

# National Cooperative Highway Research Program RESEARCH RESULTS DIGEST

August 1998—Number 229

Subject Areas: IA Planning and Administration and  
IVA Highway Operations, Capacity and Traffic Control

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## Developing Measures of Effectiveness for Truck Weight Enforcement Activities

*This NCHRP digest describes the findings of NCHRP Project 20-34, "Developing Measures of Effectiveness for Truck Weight Enforcement Activities," conducted by Fred R. Hanscom, Transportation Research Corporation, Haymarket, Virginia. The digest was prepared by Edward T. Harrigan, NCHRP Senior Program Officer, from the contractor's final report.*

### INTRODUCTION

This digest provides the practitioner with procedures for evaluating truck weight enforcement activities. It employs a set of *measures of effectiveness* (M.O.E.s) that were developed on the basis of specific truck weight enforcement objectives. Final M.O.E.s were selected on the basis of their ranked abilities to meet highway and enforcement agency needs and then validated in a four-state study to confirm their sensitivity to actual enforcement activity. Sampling procedures and data analysis operations required to apply the M.O.E.s are also described.

These procedures were developed through NCHRP Project 20-34, *Developing Measures of Effectiveness for Truck Weight Enforcement Activities*. The full text of the final report for Project 20-34 is available through the Cooperative Research Program's World Wide Web homepage at <http://www2.nas.edu/trbcrp>. (Click on "CRP Web Documents," then "NCHRP Web Document 13," and follow the instructions.)

M.O.E. sampling guidelines were developed through a statistical analysis of nationwide data and are applicable to evaluate statewide (regional), corridor (local-level), or location-specific truck weight enforcement programs. Study site number requirements are estimated for specified highway-functional and truck-percentage categories. Site-specific sample size

requirements are also designated. A software data analysis tool, the *Truck Weight Enforcement Evaluation Tool (TWEET)*, compares M.O.E. results between two conditions (e.g., with and without enforcement activity). It also estimates the effect of enforcement activities on pavement service life.

TWEET and its User's Guide are available for downloading by following the instructions on the Cooperative Research Program's World Wide Web site at <http://www2.nas.edu/trbcrp/68e6.html>. (For a limited time, TWEET and the User's Guide may also be downloaded directly from the Transportation Research Corporation's World Wide Web site at <http://www.trc-net.com/tweet/>; this site also provides access to technical support.)

### BACKGROUND

Truck weight enforcement programs are conducted to limit damage to the infrastructure and improve public safety on the highways.

The level and value of truck weight enforcement activities are currently gauged by descriptive, statistical measures of the level of enforcement activity such as: (1) the number of trucks weighed, (2) the number of violators detected, and (3) the amount of fines collected. However, such measures are poor indicators of the results of that activity in terms of overall compliance with weight laws.

A comprehensive examination<sup>1</sup> of truck weight enforcement practice over a 4-year period noted that on average more than 144 million trucks were weighed annually, resulting in over 681,000 citations. However, this examination of enforcement activity concluded that *adequate information was not being collected to assess compliance trends*.

Wide divergence in enforcement practice across the United States confounds the problem of assessing these trends. It is impossible to gauge the impact of enforcement activity without a systematic data-sampling approach that is sensitive to the actual number of trucks in the traffic stream and to their degree of compliance with weight regulations. At present, the effects of truck weight enforcement programs are generally not known in terms of: (1) actual impact on weight-law compliance, (2) effect on safety of truck operations, (3) pavement service life effects, or (4) cost-effectiveness of enforcement activity (e.g., associated cost-benefit in terms of pavement preservation).

Analysis of the effects of truck weight enforcement must be based on *measures that reflect the goals* of the weight enforcement program. An evaluation of truck weight enforcement should quantify its effect on compliance (e.g., instances and severity of overweight violations), and whether any benefit is achieved compared to a different type or the absence of enforcement. Moreover, enforcement compliance must be *systematically* measured in the context of actual truck exposure (e.g., total truck volume), in order to validly determine compliance (and the consequences of non-compliance) within a given study area. Systematic observation procedures ensure that the observed sample adequately represents the overall truck population.

## MEASURES OF EFFECTIVENESS (M.O.E.s)

An M.O.E. of truck weight enforcement activity may be defined as *a determinable quantity of what is achieved as the result of truck weight enforcement activity*. Its application should also make it possible to quantify the contribution that a particular activity makes toward achievement of the agency's goals for the weight enforcement activities. To quantify effectiveness, the M.O.E.s must show benefits in terms of: (1) compliance with operational weight and axle-spacing regulations, (2) pavement or bridge preservation, or (3) reduction of accidental deaths, injuries, and property damage.

