

- Clearing and removal,
- Excavation,
- Base stone,
- Asphalt,
- Milling,
- Structures,
- Miscellaneous concrete,
- Drainage pipe and structures/water/sewer, and
- Specialty items (fencing/guardrail/landscaping/pavement marking/signalization).

For each major category of work, the analysis is divided into two subsections. The first subsection presents the study team's analysis of the fuel use figures developed for each methodology. This analysis considers the following four data sources:

1. **Technical Advisory T5080.3.** This technical advisory presents the fuel factors calculated for the original 1974 HRB effort. These factors are still used by a large number of contractors and state DOTs. If the fuel factors calculated in the other three methodologies are similar to the figures in TAT5080.3, this will provide a level of validation. If the findings differ, the study team should carefully re-evaluate their assumptions and calculations.
2. **Contractor Survey.** The Contractor Fuel Usage Survey (CFUS) represents a cooperative effort by the NCHRP, study team, and industry organizations to engage the highway construction

contracting community. The objective of this effort was to ascertain fuel use information from contractors representing a broad sample of regions, firm sizes, project locations, and work activities. Utilizing an Excel spreadsheet tool and several iterations of a SurveyMonkey survey, this effort resulted in over 500 data observations.

3. **Engineering Analysis.** For this methodology, the study team convened an expert panel of veteran construction engineers and estimators. The engineering team first collaborated to rank construction activities by fuel use intensity and recommend items that should be further analyzed. In later efforts, the engineering team then calculated the fuel use for these activities under average project parameters. This was done by calculating the equipment needed for each activity, the fuel consumed by this equipment, production rates, and the average length of time expected to complete each project. The result is a calculation, for each work activity, that expresses the gallons of fuel consumed per a unit of measure, such as the number of gallons of diesel fuel consumed for each linear foot of sewer pipe.
4. **BidTabs Statistical Analysis.** This experimental methodology attempted to track the relationship between fuel prices and bid estimates. Unlike other elements of a typical construction bid, commodity prices (including fuel) exhibit historical fluctuations due to market variables. This methodology attempted to isolate fuel prices, coalesce them to historical BidTabs data as maintained in the Oman Systems database, and observe any correlations.

For each data source, the major category section lists the assumptions that were made and a brief summary of the findings.

The concluding subsection provides an analysis of the findings within each category and presents the final recommended factors. The chapter concludes with a summary of the general findings.

4.1.1 Clearing and Removal

This subsection presents findings regarding the fuel usage associated with clearing and removal activities. Clearing and removal activities include the clearing of trees and brush, the removal of debris, and the demolition of buildings and structures.

Analysis of the Results

- **1980 Technical Advisory—**Technical Advisory T5080.3 lists 200 gallons per acre in "Additional Fuel Usage Factors by States." There is no listing for any clearing related activities in the main guidelines table.
- **Survey Results—**The number of activities related to clearing and removal items can vary greatly from project to project and region to region. The results of the survey related mainly to the primary "clearing and grubbing" activity. The average of the survey respondents was 194.4 gallons per acre for the clearing tasks.
- **Engineering Study—**The engineering study estimated fuel use for a wide range of activities related to the clearing and removal category.
- **Statistical Analysis—**No meaningful values were able to be extracted from the statistical analysis. The units of measure from the states utilized in the study did not match the units of measure in the survey or the engineering analysis.

Exhibit 4-1 presents the fuel use estimates for clearing and removal work items.

Based on recommendations from the project review panel, the project team calculated an additional fuel usage factor for a bridge demolition task. The structure demolition assumptions and calculations are provided in Exhibits 4-2 and 4-3.

Exhibit 4-1. Clearing and removal engineering results.

Task Description	Fuel Use Per Unit	Units
Clearing – Light	128.876	Gallons/Acre
Clearing – Medium	171.459	Gallons/Acre
Clearing – Heavy	273.347	Gallons/Acre
Pavement Removal - Asphalt	1.397	Gallons/C.Y.
Pavement Removal - Concrete	0.562	Gallons/C.Y.
Pipe Removal - All Sizes	0.863	Gallons/L.F.
Structure Demolition (House/Building)	375.000	Gallons/Each
Structure Demolition (Bridge per S.F. of Deck)	0.626	Gallons/S.F.

Exhibit 4-2. Bridge demolition assumptions.

Characteristic	Assumption
Travel Lanes	Two lanes, 12 foot width each
Bridge Length	100 feet
Shoulders	6 feet each
Footers	3 (left, right, center)
Span	Dry land
Deck Area	3,600 S.F.
Deck Thickness	10 inches

Exhibit 4-3. Bridge demolition calculations.

Task Element	Quantity	Fuel Use Per Unit	Fuel Used for Task Element
Substructure Demolition	177 C.Y.	1.423	251.871 Gallons
Superstructure Demolition	155 C.Y.	1.400	217.000 Gallons
Load Haul Debris	332 C.Y.	5.380	1,785.994 Gallons
		Total Fuel	**2,254.865 Gallons**
		Per S.F.	**0.626 Gallons/S.F.**

Exhibit 4-4. Clearing and removal comparison table.

Task	Technical Advisory T5080.3	Statistical Analysis	Contractor Survey	Engineering Study
Clearing	200.000 Gallons/Acre	N/A	194.400 Gallons/Acre	191.200 Gallons/Acre
Pipe Removal	N/A	N/A	1.750 Gallons/L.F.	0.863 Gallons/L.F.
Pavement Removal	N/A	N/A	0.350 Gallons/C.Y.	0.562-1.397 Gallons/C.Y.

Conclusion

Exhibit 4-4 compares the values from the four different data sources. For comparison purposes, the heavy, medium, and light clearing tasks in the engineering study were combined into an average value, as detail by intensity was available in Technical Advisory T5080.3 or in the survey.

Using the values from Technical Advisory T5080.3 and the survey, the project team was able to confirm the values from the engineering study. Based on these favorable results, the detailed results from the engineering study were selected as the final estimates. This is because the engineering analysis provides estimates for a larger number of tasks than either of the other sources. In summary, the team recommends that the engineering study factors be used.

4.1.2 Grading and Excavation

This section presents the study findings regarding the fuel usage associated with grading activities. Grading activities involve leveling earth in preparation for the installation of highway and road infrastructure.

Exhibit 4-5. Grading engineering results.

Task Description	Fuel Use Per Unit	Units
Grading - Dirt - Off Road - Long Haul	0.320	Gallons/C.Y.
Grading - Dirt - Off Road - Short Haul	0.263	Gallons/C.Y.
Grading - Dirt - On Road - Long Haul	0.687	Gallons/C.Y.
Grading - Dirt - On Road - Short Haul	0.319	Gallons/C.Y.
Grading - Rock - Off Road - Long Haul	0.349	Gallons/C.Y.
Grading - Rock - Off Road - Short Haul	0.258	Gallons/C.Y.
Grading - Rock - On Road - Long Haul	0.687	Gallons/C.Y.
Grading - Rock - On Road - Short Haul	0.412	Gallons/C.Y.
Roadbed Finishing	0.073	Gallons/S.Y.
Rock Drilling and Blasting (Only) (No Haul)	0.053	Gallons/C.Y.

Analysis of the Results

- **1980 Technical Advisory—**The values in Technical Advisory T5080.3 range from 0.38 to 0.64 gallons per cubic yard. This range includes rock and dirt excavation activities.
- **Survey Results—**The survey results were tabulated and adjusted based on an analysis of each response. There were some values that were removed from the sample in that the values were not within realistic ranges. In addition, there were some responses that were not calculated using the requested units of measure. For example, one respondent based their calculations on a per hour fuel consumption rate which is not able to be converted into a per cubic yard rate without additional information.
- **Engineering Study—**The engineering study was able to develop grading estimates for 10 different categories of work, all related to grading activities on a project. Exhibit 4-5 lists the estimates that were developed.
- **Statistical Analysis—**No meaningful values were able to be extracted from the statistical analysis. The value returned from the statistical analysis of 367 gallons per cubic yard does not relate to any factor developed by any other method and is not in the range of realistic values.

Conclusion

Exhibit 4-6 represents the values from the four different data sources. The task list from the contractor survey is very similar to the tasks in the engineering study. Technical Advisory T5080.3 lists values for “rock” and “dirt” excavation only with ranges from low, average, and high. The values shown in the Technical Advisory T5080.3 column in Exhibit 4-6 and Exhibit 4-7 represent the average values from the Technical Advisory T5080.3 table. The engineering study lists a separate task for rock drilling and blasting. Technical Advisory T5080.3 and the contractor survey did not list this task as a separate activity. Therefore, for the purposes of comparison, the engineering study values for rock grading tasks were adjusted upward to include the rock drilling and blasting fuel use factor of 0.053 gallons per cubic yards.

Exhibit 4-6. Grading and excavation comparison table.

Task	Technical Advisory T5080.3	Statistical Analysis	Contractor Survey	Engineering Study
Grading–Dirt Off Road–Long	0.440 Gallons/C.Y.	N/A	0.380 Gallons/C.Y.	0.320 Gallons/C.Y.
Grading–Dirt Off Road–Short	N/A	N/A	0.310 Gallons/C.Y.	0.263 Gallons/C.Y.
Grading–Dirt On Road–Long	N/A	N/A	0.370 Gallons/C.Y.	0.687 Gallons/C.Y.
Grading–Dirt On Road–Short	N/A	N/A	0.310 Gallons/C.Y.	0.319 Gallons/C.Y.
Grading–Rock Off Road–Long	0.570 Gallons/C.Y.	N/A	0.440 Gallons/C.Y.	0.402 Gallons/C.Y.
Grading–Rock Off Road–Short	N/A	N/A	0.350 Gallons/C.Y.	0.311 Gallons/C.Y.
Grading–Rock On Road–Long	N/A	N/A	0.490 Gallons/C.Y.	0.740 Gallons/C.Y.
Grading–Rock On Road -Short	N/A	N/A	0.410 Gallons/C.Y.	0.465 Gallons/C.Y.
Roadway Finishing	N/A	N/A	0.190 Gallons/S.Y.	0.073 Gallons/S.Y.

Exhibit 4-7. Grading and excavation comparison table (dirt vs. rock).

Task	Technical Advisory T5080.3	Statistical Analysis	Contractor Survey	Engineering Study
Grading–Dirt	0.440 Gallons/C.Y.	N/A	0.340 Gallons/C.Y.	0.397 Gallons/C.Y.
Grading–Rock	0.570 Gallons/C.Y.	N/A	0.420 Gallons/C.Y.	0.480 Gallons/C.Y.
Percent Difference	30%		24%	21%

Exhibit 4-8. Grading and excavation comparison table (short vs. long haul).

Task	Technical Advisory T5080.3	Statistical Analysis	Contractor Survey	Engineering Study
Grading–Long	N/A	N/A	0.410 Gallons/C.Y.	0.537 Gallons/C.Y.
Grading–Short	N/A	N/A	0.360 Gallons/C.Y.	0.340 Gallons/C.Y.
Percent Difference			14%	57%

Exhibit 4-9. Grading and excavation comparison table (on road vs. off road).

Task	Technical Advisory T5080.3	Statistical Analysis	Contractor Survey	Engineering Study
Grading–Off Road	N/A	N/A	0.370 Gallons/C.Y.	0.324 Gallons/C.Y.
Grading–On Road	N/A	N/A	0.400 Gallons/C.Y.	0.553 Gallons/C.Y.
Percent Difference			8%	71%

To facilitate comparisons across estimating methodologies, Exhibits 4-7 through 4-9 provide average data for particular types of grading. Exhibit 4-7 provides data by soil type, Exhibit 4-8 provides data by length of haul, and Exhibit 4-9 provides data for on- and off-road hauls. Exhibit 4-7 allows for the closest comparison between the three studies because Technical Advisory T5080.3 includes only two categories of grading (dirt and rock). Using Exhibit 4-6 as a guide, there is substantial agreement in the overall fuel use for grading, but there is also variation concerning the impact of soil type, haul distance, and on/off road project characteristics. The percent difference between the values in Exhibit 4-7, 4-8, and 4-9 varies noticeably between the three studies. For example, the largest discrepancy is found in Exhibit 4-9, where the difference in the estimates between off-road and on-road grading varies by 71 percent in the engineering study and varies by only 8 percent in the contractor study. According to the study team's engineering experts, the cost for grading on-road with smaller, less efficient equipment combined with longer average hauling distances for on-road grading would dictate a much higher fuel use factor for on-road grading. Therefore, the variations due to project characteristics in the contractor survey appear less reliable, and the final fuel factors incorporated the engineering estimates.

4.1.3 Base Stone

This section presents the research team's findings regarding the fuel usage associated with base stone activities. The base stone category involves the hauling, placement, and compacting of base stone for the purpose of creating a stable roadway sub-layer.

Analysis of the Results

- **1980 Technical Advisory—**The values in Technical Advisory T5080.3 study range from 0.535 to 0.825 gallons per ton based on two haul distances, short and long.
- **Survey Results—**There was no meaningful data for hauling and placing base stone from the contractor survey.
- **Engineering Study—**The engineering study was based on a single average haul distance of a 10-mile haul and the results are shown in Exhibit 4-10.
- **Statistical Analysis**—The statistical analysis calculated fuel usage of 2.56 gallons of fuel consumed per ton of base stone (short haul).

Exhibit 4-10. Base stone engineering results.

Task Description	Fuel Use Per Unit	Units
Base Stone – Short Haul (Haul and Place)	0.406	Gallons/Ton

Exhibit 4-11. Base stone comparison table.

Task	Technical Advisory T5080.3	Statistical Analysis	Contractor Survey	Engineering Study
Base Stone – Short Haul	0.535 Gallons/Ton	2.56 Gallons/Ton	N/A	0.406 Gallons/Ton
Base Stone – Long Haul	0.825 Gallons/Ton	N/A	N/A	0.406 Gallons/Ton

Exhibit 4-12. Revised base stone comparison table.

Task	Technical Advisory T5080.3	Statistical Analysis	Contractor Survey	Engineering Study
Base Stone – Short Haul	0.535 Gallons/Ton	2.56 Gallons/Ton	N/A	0.406 Gallons/Ton
Base Stone – Long Haul	0.825 Gallons/Ton	N/A	N/A	0.558 Gallons/Ton

Conclusion

Exhibit 4-11 represents the values from the four different data sources. Technical Advisory T5080.3 lists values for both long and short haul, where the engineering study only lists one value for the task.

Technical Advisory T5080.3 values are considerably higher, even for the short-haul option, than the results of the engineering study. As can be seen in other areas of the study (specifically the grading and asphalt sections), the haul distance can play a significant role on the amount of fuel consumed. Based on this analysis, the research team adjusted the engineering study to reflect a short- and long-haul distance to more closely resemble Technical Advisory T5080.3. The following table represents the updated engineering study using short and long hauls. For the purposes of the engineering study, short-haul distances are defined as 10 miles from the quarry to the project site and long-haul distances are defined as 20 miles from the quarry to the project site. Exhibit 4-12 displays fuel consumption information with the revised engineering calculations.

4.1.4 Asphalt

This section presents the research team's findings regarding the fuel usage associated with asphalt activities. Asphalt activities include the laying of hot mix asphalt in leveling, structural, and surface courses.

Analysis of the Results

- **1980 Technical Advisory—**Exhibit 4-13 lists the average fuel use factors for asphalt operations in each of three tasks: production, hauling, and placement. Placement includes place and compact. The production factor is based on using diesel fuel for the plant heating and drying operation. In Attachment 1 of Technical Advisory T5080.3 there is no adjustment listed for natural gas–operated plants. However, Attachment 2 contains a note that states, ". . . if natural gas is used for aggregate drying, deduct 2.00 Gallons/Ton."
- **Survey Results—**The survey results were tabulated and adjusted based on an analysis of each response. There were some values that were removed from the sample in that the values were not within realistic ranges. In addition, some of the responses were not in the requested unit of measure and they could not be converted without additional information.

Exhibit 4-13. Asphalt items within Technical Advisory T5080.3.

Task Description	Fuel Use Per Unit	Units
Production	2.570	Gallons/Ton
Hauling (0-10 miles)	0.510	Gallons/Ton
Hauling (10-20 miles)	0.810	Gallons/Ton
Placement	0.280	Gallons/Ton

- **Engineering Study—**The engineering study was based on three different average haul distances (0–5 miles, 5–15 miles, over 15 miles) as well as three different mix types (leveling, structural, and surface courses). Each of the values in Exhibit 4-14 includes plant production, hauling, and placing and compacting. The plant production is based on diesel fuel as the main drying fuel source.
- **Statistical Analysis—**No meaningful values were able to be extracted from the statistical analysis.

Conclusion

Exhibit 4-15 represents the values from the four different data sources. Technical Advisory T5080.3 lists values for both long and short hauls while the engineering study only lists one value for the task.

As illustrated in Exhibit 4-15, the comparisons between data sources are not based on the same breakdown of cost. In order to obtain a better basis of comparison, the engineering team restructured the engineering study to separate the production, hauling, and placement activities. During this process, it was discovered that there was a substantial difference in the estimates of plant fuel consumption rates for the drying operation.

Converting the consumption rates from Technical Advisory T5080.3, the contractor survey and the engineering study based on an average plant production of 200.000 tons per hour yielded the following results:

- Technical Advisory T5080.3 (2 Gallons/Ton): 400.000 Gallons/Hour,
- Contractor Survey (1.98 Gallons/Ton): 396.000 Gallons/Hour,
- Engineering Study: 40.000 Gallons/Hour, and
- Additional Source: Astec Plant Guideline (2 Gallons/Ton): 400.000 Gallons/Hour.

Based on these values, the engineering study was updated to use a plant capacity of 200.000 tons per hour and a fuel consumption rate of 400 gallons per hour. In addition, the variance between

Exhibit 4-14. Asphalt engineering results.

Task Description	Fuel Use Per Unit	Units
Hot Mix Asphalt - Leveling Course (0-5 Mile Haul)	0.892	Gallons/Ton
Hot Mix Asphalt - Leveling Course (5-15 Mile Haul)	0.977	Gallons/Ton
Hot Mix Asphalt - Leveling Course (Over 15 Mile Haul)	1.061	Gallons/Ton
Hot Mix Asphalt - Structural Course (0-5 Mile Haul)	0.580	Gallons/Ton
Hot Mix Asphalt - Structural Course (5-15 Mile Haul)	0.718	Gallons/Ton
Hot Mix Asphalt - Structural Course (Over 15 Mile Haul)	0.745	Gallons/Ton
Hot Mix Asphalt - Surface Course (0-5 Mile Haul)	0.770	Gallons/Ton
Hot Mix Asphalt - Surface Course (5-15 Mile Haul)	0.847	Gallons/Ton
Hot Mix Asphalt - Surface Course (Over 15 Mile Haul)	0.994	Gallons/Ton

Exhibit 4-15. Asphalt comparison table.

Task	Technical Advisory T5080.3	Statistical Analysis	Contractor Survey	Engineering Study
Asphalt Production (Diesel)	2.570 Gallons/Ton (2.000 for Plant)	N/A	1.980 Gallons/Ton	N/A
Asphalt Production (Gas)	0.570 Gallons/Ton (Support Equipment)	N/A	268,000.000 BTU/Ton plus 0.110 Gallons/Ton (Support Equipment)	N/A
Hauling 0-10 Miles	0.680 Gallons/Ton	N/A	N/A	N/A
Hauling 10-20 Miles	1.070 Gallons/Ton	N/A	N/A	N/A
Placement	0.280 Gallons/Ton	N/A	0.580 Gallons/Ton (Average of All Mix Types)	N/A
Hauling 0-5 Miles	N/A	N/A	0.190 Gallons/Ton	0.747 Gallons/Ton (Average All Mix Types) (Includes Production and Placement)
Hauling 5-15 Miles	N/A	N/A	0.380 Gallons/Ton	0.847 Gallons/Ton (Average All Mix Types) (Includes Production and Placement)
Hauling >15 Miles	N/A	N/A	0.760 Gallons/Ton	0.933 Gallons/Ton (Average All Mix Types) (Includes Production and Placement)

mix types in the contractor survey was not significant, and many respondents reported the same fuel use values for each mix type. The haul distance was a much larger factor in determining fuel consumption than place and compact activities. Therefore, the engineering study was updated to include an average for all mix types.

Warm mix asphalt (WMA) represents a minor but growing segment of the asphalt paving industry. WMA is produced at temperatures that are between 30 and 120 degrees cooler than hot mix asphalt (HMA). These reduced temperatures during production result in fuel savings. Current FHWA guidance states that WMA production requires 20 percent less fuel than HMA production. Contractor survey results and selected interviews with warm mix asphalt contractors indicated that hauling and placement fuel usage does not markedly differ between hot and warm mix asphalt.

The contractor survey attempted to collect WMA fuel use information independent of HMA fuel usage. However, the survey effort did not garner enough distinct fuel use information from WMA to contribute to the development of fuel factors. To account for the growing use of WMA production procedures, the study team created three WMA production fuel usage factors. The first is for diesel plants and is presented in gallons per ton, the second is for natural gas plants in BTUs per ton, and the third is natural gas support equipment. These factors were computed by applying the 20 percent plant production fuel reduction estimate developed by the FHWA to the three existing asphalt production fuel factors. The study team also converted the two natural gas asphalt production items to a gallons of gasoline equivalent (GGE) of 125,000 BTUs per gallon, a common benchmark in the estimating industry. Exhibit 4-16 presents a comparison table that contains the revised asphalt fuel usage data.

4.1.5 Milling

This section presents the research team's findings regarding the fuel usage associated with milling activities. Milling is the act of reclaiming asphalt concrete from roadways so that it may be recycled or discarded.

Exhibit 4-16. Revised asphalt comparison table.

Task	Technical Advisory T5080.3	Statistical Analysis	Contractor Survey	Engineering Study
Asphalt Production (Diesel)	2.570 Gallons/Ton (2.000 for Plant)	N/A	1.980 Gallons/Ton	2.040 Gallons/Ton
Asphalt Production (Gas)	0.570 Gallons/Ton (Support Equipment)	N/A	2.144 Gallons (GGE)/Ton 0.110 Gallons/Ton (Support Equipment)	0.090 Gallons/Ton (Support Equipment)
Warm Mix Asphalt Production (Diesel)	N/A	N/A	N/A	1.632 Gallons/Ton
Warm Mix Asphalt Production (Gas)	N/A	N/A	N/A	1.715 Gallons (GGE)/Ton 0.072 Gallons/Ton (Support Equipment)
Hauling 0-5 Miles	0.680 Gallons/Ton (0-10 Mile Haul)	N/A	0.190 Gallons/Ton	0.183 Gallons/Ton
Hauling 6-15 Miles	N/A	N/A	0.380 Gallons/Ton	0.293 Gallons/Ton
Hauling >15 Miles	1.070 Gallons/Ton (10-20 Mile Haul)	N/A	0.760 Gallons/Ton	0.514 Gallons/Ton
Placement	0.280 Gallons/Ton	N/A	0.580 Gallons/Ton	0.273 Gallons/Ton

Exhibit 4-17. Milling engineering results.

Task Description	Fuel Use Per Unit	Units
Milling (0-1") (0-5 Mile Haul)	0.010	Gallons/S.Y.
Milling (0-1") (5-15 Mile Haul)	0.011	Gallons/S.Y.
Milling (0-1") (Over 15 Mile Haul)	0.014	Gallons/S.Y.
Milling (2-4") (0-5 Mile Haul)	0.013	Gallons/S.Y.
Milling (2-4") (5-15 Mile Haul)	0.018	Gallons/S.Y.
Milling (2-4") (Over 15 Mile Haul)	0.025	Gallons/S.Y.

Analysis of the Results

- **1980 Technical Advisory—**Technical Advisory T5080.3 does not include any data for milling operations.
- **Survey Results—**The results from the survey were consistent for each question. The detailed data for each haul distance was also consistent and logical. The results of the survey showed a significant difference from the values developed in the engineering study.
- **Engineering Study—**The engineering study was able to break down the milling activities into two basic work activities based on milling depth, and then each of these two depths was further broken down into three different haul lengths. Exhibit 4-17 lists the results.
- **Statistical Analysis—**No meaningful values were able to be extracted from the statistical analysis.

Conclusion

Exhibit 4-18 represents the values from the four different data sources. The contractor survey values are considerably higher than the engineering study for all thicknesses and haul distances. Based on these results, the engineering team revisited the parameters used in the engineering

Exhibit 4-18. Milling comparison table.

Task	Technical Advisory T5080.3	Statistical Analysis	Contractor Survey	Engineering Study
Milling 0-1” 0-5 mile haul	N/A	N/A	0.026 Gallons/Ton	0.010 Gallons/Ton
Milling 0-1” 6-15 mile haul	N/A	N/A	0.034 Gallons/Ton	0.011 Gallons/Ton
Milling 0-1” >15 mile haul	N/A	N/A	0.044 Gallons/Ton	0.014 Gallons/Ton
Milling 2-4” 0-5 mile haul	N/A	N/A	0.050 Gallons/Ton	0.013 Gallons/Ton
Milling 2-4” 6-15 mile haul	N/A	N/A	0.070 Gallons/Ton	0.018 Gallons/Ton
Milling 2-4” >15 mile haul	N/A	N/A	0.094 Gallons/Ton	0.025 Gallons/Ton

Exhibit 4-19. Revised milling production rates.

	0-1” Thick	2-4” Thick
Original Production Rate	6,250 S.Y./Hour	6,250 S.Y./Hour
Revised Production Rate	2,570 S.Y./Hour	1,150 S.Y./Hour

study. The specific areas that were re-evaluated were the hauling cycle times and the crew production rates.

Based on this analysis, it was determined that the cycle times were too short based on “average” traffic conditions. On average across each of the milling tasks this added approximately one hauling unit to each activity. The other area the team re-evaluated was the production rates used for the milling activity. After some recalculation, the per square yard production rate for 0–1″ thick milling was based on maximum machine milling rates as opposed to average project rates. In addition, the 2–4″ thick milling production rate was further reduced on a “per square yard” basis since the volume of material increases approximately three times based on the average thickness. The milling production adjustments are presented in Exhibit 4-19.

Exhibit 4-20 has been updated to reflect these two adjustments in the engineering study. With the revised factors, the values reflected in the survey and the engineering study are more reflective of current construction practice.

4.1.6 Structures

This section presents the study findings regarding the fuel usage associated with structures. Activities under this category include the various actions required to build a structure, including the laying of substructure and superstructure concrete, reinforcing steel, and steel beams.

Analysis of the Results

- **1980 Technical Advisory—**Technical Advisory T5080.3 lists fuel use factors for structures based on the number of gallons per contract dollar. This value ranges from 20 to 60 gallons per $1,000.
- **Survey Results—**The survey results were very limited. The results for the concrete pavement items were somewhat consistent with half of the responses specifically excluding the hauling from the calculations. Given the limited number of responses and the large variations in the values for the other concrete items (sidewalk, curb and gutter, and retaining walls), the data were not able to be used in the analysis.
- **Engineering Study—**The engineering team formulated fuel use estimates for each of the elements of bridge construction.
- **Statistical Analysis—**No meaningful values were able to be extracted from the statistical analysis.

Exhibit 4-20. Revised milling comparison table.

Task	Technical Advisory T5080.3	Statistical Analysis	Contractor Survey	Engineering Study
Milling 0-1” 0-5 Mile Haul	N/A	N/A	0.026 Gallons/Ton	0.028 Gallons/Ton
Milling 0-1” 6-15 Mile Haul	N/A	N/A	0.034 Gallons/Ton	0.030 Gallons/Ton
Milling 0-1” >15 Mile Haul	N/A	N/A	0.044 Gallons/Ton	0.038 Gallons/Ton
Milling 2-4” 0-5 Mile Haul	N/A	N/A	0.050 Gallons/Ton	0.062 Gallons/Ton
Milling 2-4” 6-15 Mile Haul	N/A	N/A	0.070 Gallons/Ton	0.071 Gallons/Ton
Milling 2-4” >15 Mile Haul	N/A	N/A	0.094 Gallons/Ton	0.090 Gallons/Ton

Exhibit 4-21. Structure construction assumptions.

Characteristic	Assumption
Travel Lanes	Two lanes, 12 foot width each
Bridge Length	100 feet
Shoulders	6 feet each
Footers	3 (left, right, center)
Span	Dry land
Deck Area	3,600 S.F.
Deck Thickness	10 inches

Exhibit 4-22. Structure construction calculations.

Construction Calculation			
Task Element	**Quantity**	**Fuel Use Per Unit**	**Fuel Used for Task Element**
Substructure			
Piling	840 L.F.	0.433	363.720 Gallons
Excavation	68 C.Y.	0.975	66.300 Gallons
Form Footings	3 Each	16.000	48.000 Gallons
Form Substructure	109 C.Y.	2.972	323.948 Gallons
Place and Tie Rebar	44,250 Lbs.	0.004	177.000 Gallons
Pour Footing	68 C.Y.	0.951	64.668 Gallons
Pour Substructure	109 C.Y.	3.511	382.699 Gallons
Superstructure			
Form Deck	115 C.Y.	2.522	290.030 Gallons
Place and Tie Rebar	28,750 Lbs.	0.004	115.000 Gallons
Pour Deck	115 C.Y.	1.774	204.010 Gallons
Place and Tie Rebar	10,000 Lbs.	0.004	40.000 Gallons
Pour Barrier Wall	40 C.Y.	3.600	144.000 Gallons
		Total Fuel	**2,219.375 Gallons**
		Per S.F.	**0.616 Gallons/S.F.**

Exhibit 4-23. Structures engineering results.

Task Description	Fuel Use Per Unit	Units
Reinforcing Steel	0.004	Gallons/L.B.
Steel Beams	0.180	Gallons/L.F.
Substructure Concrete	4.700	Gallons/C.Y.
Superstructure Concrete	4.150	Gallons/C.Y.
Bridges	5.200	Gallons/Contract $
Bridges (per S.F. of Deck)*	0.616	Gallons/S.F.

*Additional task calculated following panel input

One of the main products of this project is the formulation of a fuel usage factor for bridge construction that is measured on a square foot basis and not on a per contract dollar basis. The project team estimated the construction steps and components, quantities, fuel used, and—finally—the gallons of fuel used per square foot of deck for a medium-sized bridge. The assumptions of the bridge size and design, as well as the actual calculation, are presented in Exhibits 4-21 and 4-22.

Exhibit 4-23 presents the results of the engineering analysis.

Exhibit 4-24. Structures comparison table.

Task	Technical Advisory T5080.3	Statistical Analysis	Contractor Survey	Engineering Study
Reinforcing Steel	20-60 Gallons/$1,000	N/A	0.003 Gallons/Lbs.	0.004 Gallons/Lbs.
Steel Beams	20-60 Gallons/$1,000	N/A	1.390 Gallons/L.F. (2)	0.180 Gallons/L.F.
Substructure Concrete	20-60 Gallons/$1,000	N/A	7.950 Gallons/C.Y.	4.700 Gallons/C.Y.
Superstructure Concrete	20-60 Gallons/$1,000	N/A	5.110 Gallons/C.Y.	4.150 Gallons/C.Y.

Exhibit 4-25. Structures comparison table per contract dollar.

Task	Technical Advisory T5080.3	Engineering Study
Reinforcing Steel	20-60 Gallons/$1,000	5.200 Gallons/$1000

Conclusion

Exhibit 4-24 presents the values from the four different data sources.

In order to compare Technical Advisory T5080.3 values with the other results, the research team investigated average unit prices for a select group of items that closely match the items listed in the above tables. The results of this analysis are listed in Exhibit 4-25.

Based on the results of this analysis there is a very large variance in the values calculated in gallons per $1,000. It is apparent that the costs have increased substantially between 1980 and 2011. For example, if the cost has doubled over a set period of time, then a fuel factor based on dollars of contract will be reduced by 50 percent (assuming little change in construction methods requiring equipment and little change in fuel economy). Increased construction costs over the 30-year span accounts for a large amount of this change.

4.1.7 Miscellaneous Concrete

This section presents the research team’s findings regarding the fuel usage associated with miscellaneous concrete activities. This category includes the installation of concrete medians, barriers, retaining walls, curbs, gutters, and sidewalks, as seen in Exhibit 4-26.

Analysis of the Results

- **1980 Technical Advisory—**Technical Advisory T5080.3 lists item factors only for concrete pavement. These factors are further broken down by production, hauling, and placement, as shown in Exhibit 4-27.
- **Survey Results—**The survey results were limited. The results for the concrete pavement items were somewhat consistent with half of the responses specifically excluding the hauling from the calculations. Given the limited number of responses and the large variations in the values for the other concrete items (sidewalk, curb and gutter, and retaining walls) the data were not able to be used in the analysis.
- **Engineering Study—**The engineering study developed factors for each of the items listed in Exhibit 4-26. The factors in the engineering study include “ready-mix” truck hauling in the calculations and concrete plant production.
- **Statistical Analysis—**No meaningful values were able to be extracted from the statistical analysis.

Exhibit 4-26. Miscellaneous concrete engineering results.

Task Description	Fuel Use Per Unit	Units
Concrete Pavement (</= 6 Thick)	0.650	Gallons/S.Y.
Concrete Pavement (>6 Thick)	0.867	Gallons/S.Y.
Curb and Gutter	0.135	Gallons/L.F.
Retaining Wall	0.729	Gallons/S.F.
Sidewalk	0.360	Gallons/L.F.
Concrete Curb/Gutter*#	0.152	Gallons/L.F.
Concrete Sidewalk*#	0.090	Gallons/S.F.
Retaining Wall (Cast-in-Place)*#	0.646	Gallons/S.F.
Noise Wall (Pre-Cast)*	0.304	Gallons/S.F.
Concrete Median Barrier*#	0.309	Gallons/L.F.

* Additional tasks calculated following panel input.
# Includes concrete production and hauling.

Conclusion

Exhibit 4-27 represents the values from the four different data sources.

Based on these estimates, the engineering team separated the hauling of the concrete from the placement activities in order to facilitate comparisons. The original study was based on a single average haul distance of 10 miles. To be consistent with other areas within the engineering study, the team established a short- and a long-haul activity using 10 miles for the short haul and 20 miles for the long haul. Exhibit 4-28 presents a comparison table that reflects the revised hauling calculations.

As can be seen in the adjusted engineering calculations, the factors between the three studies are consistent. Two observations in the study need to be highlighted. First, there is an observable variance between the Technical Advisory T5080.3 factor for placement (0.450 Gallons/C.Y.) and the other two results in the survey and engineering study (0.300 and 0.267 Gallons/C.Y.). The second area relates to the value for the concrete production. The survey and the engineering study did not address this activity. This is because production of concrete is generally undertaken by a third party, not by the contractor placing the concrete.

Exhibit 4-27. Miscellaneous concrete comparison table.

Task	Technical Advisory T5080.3	Statistical Analysis	Contractor Survey	Engineering Study
Concrete Production	0.43 Gallons/C.Y.	N/A	N/A	N/A
Concrete Hauling	1.00 Gallons/C.Y.	N/A	0.050 Gallons/C.Y./Mile (1 Response)	N/A
Placement	0.45 Gallons/C.Y.	N/A	0.300 Gallons/C.Y.	0.759 Gallons/C.Y. Average Including Haul

Exhibit 4-28. Revised hauling comparison table.

Task	Technical Advisory T5080.3	Statistical Analysis	Contractor Survey	Engineering Study
Concrete Production	0.430 Gallons/C.Y.	N/A	N/A	N/A
Concrete Hauling – Short Haul	1.000 Gallons/C.Y.	N/A	0.050 Gallons/C.Y./Mile (1 Response)	0.600 Gallons/C.Y.
Concrete Hauling – Long Haul	1.000 Gallons/C.Y.		0.050 Gallons/C.Y./Mile	1.100 Gallons/C.Y.
Placement	0.450 Gallons/C.Y.	N/A	0.300 Gallons/C.Y.	0.267 Gallons/C.Y.

Exhibit 4-29. Drainage pipe and structures engineering results.

Task Description	Fuel Use Per Unit	Units
Drainage Structures	8.725	Gallons/C.Y.
Large Pipe Crew (> 36" Pipe)	4.338	Gallons/L.F.
Medium Pipe Crew (>18" to 36" Pipe)	1.481	Gallons/L.F.
Sewer Line (Over 4' Depth)	2.090	Gallons/L.F.
Sewer Line (Up to 4' Depth)	1.045	Gallons/L.F.
Small Pipe Crew (</= 18" Pipe)	0.871	Gallons/L.F.
Water Line (Over 4' Depth)	2.090	Gallons/L.F.
Water Line (Up to 4' Depth)	1.045	Gallons/L.F.
Water/Sewer Manholes	5.000	Gallons/Each

4.1.8 Drainage Pipe and Structures

This section presents the research team's findings regarding the fuel usage associated with drainage pipe and structure activities. This category includes the installation of concrete water and sewage pipes.

Analysis of the Results

- **1980 Technical Advisory—**Technical Advisory T5080.3 does not include any data for laying any type of pipe (storm drain, water, or sewer).
- **Survey Results—**The survey results were limited and varied substantially between water and sewer items to the point where the results were not meaningful.
- **Engineering Study—**The engineering study was able to break down the drainage tasks into multiple categories of work all related to storm sewer, water line, and sanitary sewer activities on a project. Exhibit 4-29 lists the results.
- **Statistical Analysis—**No meaningful values were able to be extracted from the statistical analysis.

Conclusion

Exhibit 4-30 represents the values from the four different data sources where there was data available to compare. As mentioned in the contractor survey section, the limited and variable data for the water and sanitary sewer activities were not able to be used in a comparison.

The values in all the tasks are somewhat variable with the storm pipe structures item variance significantly higher than that for the other tasks. This is due to the unit of measures being different between the two studies. The survey results are based on a per structure basis, whereas the engineering study is based on a per cubic yard of concrete included in each structure. In order to compare these values, the engineering team developed an estimate of the number of cubic yards per structure for "average" conditions of 3.000 cubic yards per structure. Based on this factor, the storm pipe comparison is shown in Exhibit 4-31.

Exhibit 4-30. Drainage pipe and structures comparison table.

Task	Technical Advisory T5080.3	Statistical Analysis	Contractor Survey	Engineering Study
Large Pipe Crew	N/A	N/A	3.308 Gallons/Ton	4.338 Gallons/L.F.
Medium Pipe Crew	N/A	N/A	2.332 Gallons/Ton	1.481 Gallons/L.F.
Small Pipe Crew	N/A	N/A	1.600 Gallons/Ton	0.871 Gallons/L.F.
Storm Pipe Structures	N/A	N/A	40.715 Gallons/Each	8.725 Gallons/C.Y.

Exhibit 4-31. Revised drainage pipe and structures comparison table.

Task	Technical Advisory T5080.3	Statistical Analysis	Contractor Survey	Engineering Study
Storm Pipe Structures	N/A	N/A	40.715 Gallons/Each	26.175 Gallons/Each

Exhibit 4-32. Specialty items engineering results.

Task Description	Fuel Use Per Unit	Units
Fence Gates	4.250	Gallons/Each
Fencing (Over 6' Height)	0.043	Gallons/L.F.
Fencing (Up to 6' Height)	0.043	Gallons/L.F.
Grassing (Hydro Seeding)	3.497	Gallons/Acre
Guardrail Posts	0.042	Gallons/Each
Intersection Signalization (2 Lane)	170.000	Gallons/Each
Intersection Signalization (4 Lane)	340.000	Gallons/Each
Seedbed Preparation	10.000	Gallons/Acre
Skip Pavement Marking	4.500	Gallons/L.M.
Solid Pavement Marking	4.500	Gallons/L.M.
Sod	0.017	Gallons/S.Y.
Steel Guardrail	0.037	Gallons/L.F.
Strip Topsoil	0.167	Gallons/C.Y.
Wire/Cable Guardrail	0.105	Gallons/L.F.

4.1.9 Specialty Items

This section presents the research team's findings regarding the fuel usage associated with specialty items. This category includes other items that are not categorized in the above areas, including signalization, fencing, striping, and other activities.

Analysis of the Results

- **1980 Technical Advisory—**Technical Advisory T5080.3 lists none of the activities included in this section.
- **Survey Results—**No meaningful values were able to be extracted from the contractor survey.
- **Engineering Study—**The engineering study developed factors for each of the items listed in Exhibit 4-32.
- **Statistical Analysis—**No meaningful values were able to be extracted from the statistical analysis.

4.1.10 Conclusion

For this effort, the research team compared data across the three study methodologies and the original fuel factors as presented in Technical Advisory T5080.3. Where the research had enough data to make a valid comparison, there was substantial agreement between the sources regarding activity fuel use. In particular, the survey data validated the engineering estimates. Where there was disagreement among the data sources, the engineering estimates were reassessed and generally revised to reflect the figures garnered from the survey effort.

4.2 Other Potential Applications of Fuel Use Data

The purpose of this section is to explore other potential applications of the fuel usage data developed in this study. The primary intended audience or "market" for the products of this study will be the state DOTs and, in particular, the contracting authorities that request bids for highway construction or maintenance. However, this guidance will also be useful for a variety of other entities and uses.

The research team undertook a variety of activities in order to explore these other potential activities. First, the team queried selected state DOT representatives to ascertain whether they envisioned additional uses for the fuel factor data. Second, the team reached out to the NCHRP project panel for their input and assistance. In both instances, the inquiries polled respondents on their impressions as to the usefulness of the data to potential users. Finally, the team reviewed pertinent literature collected throughout the study for information on potential additional audiences.

The research revealed six major additional markets for the results of this study. These include the following:

- Other agencies responsible for highway contracting;
- Agencies responsible for construction of facilities for other transportation modes;
- Associations representing industries that build highways or provide goods to highway builders;
- Officials interested in improving planning and budgeting;
- Contractors interested in better understanding and managing their fuel use or in preparing more accurate cost estimates; and
- Researchers examining energy requirements, emissions, and climate change.

The following sections describe each of these markets. Included in each section is a description of the market, an overview of the potential application of the fuel factors data within that market, and a summary of respondent's impressions as to the usefulness of the data to potential users in that market.

4.2.1 Other Agencies Responsible for Highway Contracting

The most evident alternative application of fuel factors is their use by contracting authorities at other governmental levels (federal, county, MPO, city, town, local) that purchase highway construction. Based on the knowledge of the expert engineering panel, at present, the use of fuel factors at these jurisdictions is extremely rare because these entities employ a much lower level of budgeting and project estimating.

State DOTs, however, do not maintain ownership over the majority of roads. For example, Exhibit 4-33 provides data for 2008 on the ownership of road mileage by jurisdiction. State highway agencies own only 19.3 percent of roads, while counties own 44.0 percent, and towns and municipalities own 32.0 percent. These totals include 1,324,245 miles of unpaved roads,

Exhibit 4-33. Ownership of road mileage by jurisdiction, 2008.

Ownership	Miles	Percent of Miles
State Highway Agency	784,312	19.3
County	1,788,039	44.0
Town, Township, Municipal	1,298,413	32.0
Other Jurisdictions	57,021	1.4
Federal Agency	131,558	3.2
Total	**4,059,343**	**100.0**

Highway Statistics 2008, Table HM-16, "Public Road Length – 2008 Miles by Ownership and Federal-Aid Highways National Summary," October 2009, Federal Highway Administration, accessed at URL: http://www.fhwa.dot.gov/policyinformation/statistics/2008/hm16.cfm

Exhibit 4-34. Ownership of bridges by jurisdiction, 2008.

Ownership	Bridges	Percent of Bridges
State Highway Agency	281,725	46.6
County Highway Agency	229,047	37.9
Town or Township Highway Agency	29,560	4.9
City or Municipal Highway Agency	42,811	7.1
State Park, Forest, or Reservation Agency	1,040	0.2
Local Park, Forest, or Reservation Agency	78	0.0
Other State Agencies	904	0.1
Other Local Agencies	1,292	0.2
Private (other than railroad)	510	0.1
Railroad	856	0.1
State Toll Authority	7,476	1.2
Local Toll Authority	743	0.1
Federal	8,150	1.3
Unknown	301	0.0
Total	**604,493**	**100.0**

Highway Statistics 2010, Table BR-6, "Highway Bridge by Owner – Counts as of December 2010," October 2009, Federal Highway Administration, accessed at URL: http://www.fhwa.dot.gov/bridge/nbi/ownercount10.cfm

which account for 32.6 percent of all roads. Although ownership data for paved roads is only available for select functional classes, available data are sufficient to establish that state highway agencies own no more than 28.5 percent of paved roads. The upper range estimate assumes that state highway agencies own all minor collectors (179,622 miles). Also included is mileage for functional classes for which paved mileage is available for state highway agencies including rural roads (472,237 miles) and urban roads (128,155 miles). The sum represents 28.5 percent off all paved roads (2,734,102 miles).

The ownership situation is similar for bridges. As shown in Exhibit 4-34, state highway agencies own only 46.6 percent of bridges while counties own 37.9 percent, towns own 4.9 percent, and cities and municipalities own 7.1 percent.

Given the large percentage of roads that non-state jurisdictions build, own, and maintain, these other jurisdictions represent a large potential user of fuel factors and price adjustment clauses.

4.2.2 Agencies Responsible for Other Modes

In addition to public roads, a number of public and private entities build and maintain roads, other paved surfaces similar to roads, and other graded rights-of-way that require preparation similar to a highway right-of-way. Some of these facility types include

- Airports,
- Parking facilities,
- Transit facilities,
- Private roads at commercial and industrial facilities,
- Private roads at residential communities or subdivisions,
- Railroads, and
- Ports.

Airports, both public and private, maintain entrance roads, service roads, parking lots, and runways. Grading and paving activities, for which fuel factors were developed, would carry over to airport construction and expansion. Parking facilities include roadways, parking surfaces (which are akin to road surfaces), and parking ramps (which are structures with some similarities to bridges). Transit facilities include roadways and rail rights-of-way, which require clearing, grading, landscaping, drainage, and base stone activities that are similar to roadways. Many commercial and industrial facilities include roadways. Similarly, many residential communities, subdivisions, and multifamily developments include private roads.

Additionally, freight bureaus within DOTs and MPOs work with local agencies and railroad companies and often are involved with rail-highway grade crossing improvements and reconstruction, which is another area where fuel factors could apply. In addition, railroads use construction materials in their bituminous underlayment of tracks and other facilities. Such activities might apply to port facility construction as well.

Additionally, there is a possibility that the fuel factors formulated for several heavy construction activities, such as clearing and grubbing or grading, could be used as surrogates for activities in open-pit mining, farming, environmental clean-up, or heavy industrial operations.

Each of the entities procuring these roadways or roadway type elements may have interest in adopting fuel-price adjustment clauses for their contracts. The fuel factors developed in this study or the methodology used to develop the fuel factors may be useful in developing project-specific fuel quantities that will be subject to the adjustment factor.

4.2.3 Associations Representing Relevant Industries

Association officials involved with industries that build highways or provide goods to highway builders may be interested in fuel factors for various reasons. One use would be to educate their members as to the benefits of conservation efforts. Another would be to help their members understand how price fluctuations can affect both their bottom line and their competitiveness. Associations can also provide the data in guidance and tools that allow their members to develop estimates for bidding purposes that are more accurate.

4.2.4 Officials Interested in Improving Planning and Budgeting

State DOTs can also use the updated fuel factors in the development of more accurate state engineer's estimates for planning and budgeting purposes. For example, the NCHRP noted that the fuel factors might be useful to planning groups or planning studies in developing comparative data for impacts of alternative development scenarios.

In particular, rapid changes in fuel prices can complicate highway construction planning and budgeting. DOTs may find that bids come in higher or lower than expected or that price adjustment clauses cause unexpected changes in project costs. For example, fuel and asphalt prices during fall 2009 allowed ARRA funds to cover more projects than expected. "States are routinely receiving low bids for highway and airport construction projects that are 10 to 20 percent, and in some cases, 30 percent lower than expected." Understanding the amounts of fuel that projects will consume can allow DOTs to better understand and plan for price fluctuations.

However, according to one state DOT official, fuel price information is useful for formulating price adjustments based on what actually happens. The intent of all the price adjustments is to minimize that portion of cost risk in the longer duration public contracts. In this official's opinion, trying to use historical data for future planning and estimating is a futile attempt, as "past performance should be taken as no indication of future performance."

4.2.5 Contractors

Contractors can use fuel factor data to better understand and manage their fuel use and to prepare more accurate cost estimates. Although most contractors have systems and other methods to estimate their fuel use, the availability of updated fuel factors can provide them with a benchmark to assess their estimates as well as their level of fuel efficiency.

One state DOT official, however, had a contrasting view of contractor need for fuel factors. Based on this official's experience with the contracting industry, it was this state DOT official's belief that "Contractors already have a thorough understanding of fuel futures. The only thing that may be useful is the maximum expected growth of a factor."

4.2.6 Researchers and Modelers

Researchers and modelers may use fuel factors or the engineering data on equipment and fuel consumption rates in research studies. Topics might include climate change, particulate emissions, or the energy requirements of alternative construction techniques. For example, fuel factor data might be useful in the development of air pollution models in non-attainment areas.

The fuel factors and related estimates could be especially beneficial for transportation planning purposes. Although many MPOs and some DOTs have begun to estimate energy and operational greenhouse gas (GHG) emissions from the transportation systems they oversee, few have gone beyond that level of effort to evaluate construction and maintenance emissions. These emissions can be a significant contribution to the overall carbon footprint of the transportation system. In addition, many state climate action plans (and in the future, perhaps, MPO/state DOT GHG reduction plans) include infrastructure strategies such as HOV/HOT lanes, bus and rail transit, congestion reduction in general purpose lanes, and bicycle and pedestrian projects. Without a good understanding of the construction and maintenance impacts of these types of projects, planners cannot know whether these projects truly reduce energy and emissions on a life-cycle basis, or whether they provide meaningful reductions by the target years in the climate action plan or other GHG planning document.

There are many examples of these types of research. For example, the authors of this report are currently part of a team developing a tool for the FHWA designed to quantify emissions from the construction and maintenance of transportation infrastructure projects (e.g., roadways and transit projects). That study uses the results of this study in its application. Specifically, the fuel factors developed in this study are combined with quantities to directly estimate GHG emissions. In order to produce a comprehensive analysis of the GHG impacts of proposed regional or statewide transportation plan alternatives, planners must consider the emissions associated with construction and maintenance. The information gathered in this project will be useful for both planners interested in quantifying these emissions, and state and local DOTs interested in reducing these emissions. This will also include information and data regarding the costs associated with the practices to reduce GHG emissions. These will provide practitioners with the basis for cost-benefit or cost-effectiveness analyses.

In a recently published research synthesis, S. T. Muench provided an overview of roadway construction sustainability (Muench 2010). Muench's review of 14 roadway construction life-cycle papers reveals some consistent observations about the ecological impacts of such projects. Key observations are

- The energy expended during roadway construction is roughly equivalent to that used by traffic operating on the facility for 1 or 2 years,
- Materials production makes up 60 to 80 percent of energy use and 60 to 90 percent of CO_2 emissions associated with construction,

- Construction activities at the jobsite make up less than 5 percent of energy use and CO_2 emissions, and
- Transportation associated with construction makes up 10 to 30 percent of energy use and about 10 percent of CO_2 emissions associated with construction.

The fuel factors data developed for this study could provide additional data observations for use in similar studies.

The GreenDOT model, developed by AASHTO, provides a framework for estimating emissions from construction equipment. GreenDOT is a spreadsheet tool that enables state DOTs to calculate CO_2 emissions from their operations and projects. Depending on the user's need, the model can calculate CO_2 emissions from an agency or a project over a defined time period (ICR International 2010). Updated fuel use inputs produced for this study could be incorporated into the GreenDOT model.

Another source specifically focused on life-cycle emissions from different types of pavement is a recent paper by three researchers, Hanson, Noland, and Cavale, at Rutgers University's Voorhees Transportation Center. This paper, "Life Cycle Greenhouse Gas Emissions Used in Road Construction," aggregates research on life-cycle emissions for asphalt and for Portland cement. The newly calculated fuel usage factors for relevant asphalt and concrete items could be included in an updated version of this report, or a similar report compiled in the future.

The most comprehensive regional-scale analysis of greenhouse gas emissions embodied in transportation infrastructure, incorporating estimates of material volumes, is contained in the 2008 doctoral dissertation of Mikhail Chester. Chester uses emission factors from the PaLATE model to estimate emissions embodied in the construction of regional road networks and rail transit networks. Chester estimates volumes of construction materials separately for 10 roadway types: interstate, major arterials, minor arterials, collectors, and local roadways in both the urban and rural context. The author developed standard dimensions for each roadway type from AASHTO's 2001 guidance on roadway geometry and historical miles of each roadway type constructed in the United States from the Bureau of Transportation Statistics. Finally, the author estimated market shares of various paving types from EPA's Emission Inventory Improvement Program. Chester effectively forecasts the total emissions embodied in construction of roadway pavement in the United States over a 10-year period. The fuel usage factors developed for this effort may be used as inputs to similar emission calculation models.

State DOTs, in their GHG inventory development, do not appear to have maintained data for specific construction or maintenance activities. The new fuel factors data produced for this study could be incorporated into these models, with some regional and/or geographical tailoring occurring. The Washington State DOT (WSDOT), in its 2007 GHG inventory, followed a more traditional GHG reporting protocol, thinking primarily of their fleet and their buildings as their major categories of Scope 1 and Scope 2 emissions (WSDOT 2007). The inventory does not describe estimates of emissions by project category or by activity. The inventory does not contemplate life-cycle emissions from materials as part of the inventory. This may change, as AASHTO's Standing Committee on the Environment has recently commissioned a guide for state DOTs entitled "Greenhouse Gas Emission Inventory Methodologies for State Transportation Departments." This document, prepared by ICF and finalized in the summer of 2011, contains simple estimates of upstream emissions for purchased inputs to construction projects, such as gas, diesel, and natural gas fuels as well asphalt, steel, and aluminum.

4.2.7 Summary and Conclusions

A range of potential uses exists for the fuel usage factors data collected in this study. The data can be used by entities other than state DOTs for both highway contracting and construction of facilities for other transportation modes. Associations may value the data for dissemination of information and policy guidance for their members. Officials interested in improving planning and budgeting may find information on fuel use in their projects extremely useful. At the same time, contractors interested in better understanding and managing their fuel use or in preparing more accurate cost estimates will find value in the fuel factors. Finally, researchers examining energy requirements, emissions, and climate change can use the data in preparing estimates, inventories, and action plans.

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APPENDIX A

Recommended Practice and Model Specification

A.1 Purpose and Scope

The purpose of this document is to set forth revised fuel usage factors and procedures for development and use of fuel price adjustment contract provisions. These provisions minimize the cost effects of price uncertainty for fuel used in highway construction. This document also presents information on criteria for application of the fuel usage factors, sample wording successfully used in specifications by various states, and example calculations and worksheets.

A.2 Background

Price volatility of construction materials and supplies such as asphalt, fuel, cement, and steel can result in significant problems for contractors in preparing realistic bids. In many cases, prospective bidders cannot obtain firm price quotes from material suppliers for the duration of the project. This leads to price speculation and inflated bid prices to protect against possible price increases. This document will provide contracting authorities with information for development and application of fuel usage factors and price adjustment provisions for fuel usage to respond to this price volatility for fuel by transferring a portion of the risk to the contracting agency, resulting in lower bids.

A.3 Sponsors, Participating Organizations, and Study Methodology

The National Cooperative Highway Research Program (NCHRP) is a major research program within the Transportation Research Board (TRB) of the National Academy of Sciences. The NCHRP is sponsored by the American Association of State Highway and Transportation Officials (AASHTO) in cooperation with the Federal Highway Administration (FHWA). The NCHRP was the sponsor of this project effort, which was designated as NCHRP Project 10-81. Participants included an NCHRP project officer and a technical review panel. The FHWA also contributed one of its employees to serve as a liaison between the NCHRP and the FHWA.

State DOTs have also participated in this study. In the first phase of the project, the project team contacted all 50 state DOTs and acquired information on their price adjustment programs, perceptions of fuel intensity, and the features that they would like included in the research products of this project effort.

This project has benefitted from the support of several industry organizations. The American Road & Transportation Builders Association (ARTBA), the Associated General Contractors of America (AGC), the National Asphalt Pavement Association (NAPA), and the American Concrete

Pavement Association (ACPA) each agreed to cooperate with the project team and aid in survey review and dissemination.

This project in general, and the survey aspect in particular, depended on the participation of highway construction contractors. The project team attempted to contact over 10,000 contractors through email, industry organizations' newsletters, and direct phone calls. This study also utilized fuel consumption information provided by the National Ready Mixed Concrete Association (NRMCA). In total, this study utilized information provided by 270 contractors who provided over 500 individual data points regarding fuel consumption.

The work plan for this effort proposed a three-pronged methodology to investigate the research problem. As was the case for the original fuel factors, the research team surveyed the contracting community. The survey effort, conducted using both an Excel spreadsheet survey and several iterations of surveys created using SurveyMonkey, asked contractors to provide both biographical information and fuel usage for specific work items.

In addition, the research team proposed to conduct both an engineering study and a statistical analysis. The engineering study relied on an expert panel of engineers and estimators to calculate fuel usage for a variety of construction work items. In this effort, the expert panel selected the necessary equipment for each task, calculated the fuel used by that equipment, calculated the time needed to complete each activity, and ultimately calculated the fuel use per unit of measure for an average project under each work item. For the statistical analysis, the research team studied the relationship between bid prices and diesel fuel index prices. Unfortunately, this effort did not yield meaningful results due to the complexity of the relationship and a number of confounding variables.

A.4 Definitions

This section defines terms that are used in this guide and throughout the NCHRP Project 10-81 study.

Fuel Usage Factor

The gallons of fuel required to perform a specified unit of construction. For example, this study has calculated that the fuel usage factor necessary to lay one linear foot of large pipe is 4.338 gallons. The fuel usage factor is a numerical input to price adjustment formulas.

Price Adjustment Clause

A clause that may be added to contract agreements between procuring agencies, such as state departments of transportation (DOTs) and construction contractors. A price adjustment clause, or PAC, allows for contractors to be compensated in the case of fluctuating commodity prices.

Price Index

A historical time series that displays an index of relative prices compared to a base year price for a particular good or commodity in a specific area. A price index is a frequent input to price adjustment clauses.

Trigger

The percentage change in price of a commodity in relation to an established base price that initiates the payment of a price adjustment. A trigger value is often included in price adjustment clauses and typically ranges between zero percent and 20 percent change in base price in either direction. Exceeding the contractually established trigger value will lead to either contractor reimbursement by their DOT or the return of contractor funds to the DOT, depending on the direction of the price fluctuation.

Indexed Item per Unit Method

The predominant method for conducting a PAC program. The method of measurement for this PAC method relates directly to the quantity of work performed on the specific bid items outlined in the specifications. For fuel, this is related to specific bid items that are assigned a fuel usage factor assigned to those items.

Total Fuel Requirement Method

An alternative PAC method. In this method, the state DOT will set an amount of a commodity to be used on a project. An allocation schedule is then created that details the estimated amount of the commodity used at each point of the construction process. The percent of the commodity used to date is then applied to the total commodity amount needed after the completion of each increment of work. This method is not currently used by any DOTs.

Bid Item Method

An alternative PAC program method. This method is used by creating a bid item for commodity cost for the project and the bidder enters a value from zero up to the maximum amount designated by the owner.

Percent of Cost Method

An alternative PAC program method that is used by several states. Under this model, the percent of contract dollars that will be used on a commodity is specified. The method of measurement of this method involves multiplying the current pay estimate value by the predetermined percent of cost. This value is then compared to the index values of the commodity.

A.5 Reference Documents

This section presents selected publications and projects that have informed the research team in this present effort. The presented sources include previous federal research efforts, relevant efforts by the current research team, and academic sources.

Highway Research Board Circular 158

The original research on fuel usage factors includes Highway Research Circular Number 158 by the Highway Research Board (now the Transportation Research Board) in July 1974. A mailed survey of 3,000 highway contractors netted 400 responses, and the FHWA compiled and analyzed the data. Factors were computed for construction activities such as excavation, aggregate and asphalt production, and structure construction. Each of these activities received a high, low, and average factor. Both diesel and gasoline were included. The team did not fully investigate the effects of different terrain and did not account for contingencies such as high altitude.

FHWA Technical Advisory T5080.3

The Federal Highway Administration (FHWA) incorporated the Circular 158 factors in Technical Advisory T5080.3, originally released in 1980. The FHWA website provides the updated version of this advisory. It contains methods for developing price adjustment provisions such as downward and upward contract provisions, using an average of quotes to avoid manipulation, triggers based on a 5 percent change in fuel price indices, and ad hoc adjustments on fuel usage factors in cases of extreme elevation, rough terrain, etc. It also provides the original fuel usage factors as well as additional fuel usage factors developed by the states.

AASHTO Price Adjustment Clause Survey

The Contract Administration Section of AASHTO's Highway Subcommittee on Construction (AASHTO SOC) maintains a spreadsheet that summarizes the current use of price adjustment clauses for fuel, asphalt, cement, steel, and other highway materials. The 2009 version of a summary spreadsheet includes general information regarding trigger values, indices, Web references, general comments, and state DOT contacts. This set of literature also includes the individual state policies for which the spreadsheet provides Web references.

NCHRP Project 10-81

This Specifications Guide and Recommended Practice effort is part of the larger NCHRP Project 10-81. The objectives of this study are to (1) identify present highway construction contract activities that are major consumers of fuel; (2) prepare fuel usage factors for these activities, including those items of work presented in Attachment 1 of FHWA Technical Advisory T5080.3, for base year 2012; and (3) develop a recommended practice for state DOTs to implement use of fuel adjustment factors and adjust them for both state-specific conditions and changes in construction costs, methods, and equipment.

The selected research organization designed a three-pronged research plan to achieve the above objectives. A survey approach allowed the project team to determine the prevalence of price adjustment clauses and fuel usage factors among state DOTs as well as to determine contractor fuel usage by work category and pay item. A statistical analysis modeled the relationship between fuel prices and construction bid prices. An engineering software analysis identified construction activities that are high in fuel use as well as the relative cost of fuel compared to the overall costs of construction activities.

In addition to this guidance, there are several research products for this project. A final report synthesizes the total research effort. An Excel-based spreadsheet tool allows users to quickly calculate fuel adjustments and modify their project parameters. A webinar conducted by the research team presented the project efforts to interested parties from around the country.

NCHRP Project 20-07, Task 274

The research team conducted an examination of the use of price adjustment clauses in construction contracting for NCHRP Project 20-07. When market prices of cement, steel, asphalt, fuel, or other commodities used in transportation infrastructure construction are increasing, DOTs face demands to incorporate price indexing or cost escalation clauses into construction contracts. Agency decisionmakers seek guidance for judging if indexing and escalation clauses are warranted, whether the benefits an agency may gain using such clauses outweigh the costs, and how best to implement indexing. This is a particularly important issue in recent years.

Fluctuating petroleum prices have led to increases and decreases in the costs of fuel and asphalt products. Rising demand from China and other developing countries drove up prices for steel and other building materials. The worldwide recession then led to drops in prices for many commodities.

Price indexing and cost escalation clauses shift business risk (and potential rewards from falling commodity prices) from the contractor to the DOT. While this shifting of risk may benefit the agency through contractors' willingness to submit lower bids, the agency faces greater uncertainty in budgeting and managing the final costs of a project. There is little information available on how agencies' use of such clauses may affect construction-market competition or commodity prices within a regional market. There is also little information on how the effectiveness of these clauses vary based on their design such as the trigger point for the index, the relative project size, the type of commodity or bid item, and the presence of opt-in or opt-out clauses. Data on the administrative costs of these clauses is also lacking.

The objectives of this research were to

- Describe the current state of DOT practice in using price indexing or cost escalation clauses in construction contracts;
- Collect data on the experience with escalation clauses from state DOTs, highway construction contractors, and other industries;
- Conduct a quantitative analysis of the effectiveness of the clauses using highway construction bid item data; and
- Provide guidance for DOT staff making decisions about whether and how they should use such clauses.

The research team compiled a final report detailing their efforts in January 2011. The final report includes a survey of current PAC practices, an evaluation of their costs and benefits, and final guidance for state DOTs regarding their use.

National Highway Construction Cost Index

The research team aided FHWA with the development of the new National Highway Construction Cost Index (NHCCI). For the study, the research team assisted in the development of the methodology, provided highway construction bid data by pay item for 48 states, carried out custom programming to extract the data for the index, and developed recommendations for future improvements and research.

"Evaluation of Fuel Usage Factors in Highway Construction in Oregon"

Several academic papers examine fuel usage factors. Perhaps the most relevant is "Evaluation of Fuel Usage Factors in Highway Construction in Oregon" by Ken Casavant, Professor at Washington State University with co-authors Eric Jessup and Mark Holmgren. This analysis compiles information regarding how other states address the issue of inflation in fuel factors and develops an approach to updating the estimation of fuel factors used for various types of structures. The authors present three major errors with the current fuel adjustment system. The first is the effects of inflation on construction costs exacerbated by the failure to correct for inflation on the 1980 fuel adjustment factors for structures and miscellaneous costs. The second is improvements in construction practices and fuel efficiency. Lastly, fuel preferences have shifted, with the change from diesel to natural gas in asphalt plants being the most notable. The study proceeds with an overview of state practices for formulating fuel adjustments and a survey of state DOTs, which found that most consider their current fuel adjustments to be fair despite contractor complaints and recently implemented or planned changes in many of their fuel adjustments. Two primary recommendations are presented. The first is to cut the fuel usage factors for structures approximately in half, from 19 to 9 for cast-in-place structures and from 10 to 5 for pre-cast structures. A review and recalculation of fuel usage factors every 3 years is also suggested.

A.6 Revised Fuel Factors

This section presents the updated fuel factors developed during the course of this study. Exhibit A-1 presents these factors in a table. Exhibit A-1 contains four columns. From left to right, these columns are work category, work item, unit of measurement, and the fuel factor. For example, the "Clearing" work item, under the "Clearing and Removal" category, is estimated to consume 191.2 gallons per acre assuming normal project conditions. Exhibit A-1 is followed by brief descriptions of each work item.

Clearing and Removal Items

Clearing and removal activities may vary widely between projects. The general assumptions used to develop the equipment and production rates for these tasks relate to the density and type of materials to be removed from the site.

Light clearing would consist of areas that have only a minimal growth of trees and brush. This would generally be related to projects that are widening or where existing roads are being reconstructed. In addition, light clearing areas would contain little or no general clearing items such as fence rows or other debris.

Medium clearing would be in areas where the trees and brush are only moderately dense. An example of these areas would be in residential areas where trees and open areas are mixed.

Heavy clearing would consist of areas that are densely populated with trees and brush and in more virgin area projects where there are no current roads.

For removal items, the largest cost relates to the distance required to haul the debris. Removal items are not generally "production" type items and cycle times are not calculated in the same way grading items are calculated. The estimating panel assumed that the crew will include sufficient trucks to cycle within a 10-mile radius of the project site. Also note that the asphalt pavement removal item is separate from the milling item that is described later in this section.

Technical Advisory T5080.3 did not include a specific category for clearing activities. By definition, these activities were included in the excavation activities. Separating the clearing activities from the grading activities allows for the development of a more accurate fuel factor in areas where the clearing is more or less intense than average. In addition, many projects include identifiable clearing and removal pay items, and the separation of these activities allows for the application of more specific fuel use factors.

Grading Items

The largest on-site consumers of fuel on highway projects are the grading items. These items are also the most variable from project to project and even within a project. The equipment utilized to perform the grading activities can also vary from contractor to contractor depending on the experience of the contractor and the equipment that is available.

The grading activities have been separated into tasks that would require different equipment and production rates. Within a single project, one or more of these tasks will be used in the development of the excavation pay item.

Exhibit A-1. Fuel usage factor summary table.

Category	Item of Work	Units	FUF	1980 FUF
Clearing and Removal	Clearing	Gallons/Acre	191.200	200.000
	Pipe Removal	Gallons/L.F.	0.863	
	Pavement Removal – Asphalt	Gallons/C.Y.	1.397	
	Pavement Removal – Concrete	Gallons/C.Y.	0.562	
	Structure Demolition (House/Building)	Gallons/Each	375.000	
	Structure Demolition (Bridge per S.F. of Deck)	Gallons/S.F.	0.626	
Excavation	Excavation - Earth - Off Road - Long Haul	Gallons/C.Y.	0.320	0.440
	Excavation - Earth - Off Road - Short Haul	Gallons/C.Y.	0.263	
	Excavation - Earth - On Road - Long Haul	Gallons/C.Y.	0.687	
	Excavation - Earth - On Road - Short Haul	Gallons/C.Y.	0.319	
	Excavation - Rock - Off Road - Long Haul	Gallons/C.Y.	0.402	0.570
	Excavation - Rock - Off Road - Short Haul	Gallons/C.Y.	0.311	
	Excavation - Rock - On Road - Long Haul	Gallons/C.Y.	0.740	
	Excavation - Rock - On Road - Short Haul	Gallons/C.Y.	0.465	
	Strip Topsoil	Gallons/C.Y.	0.167	
	Roadway Finishing	Gallons/S.Y.	0.073	
Base Stone	Base Stone - Short Haul (Haul and Place)	Gallons/Ton	0.406	0.510
	Base Stone - Long Haul (Haul and Place)	Gallons/Ton	0.558	0.810
Asphalt	Asphalt Production (Diesel)	Gallons/Ton	2.040	2.570
	Asphalt Production (Natural Gas)	Gallons (GGE)/Ton	2.144	
	Asphalt Production (Natural Gas) (Support Equipment)	Gallons/Ton	0.090	
	Warm Mix Asphalt Production (Diesel)	Gallons/Ton	1.632	
	Warm Mix Asphalt Production (Natural Gas)	Gallons (GGE)/Ton	1.715	
	Warm Mix Asphalt Production (Natural Gas) (Support Eqp.)	Gallons/Ton	0.072	
	Asphalt Hauling (0-5 miles)	Gallons/Ton	0.183	0.770
	Asphalt Hauling (6-15 miles)	Gallons/Ton	0.293	
	Asphalt Hauling (>15 miles)	Gallons/Ton	0.514	1.070
	Asphalt Placement	Gallons/Ton	0.273	0.280
Milling	Milling - 0-1" (0-5 mile haul)	Gallons/Ton	0.028	
	Milling - 0-1" (6-15 mile haul)	Gallons/Ton	0.030	
	Milling - 0-1" (>15 mile haul)	Gallons/Ton	0.038	
	Milling - 2-4" (0-5 mile haul)	Gallons/Ton	0.062	
	Milling - 2-4" (6-15 mile haul)	Gallons/Ton	0.071	
	Milling - 2-4" (>15 mile haul)	Gallons/Ton	0.090	
Structures	Reinforcing Steel	Gallons/Lbs.	0.004	
	Steel Beams	Gallons/L.F.	0.180	
	Substructure Concrete	Gallons/C.Y.	4.700	
	Superstructure Concrete	Gallons/C.Y.	4.150	
	Bridges	Gallons/Contract $	5.200	41.000
	Bridges (per S.F. of deck)	Gallons/S.F.	0.616	
Misc. Concrete	Concrete Production (Support Equipment)	Gallons/C.Y.	0.090	0.430
	Concrete Hauling - Short Haul	Gallons/C.Y.	0.600	1.000
	Concrete Hauling - Long Haul	Gallons/C.Y.	1.100	1.000
	Concrete Placement	Gallons/C.Y.	0.267	0.470
	Concrete Curb/Gutter	Gallons/L.F.	0.152	
	Concrete Sidewalk	Gallons/S.F.	0.090	
	Retaining Wall (Cast in Place)	Gallons/S.F.	0.646	
	Noise Wall (Pre-Cast)	Gallons/S.F.	0.304	
	Concrete Median Barrier	Gallons/L.F.	0.309	0.300
Drainage Pipe and Structures	Large Pipe Crew	Gallons/L.F.	4.338	
	Medium Pipe Crew	Gallons/L.F.	1.481	
	Small Pipe Crew	Gallons/L.F.	0.871	
	Drainage Structures	Gallons/Each	26.175	
Specialty Items	Fence Gates	Gallons/Each	4.200	
	Fencing	Gallons/L.F.	0.043	
	Grassing (Hydro Seeding)	Gallons/Acre	3.497	
	Grassing (Seedbed Preparation)	Gallons/Acre	10.000	
	Sodding	Gallons/S.Y.	0.017	
	Guardrail Posts	Gallons/Each	0.042	
	Guardrail – Steel	Gallons/L.F.	0.037	0.230
	Guardrail - Wire/Cable	Gallons/L.F.	0.105	
	Intersection Signalization (2 Lane)	Gallons/Each	170.000	
	Intersection Signalization (4 Lane)	Gallons/Each	304.000	
	Pavement Marking	Gallons/L.M.	4.500	

Exhibit A-2. Alternative grading combinations summary table.

Item of Work	Units	Fuel Use Factor
Excavation (Unclassified - Dirt and Rock)		
Grading - Short Haul	Gallons/C.Y.	0.537
Grading - Long Haul	Gallons/C.Y.	0.340
Excavation (All Haul Distances)		
Grading - Dirt	Gallons/C.Y.	0.397
Grading - Rock	Gallons/C.Y.	0.480
Excavation (Unclassified - All Haul Distances)		
Grading - Off Road	Gallons/C.Y.	0.324
Grading - On Road	Gallons/C.Y.	0.553

Based on each estimator's experience and background, they each developed different equipment lists and production rates to accomplish each task. The end result, however, was that the fuel consumption rate for each activity was very consistent for each activity.

Technical Advisory T5080.3 had three categories of excavation: Earth, Rock and Other. In addition, other activities such as clearing and grubbing are included in the fuel use factors. This study expands on the number of activities within the excavation category as well as breaking out any activities not specifically related to excavation. This allows for the development of a more accurate fuel use factor based on the specific geographic and topographic area.

In Exhibit A-1, the grading items were presented in a manner that displayed various combinations of short and long hauling distances and whether or not the haul was on or off road. Exhibit A-2 presents a number of additional combinations.

Base Stone

The base stone category will have a more standard crew compared to clearing and grading items. The largest variable in the base stone task is the haul distance from the quarry to the project site which can vary widely from project to project and state to state. In this study, the estimating panel assumed a moderate haul distance of 10 to 15 miles. The equipment used for placing and compacting the stone is much more consistent from project to project.

Technical Advisory T5080.3 listed a category for aggregates. This category has been replaced by the base stone category. This category includes the hauling, placing, and compacting of roadway base material but can also be applied to other stone activities such as shoulder widening and rip rap. The production of the material is typically covered by a fixed price purchase order and fuel price changes would not apply. Accordingly, the fuel consumption for the production activities is not included in this category.

Asphalt

The equipment list for the asphalt category is relatively standard from contractor to contractor. The specific types of pavers, rollers, and other support equipment vary from contractor to contractor, but the overall fuel consumption would change little. The two main variables in asphalt activities relate to the project conditions and the haul distance from the plant to the project site. The primary project conditions that can affect production rates for lay-down operations are traffic conditions, pavement depth, pavement width, lengths of runs. In this exercise we assumed "general" conditions for each of these factors. Projects with long uninterrupted runs will exceed the listed production rates and projects with high traffic interference and many intersections will fall short of the listed production rates.

The most variable cost of asphalt operations is the haul distance from the plant to the project. In order to minimize this effect on fuel use, we have broken each of the three main asphalt activities (structural, surface, and leveling courses) into three haul distance ranges. Each of the three haul distances (0 to 5 miles, 5 to 15 miles, and more than 15 miles) increases the number of trucks required to service the lay-down crew and increases the amount of fuel consumed.

Technical Advisory T5080.3 lists similar activities for the production, hauling, and placement of asphalt materials. Since the original study, the heating and drying operations for the production of asphalt have shifted from using diesel fuel to natural gas. This study adds additional factors for the production of asphalt to include natural gas as the heating and drying fuel.

Milling

Unlike many other categories, the milling category will have the most standard crew among the examined work categories. Although there are different sizes of milling machines and the production rates can vary based on the material being milled, all the equipment lists and production rates were similar across all estimators.

The largest variable in calculating the production rate for a milling item is the haul distance from the project site to the disposal site. As mentioned previously, these distances can vary dramatically from project to project and state to state. In this study, the estimating panel assumed a moderate haul distance of 10 to 15 miles.

The equipment used for milling and hauling is consistent from project to project. Other factors that affect the production rates for milling activities relate to specific project conditions related to length of runs, number of turnouts, width of pavement, and traffic conditions. This exercise assumed an average of all these factors.

Technical Advisory T5080.3 does not list any fuel use factors for milling activities.

Structures

Activities related to structures vary widely from project to project and state to state. In this exercise, the estimating panel identified four main activities that are common to many structures. Each estimator then identified the equipment needed to perform each activity. The equipment lists were fairly consistent among the estimators. The largest difference in equipment is the size of the crane that each estimator used in the calculation. There is also a large variance in the cranes that would be used by different contractors.

The largest variance in the estimates is the production rates for each item. This is consistent with the idea that each structure on each project would also be unique to that project. There are many factors that can have an impact on the productivity for each of these work items. These factors include location, size, design, height, width, span, and type. The production rates used are also average productivity across the duration of the task. The concrete structure items are based on the cubic yards of concrete poured. Although the actual pouring of the concrete takes place relatively quickly, the production rate accounts for the preparation, forming, pouring, wrecking, and finishing of the concrete.

Technical Advisory T5080.3 only included fuel use factors based on the number of gallons per $1,000 of contract value. As prices rise over time, the fuel use factor will necessarily decrease. This study develops factors for the major activities included in bridge construction (reinforcing steel, beams, substructure concrete, and superstructure concrete) to create a more price-insensitive fuel use factor.

Miscellaneous Concrete, Concrete Pavement, and Retaining Wall

The items within this section are relatively standard and all the estimators calculated similar equipment lists and production rates. Although concrete curb specifications can vary from state to state, the equipment required and production rates are relatively consistent. Another factor that can have an impact on the equipment used, as well as the production rate, is the ability to use a machine to slip-form the item. Some projects can have unique circumstances that require hand forming and pouring of the concrete instead of using a paver. For this exercise, the estimating panel assumed the use of pavers to perform the majority of the work.

Technical Advisory T5080.3 lists similar activities for the production, hauling, and placement of concrete pavement.

Storm Drainage, Water, and Sewer

Pipe crews are generally consistent from project to project and generally vary by pipe size and depth. The estimators developed consistent equipment lists and production rates. In this exercise, the estimating panel generally assumed standard open conditions with standard specification depths for pipe. These production rates would not be for urban areas where site conditions limit the work area and for unusual depth requirements.

Technical Advisory T5080.3 does not list any fuel use factors for pipe laying activities.

Specialty Items

The equipment lists for most of the specialty items are much less than for many of the previous items. Labor and material costs make up a much larger percentage of the cost for these items. In addition, most of these items are performed by companies that specialize in the items listed and are not performed by the average highway contractor. Although the equipment lists are generally used, the production rates for many of these items can vary for each subcontractor depending on a number of project-specific factors. For example, signalization installations can vary from one intersection to the next within the same project. The estimating team relied on information from specialty subcontractors for much of the information in this section.

Technical Advisory T5080.3 does not list any fuel use factors for specialty activities.

A.7 Criteria for Application

Procuring agencies should carefully evaluate when and how to employ fuel use factors and price adjustment clauses. The following provides discussion regarding several features that should be considered:

- Procuring agencies should consider whether the history of fuel prices compared to current prices reveals unpredictable, uncontrollable shifts away from normal price trends over the longer term. Agencies should attempt to determine the primary cause for the indicated price variance and assess whether they expect that condition to exist for the likely term of typical projects and contracts.
- Procuring agencies should consider whether contractors could obtain firm price quotations from fuel suppliers for the likely term of typical projects and contracts. Agencies should attempt to verify that suppliers are not withholding quotes in hopes that agencies will provide fuel price adjustments.
- Agencies should not incorporate fuel price adjustment provisions into standard specifications for permanent application to all projects. If included in standard specifications, the price

adjustment should apply only when provided for in the bidding proposal for a specific project. Agencies should assess the need to include price adjustment provisions on a project-by-project basis.

- Agencies should apply price adjustment provisions only where fuel costs represent a significant portion of project costs? For example, fuel costs would probably have a significant effect on major items of a grade and drain project, but not on a traffic signal installation project.
- Whenever price adjustment provisions are adopted, they should be continually evaluated for need, effectiveness, and fairness. Administrative problems may indicate the need for incorporating revisions to the clauses. A system for feedback from contractors and industry groups is desirable.

A.8 Development of Contract Provisions

Procuring agencies should consider the following points when developing contract provisions for calculation and payment of fuel price adjustments.

Upward and Downward Movement of Prices

Price adjustments normally apply for both upward and downward movement of prices. An option is for the agency to deduct for decreased cost only to the extent of any increased compensation previously paid.

Ceiling on Upward Adjustment

Price adjustment provisions sometimes include a limit on upward or downward adjustments, preferably in percentage form rather than in absolute dollars. Georgia has a maximum percentage above the price at letting of 125 percent. Maryland caps adjustments at 5 percent of total contact amount.

Index or Other Economic Barometer

Procuring agencies should base price adjustments on actual fuel prices, a fuel price index, or another economic barometer that is not susceptible to manipulation by contractors and suppliers acting singly or as a group. The contracting agency should develop the index or use other government price data. Procuring agencies can develop indices from statewide or areawide data secured on the same date each period. The Procuring agency should include in the contact provisions the basis for establishing the indices used in making price adjustments.

Many state DOTs have developed internal indices for fuel and other commodities. If this step has not been undertaken, the following sources have been successfully used for price indexing. These sources of price information are not meant to be exclusive of any other agency, organization, or publication which now provides, or may provide in the future, the type of price information which may be useful.

- Producer Price Index: Number Two Diesel Fuel. Bureau of Labor Statistics. http://data.bls.gov/timeseries/WPU057303?data_tool=XGtable
- "Petroleum and Other Liquids" Indices. U.S. Energy Information Administration. http://www.eia.gov/petroleum/gasdiesel/
- AAA National Average Fuel Price. http://fuelgaugereport.aaa.com/?redirectto=http://fuelgaugereport.opisnet.com/index.asp
- Platts Oilgram Report. http://www.platts.com/Products/oilgrampricereport

- Engineering News-Record. http://enr.construction.com/
- Oil Daily. http://www.energyintel.com/pages/about_tod.aspx

Trigger Value

The lower the trigger value, the more effective the index is for stabilizing the market as well as the increased likelihood of reduced bid prices. The drawback of a low trigger value is increased administrative burdens. Most states believe that price adjustments should be "triggered" only by a significant change in the index rather than being responsive to minor fluctuations in price. The original guidance by AASHTO suggested a 5 percent trigger level in its publication titled "Suggestions and Guidelines for Combating Shortages and Minimizing the Effects of Price Uncertainties for Materials and Fuel in Construction," published in 1974. As of 2009, seven states had a trigger between zero and 3 percent, 19 had a trigger between 5 and 7.5 percent and 13 had a trigger of 10 percent or more.

Specified Interval for Computation

Agencies should perform price adjustment computations at specified intervals rather than as each change in price occurs. Most agencies compute price adjustments on a monthly basis.

Option to Accept or Reject Price Adjustment Provision

Some states allow the contractor an option to accept or reject price adjustment provisions in the contract. As of 2009, 12 states had an opt-in policy for fuel while 28 did not. For example, Alabama allows the contractor to not bid the construction fuel item by including fuel costs in other pay items. Utah allows the contractor to invoke the clause at any time during the contact and it is retroactive to the beginning of the project. Virginia requires contractors to opt in or out within 21 days of bid opening. The contract's additional payment or any credit due the state for decreased prices should not depend on whether the contractor chooses to claim the difference. The agency should automatically incorporate adjustment calculations and payments or credits into the normal estimate payment process.

Use of the Invoice Method

Provisions for payment of actual cost increases based on receipted invoices or other documentation submitted by the contractor are not recommended. This is because of the additional administrative and audit requirements imposed on states and contractors. There is also the potential for manipulation and fraud.

Price Adjustment Provisions and Completion Incentive

Price adjustment provisions should provide an incentive for the contractor to complete the contract within the allotted time specified. States should limit any upward price adjustment, at maximum, to the price or price index in force at the end of the contract. States may also require completion of the project at the original fuel price at letting without any adjustment during any unapproved time overrun.

Application to Individual Contacts and Bid Items

Many procuring agencies limit the applicability of fuel price adjustments in some manner. Some agencies offer the clause only on projects over certain durations. This is because contacts with short durations will experience less price volatility. Similarly, some agencies only include fuel use factors for specific items or impose minimum quantities. This is because certain items or smaller quantities result in low levels of fuel use and, as a result, the adjustment would be small in comparison to administrative cost.

Structures

A typical contract between a state DOT and a construction contractor for the building of a bridge or other structure includes a large variety of tasks, materials, and quantities. Quantities of materials are purchased utilizing many different units of measure. These units of measure include lump sum, cubic yards of concrete (substructure and superstructure), linear feet of beam, square feet or square yards of deck, linear feet of barrier, and pounds of steel. This variety of units provided some challenges in creating fuel usage factors for these items. In order to develop a fuel usage factor that can be implemented across many different contracting methods, this specification contains a fuel usage factor that was developed using both gallons of fuel used per square foot of bridge deck and gallons of fuel used per $1,000 of contract amount.

The advantage of utilizing a fuel usage factor on a square foot of bridge deck is that it does not rely on input prices. Implementing a fuel usage factor based on contract value will fluctuate based on prices and will eventually become skewed due to the effects of inflation.

A list of tasks associated with the demolition and construction of a standard bridge was developed for this specification. The assumptions regarding bridge dimensions include the following:

- Two travel lanes (12′ width);
- 100′ bridge length;
- 6′ shoulders;
- Three footers (left, right, center);
- Dry land span;
- 3,600 S.F. deck area; and
- 10″ deck thickness.

Accompanying the above assumptions is the development of a list of tasks associated with the demolition and construction of the structure. The results are then divided by the deck square footage to create fuel usage factors. The tasks included in the analysis are as follows:

- Substructure demolition,
- Superstructure demolition,
- Load/haul debris,
- Drive piling,
- Excavation,
- Form footings,
- Form substructure,
- Place and tie rebar (substructure),
- Pour footings,
- Pour substructure,
- Form deck,
- Place and tie rebar (superstructure),
- Pour and finish deck,
- Place and tie rebar (barrier wall), and
- Pour barrier wall.

Based on the above tasks, the total fuel consumed to demolish and/or construct a bridge was calculated to be

Demolition: 2,554.865 Gallons = **0.626 Gallons/Square Foot**
Construction: 2,219.375 Gallons = **0.616 Gallons/Square Foot**

To calculate the number of gallons per $1,000 of contract value, it was necessary to calculate the historical averages for concrete and steel then multiply the average bid price by the quantities calculated for constructing the average structure. The result is an average contract value of the bridge items. The number of gallons to construct a bridge was divided by the contract value to get a fuel use factor based on the contract value, as follows:

Construction Cost: 2,219.375 Gallons/$54,131 = 0.041 × 1000 = **41.000 Gallons/$1,000**

Creating Specialized Fuel Usage Factors

The process of creating a fuel usage factor consists of three initial data collection steps and one step to calculate the fuel consumption rate. The first three steps are to

1. Determine the equipment requirements that will be utilized in the crew that will perform the work. This can vary from project to project and contractor to contractor. Many contractors will base the equipment requirements as much on available equipment as on optimal equipment.
2. Determine the crew production rate in units per hour.
3. Determine the hourly fuel consumption rate for "average working conditions" in gallons per hour.

Once the data collection effort is completed, the computation of the equipment rate is a relatively simple mathematical exercise that consists of two steps. These steps are to

1. Sum up the hourly fuel consumption rates per hour for the needed equipment
2. Divide the total by the crew production rate per hour

The resulting value is the fuel consumption rate calculated in gallons per unit of measure.

Sample Calculation:

Task: Lay 18″ concrete pipe (linear feet)

Equipment requirements:

Backhoe	(5.0 Gallons/Hour)
Dozer (small)	(2.2 Gallons/Hour)
Loader	(4.0 Gallons/Hour)
Trench compactor	(1.5 Gallons/Hour)
Crew truck	(3.5 Gallons/Hour)

Production Rate:

24 L.F./Hour

Rate computation:

5.0 + 2.2 + 4.0 + 1.5 +3.5 = 16.2 Gallons/Hour

16.2 G.P.H./24 L.F./Hour = **0.675 Gallons/L.F.**

Time of Year

Adjustments to fuel consumption factors for time of year or season are problematic for several reasons. First, at the time the contract documents containing the fuel use factors are drafted, the time the contract will be let as well as the time the work will be performed is not known. Therefore, adjusting the factors in the contract is not feasible. This could be overcome by including provisions in the formulation of the specifications to adjust the fuel factors based on when the work is completed. This would add complexity to the process of calculating the fuel consumption to be used in the price adjustment clause of the contract. The final and most compelling reason is that the variance in fuel consumption per unit of measure is very small from season to season. Although productivity will vary from peak to off-peak seasons, the amount of work accomplished in off-peak seasons will vary as well. The methodology for calculating the fuel usage factors should be based on average conditions using average equipment. No two projects are the same and there are many specific conditions that will impact the ultimate fuel consumed on a task. Creating a fuel usage factor that addresses an average condition is the most sensible approach to satisfying the purpose of the fuel usage factor: minimizing (not eliminating) the risk associated with fuel price changes.

Risk Sharing between DOTs and Contractors

The basis of implementing fuel factors and a price adjustment clause within a contract is for the mitigation of the risk associated with fuel price changes. It is not possible to develop a perfect fuel usage factor for all circumstances due to the many variables associated with constructing a project. Contracting methods, productivity, and project-specific variables all contribute to changes in fuel used from project to project and from day to day. Creating an average fuel factor that is based on average conditions will mitigate, but not eliminate, these risks. Historically, prices have risen over time, but there have been periods where prices have decreased. Therefore, creating a system where both parties are protected from price changes reduces the overall risk from fuel price changes.

Lump Sum Contracts

Lump sum projects present a challenge when attempting to implement fuel use factors and price adjustment clauses. This is because lump sum contracts do not break out fuel consumption for each particular task. Some contracting authorities are increasingly utilizing this type of contract, especially for overlay projects. Without the ability of the owner to establish quantities during the construction phase, other options should be considered when attempting to implement fuel usage factors.

One alternative would be to have the contract documents include the fuel usage factors in the specifications for those items that will be performed in the contract and for those items where the quantities can be verifiably measured. One example would be the tons of asphalt placed for a project, because delivery tickets can be collected by the owner's representatives. Utilizing the quantities as reported, the same methodology for calculating price adjustments can be used as in a unit price contract.

ID/IQ Projects

There are two methods of properly utilizing fuel usage factors for indefinite delivery/indefinite quantity (ID/IQ) contracts. At the time of the initial contract award, unit prices and fuel usage factors for appropriate items may be included as elements of the contract's price adjustment clause. Additionally, the contracting parties may include unit prices and fuel usage factors for individual contract tasks as they are ordered.

A.9 Description of Model Specifications and Sample Calculations

This section describes the formulation and features of the model specifications created for this effort. It contains three sections: an introduction to the model specifications, a listing of state specifications that informed the research team during the specification drafting process, and several sample calculations for the end user.

Model Specifications

Two model specifications have been constructed for this effort. The first model specification (Annex 1) is designed to be used by states that calculate price adjustments through the use of a price index. The second model specification (Annex 2) is designed to be used by states that perform price adjustments with the actual fuel prices. Each of the specifications contains the following sections and elements:

- The source for historical commodity prices (entered by user),
- The positive and negative trigger values that trigger a price adjustment (entered by user),
- The letting date and base commodity prices (entered by user),
- The relevant fuel factors (entered by user),
- The price adjustment calculation formula,
- Definitions for formula inputs, and
- Sample calculations.

Note that the model specification contains a chart of fuel factors to use in the payment adjustment. Exhibit A-1, provided earlier, offers fuel factors that states can enter into this chart, along with their state-specific bid pay item numbers. States may also supplement the fuel use factors provided in Exhibit A-1 with additional factors that they develop on their own.

Sample Clauses from Selected States

In creating these two draft specifications, the research team studied several state DOT price adjustment specifications. These state DOTs include

- Tennessee,
- Vermont,
- Wisconsin,
- South Carolina,
- Washington,
- Illinois,
- Montana,
- Ohio, and
- Colorado.

These specifications were helpful in determining which discussion items to include, the order in which they should be presented, and other factors. These specifications often contain many of the same elements and general order of discussion points. They may be useful to procuring agencies developing or revising their price adjustment clauses.

Sample Calculations

The remainder of this section includes sample calculations for the two model specifications. For Model A, begin with recording the following project data, which is presented as an example in Exhibit A-3.

Assume that the index for the current month is 118, an 18 percent increase from the base index. If the trigger value is 5 percent, then the price adjustment will apply. The calculation is then carried out as indicated in Exhibit A-4.

For Model B, begin by compiling the following data (as presented in Exhibit A-5, with sample quantities).

Assume that the fuel price has increased to $4.05 in the current month, a 17.4 percent increase from the initial price of $3.45. If the trigger value is less than or equal to 17.4 percent, the price adjustment provision will take effect. Exhibit A-6 displays the four-step methodology to calculate the fuel price adjustment.

Exhibit A-3. Sample data for Model A calculation.

Project Number	Letting Date	Base Index for this Contract	Base Fuel Price for this Contract
123456	10/01/2011	100	3.50

Item Number	Description of Work	Fuel Use Factor (Gallons/Unit)	Unit of Measure	Current Units Placed
101-01	Unclassified Excavation	0.320	C.Y.	25,000
301-01	Base Stone	0.406	Ton	2,800
401-01	Asphalt Surface Course	0.566	Ton	4,300

Exhibit A-4. Calculation of fuel price adjustment (Model A).

Calculation for Unclassified Excavation	[(118÷100) – 1] × (25,000 x 0.320) x 3.50	$5,040.00
Calculation for Base Stone	[(118÷100) – 1] × (2,800 x 0.406) x 3.50	$716.18
Calculation for Asphalt Surface Course	[(118÷100) – 1] × (4,300 x 0.566) x 3.50	$1,533.29
	Summation/Total Adjustment for Period	$7,289.47

Exhibit A-5. Sample data for Model B calculation.

Project Number	Letting Date	Base Fuel Price for this Contract
654321	10/01/2011	3.45

Item Number	Description of Work	Fuel Use Factor (Gallons/Unit)	Unit of Measure	Current Units Placed
101-01	Unclassified Excavation	0.320	C.Y.	25,000
301-01	Base Stone	0.406	TON	2,800
401-01	Asphalt Surface Course	0.566	TON	4,300

Exhibit A-6. Calculation of fuel price adjustment (Model B).

Calculation for Unclassified Excavation	(4.05 - 3.45) × (25,000 x 0.320)	$4,800.00
Calculation for Base Stone	(4.05 - 3.45) × (2,800 x 0.406)	$682.08
Calculation for Asphalt Surface Course	(4.05 - 3.45) × (4,300 x 0.566)	$1,460.28
	Summation/Total Adjustment for Period	$6,942.36

Annex 1 Fuel Price Adjustment Provision or Specification for Agencies Using Fuel Price Index

Table A1-1.

State Fuel Price Adjustment Clause Summary Table	
State or Agency	
Provision or Section Number	
Effective Date of Provision or Specification	
Trigger Values	
Opt-In/Opt-Out Clause Present?	
Adjustment Frequency (Monthly, Weekly, Other)	
Index Name	
Organization Developing Index	
Index URL/Source	

General Description

This specification covers the method of calculating the payment of price adjustments for fuel increases and decreases during the contracting period. This adjustment is designed to protect the agency and contractor(s) from the effects of volatility in the cost of fuel.

Positive and Negative Adjustments

Price adjustments may be either positive or negative. A positive adjustment will result in a payment to the contractor and a negative adjustment will result in a deduction.

Price Index

The index method of calculation for fuel price adjustments requires the use of a fuel price index. Information on the index or indices used is provided in Table A1-1.

Trigger Values

The price adjustment for any period will only be paid if the current index varies from the base index by more than the trigger value. If the trigger value threshold is not reached, there will be no payment on the current progress estimate.

Fuel Use Factors

The fuel usage factors, in gallons of fuel use per unit of work, are provided in Table A1-2. Price adjustments will be made only for those items listed in this specification.

Minimum Quantities

For some items or contracts, fuel adjustments will only be calculated for quantities above an established minimum amount. These minimum amounts are listed in the fifth column of Table A1-2.

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Adjustment Frequency

Calculations and payments are typically done on a monthly basis for contracts that include this provision.

Method of Calculation

The payment adjustment will be calculated using the following formula:

$$PA = [(Ic \div Ib) - 1] \times [\sum (Q \times Fuf)] \times Fb$$

where:

PA = Payment adjustment (+/−)
Ic = Index for current month
Ib = Base index price for this contract
Q = Quantity of work placed during the current pay period for each item
Fuf = Fuel use factor for each item
Fb = Base fuel price for this contract

Expiration of Allocated Working Time

Upon the expiration of the allocated working time, as set forth in the original contract or as extended by supplemental agreement, all payment adjustments for fuel will discontinue, except that when the current price indexes are less than the price index for bidding, payment adjustments will continue to be made.

Final Payment

Upon completion of the work under the contract, any difference between the estimated quantities and the final quantities will be determined. An average Ic, calculated by averaging the Ic for all months that fuel cost adjustment was applied, will be applied to the quantity differences. The average Ic shall be applied in accordance with the above formula.

Table A1-2.

Fuel Use Factors to Use in the Calculation of the Payment Adjustment				
Bid or Pay Item Numbers	**Work Categories or Descriptions**	**Fuel Use Factor (Gallons/Unit)**	**Unit of Measure**	**Quantity Threshold**

Note: There is no separate designation in the fuel use factors in the above table for gasoline or diesel fuel. The fuel use factors are estimated for all light fuel oils.

Payment Adjustment for Fuel Worksheet

Contract-Specific Information	
State or Agency	
Project or Contract Number	
Letting Date	
County or Location	
Period of Performance	
Price Adjustment Period	
Base Index Price for Contract (Ib)	
Current Price Index (Ic)	
Base Fuel Price (Fb)	

Adjustment Calculation Worksheet							
Bid or Pay Item Numbers	**Work Categories or Descriptions**	**Unit of Measure**	**Fuel Use Factor (Gallons/Unit)**		**Quantity Used in PA Period**		**Fuel Used**
				x		=	
				x		=	
				x		=	
				x		=	
				x		=	
				x		=	
				x		=	
				x		=	
				x		=	
				x		=	
				x		=	
				x		=	
				x		=	
				x		=	
				x		=	
				x		=	
				x		=	
				x		=	
				x		=	
				x		=	
				x		=	
				x		=	
				x		=	
				x		=	
				x		=	
				x		=	
				x		=	
				x		=	
				x		=	
				x		=	
				x		=	
				x		=	
Total Sum of Fuel Used During Adjustment Period (Σ of Far Right Column)							
Fuel Price Adjustment (PA = [(Ic÷Ib) – 1] × [Σ (Q x Fuf)] x Fb)							

Annex 2 Fuel Price Adjustment Provision or Specification for Agencies Using Fuel Prices

Table A2-1.

State Fuel Price Adjustment Clause Summary Table	
State or Agency	
Provision or Section Number	
Effective Date of Provision or Specification	
Trigger Values	
Opt-In/Opt-Out Clause Present?	
Adjustment Frequency (Monthly, Weekly, Other)	

General Description

This specification covers the method of calculating the payment of price adjustments for fuel increases and decreases during the contracting period. This adjustment is designed to protect the agency and contractor(s) from the effects of volatility in the cost of fuel.

Positive and Negative Adjustments

Price adjustments may be either positive or negative. A positive adjustment will result in a payment to the contractor and a negative adjustment will result in a deduction.

Price Index

The index method of calculation for fuel price adjustments requires the use of a fuel price index. Information on the index or indices used is provided in Table A2-1.

Trigger Values

The price adjustment for any period will only be paid if the current index varies from the base index by more than the trigger value. If the trigger value threshold is not reached, there will be no payment on the current progress estimate.

Fuel Use Factors

The fuel usage factors, in gallons of fuel use per unit of work, are provided in Table A2-2. Price adjustments will be made only those items listed in this specification.

Minimum Quantities

For some items or contracts, fuel adjustments will only be calculated for quantities above an established minimum amount. These minimum amounts are listed in the fifth column of Table A2-2.

Adjustment Frequency

Calculations and payments are typically done on a monthly basis for contracts that include this provision.

Method of Calculation

$$PA = (Fc - Fb) \times \left[\sum (Q \times Fuf)\right]$$

where:

PA = Payment adjustment (+/−)
Fc = Fuel price for current month
Fb = Base fuel price for the contract
Q = Quantity of work placed during the current pay period
Fuf = Fuel use factor for each item

Expiration of Allocated Working Time

Upon the expiration of the allocated working time, as set forth in the original contract or as extended by supplemental agreement, all payment adjustments for fuel will discontinue, except that when the current price indexes are less than the price index for bidding, payment adjustments will continue to be made.

Final Payment

Upon completion of the work under the contract, any difference between the estimated quantities and the final quantities will be determined. An average Ic, calculated by averaging the Ic for all months that fuel cost adjustment was applied, will be applied to the quantity differences. The average Ic shall be applied in accordance with the above formula.

Table A2-2.

Fuel Use Factors to Use in the Calculation of the Payment Adjustment				
Bid or Pay Item Numbers	Work Categories or Descriptions	Fuel Use Factor (Gallons/Unit)	Unit of Measure	Quantity Threshold

Note: There is no separate designation in the fuel use factors in the above table for gasoline or diesel fuel. The fuel use factors are estimated for all light fuel oils.

Payment Adjustment for Fuel Worksheet

Contract-Specific Information	
State or Agency	
Project or Contract Number	
Letting Date	
County or Location	
Period of Performance	
Price Adjustment Period	
Base Fuel Price (Fb)	
Current Fuel Price (Fc)	

Adjustment Calculation Worksheet							
Bid or Pay Item Numbers	Work Categories or Descriptions	Unit of Measure	Fuel Use Factor (Gallons/Unit)		Quantity Used in PA Period		Fuel Used
				x		=	
				x		=	
				x		=	
				x		=	
				x		=	
				x		=	
				x		=	
				x		=	
				x		=	
				x		=	
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				x		=	
				x		=	
				x		=	
				x		=	
				x		=	
				x		=	
				x		=	
				x		=	
Total Sum of Fuel Used During Adjustment Period (Σ of Far Right Column)							
Fuel Price Adjustment (PA = (Fc - Fb) × [Σ (Q x Fuf)])							

Abbreviations and acronyms used without definitions in TRB publications:

A4A	Airlines for America
AAAE	American Association of Airport Executives
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACI–NA	Airports Council International–North America
ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
HMCRP	Hazardous Materials Cooperative Research Program
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
MAP-21	Moving Ahead for Progress in the 21st Century Act (2012)
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
PHMSA	Pipeline and Hazardous Materials Safety Administration
RITA	Research and Innovative Technology Administration
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S.DOT	United States Department of Transportation