Table 1 presents the M.O.E.s recommended by Project 20-34. The field validation studies showed that all of these M.O.E.s are sensitive to real-world, truck weight enforcement

activities. This sensitivity is affected by several factors: actual truck weight/configuration characteristics, commodity shipping demands, observed truck sample size, and the characteristics of weigh-in-motion (WIM) equipment. Those measures in Table 1 most strongly supported by the field data (in descending order) are as follows:

1. Excess ESALs (equivalent single-axle load), severity;
2. Tie: Gross weight violation, severity; and excess ESALs, proportion; and
3. Tie: Gross weight violation, proportion; single-axle weight violation, proportion; and tandem-axle weight violation, severity.

## M.O.E. USER'S GUIDE

The M.O.E. User's Guide provides practitioners with techniques to evaluate truck weight enforcement activity and apply validated M.O.E.s developed and tested in Project 20-34. The User's Guide consists of two parts: sampling guidelines and a software data analysis tool.

- *Sampling (data collection) guidelines* help estimate the number of WIM data collection sites and the sample sizes required to measure the effectiveness of an enforcement activity. They provide users with estimates for specified roadway classification and truck percentage conditions.
- *Software (data analysis) tool (TWEET)* calculates and statistically compares M.O.E. values between two observed enforcement conditions. Software users can conduct, if desired, an automated pavement design life analysis, estimating the theoretical effect on pavement life that results from differences produced by the two observed enforcement activities.

## M.O.E. SAMPLING (DATA COLLECTION) GUIDELINES

These sampling guidelines provide straightforward data collection requirements to measure enforcement effects by using the validated M.O.E.s. The guidelines include estimates of observation site numbers and associated truck sample sizes. These estimates are provided for specified roadway classification and truck percentage conditions and are based on an analysis of nationwide WIM data.

Sampling guidelines are directed toward WIM data gathering. The soundness of the WIM input data and its subsequent analysis to measure the effectiveness of truck weight enforcement are highly dependent on the calibration and maintenance of WIM equipment.

In the guide, sampling requirements use two statistical concepts, *level of significance* and *power of test*:

<sup>1</sup>U.S. Department of Transportation, "Overweight Vehicles – Penalties and Permits, An Inventory of State Practices for Fiscal Year 1991," Report to the United States Congress, Federal Highway Administration, Washington, DC, April 1993.

TABLE 1 Designated measures of effectiveness (M.O.E.s) and their definitions

Truck Weight Enforcement M.O.E.	Definition
Gross Weight Violation, Proportion	The fraction (or percentage) of the total observed truck sample which exceeds the legal gross weight limit.
Gross Weight Violation, Severity	The extent to which average measured gross weights for the observed sub-sample of gross weight violators exceeds the legal gross weight limit.
Single-Axle Weight Violation, Proportion	The fraction (or percentage) of the total observed truck sample with one or more axles which exceeds the legal single-axle weight limit.
Single-Axle Weight Violation, Severity	The extent to which average measured single-axle weights for the observed sub-sample of single-axle weight violators exceeds the applicable legal limit.
Tandem-Axle Weight Violation, Proportion	The fraction (or percentage) of the total observed truck sample with one or more tandems which exceeds the legal tandem-axle weight limit.
Tandem-Axle Weight Violation, Severity	The extent to which average measured tandem-axle weights for the observed sub-sample of tandem-axle weight violators exceeds the applicable legal limit.
Bridge Formula Violation, Proportion	The fraction (or percentage) of the total observed truck sample which exceeds the legal Bridge Formula weight.
Bridge Formula Violation, Severity	The extent to which average measured Bridge Formula weights for the observed sub-sample of Bridge Formula violators exceeds the legal weight.
Excess ESALs, Proportion	The fraction (or percentage) of the total observed truck sample exhibiting Excess ESALs; i.e., ESALs attributable to the illegal portion of the individual single- or tandem-axle group.
Excess ESALs, Severity	The average value of Excess ESALs observed for the truck sub-sample exhibiting Excess ESALs.

- *Level of significance* is the probability that the user is willing to risk the error of rejecting a valid change in M.O.E. occurrence. In statistical terminology, the level of significance is the maximum probability at which the user would be willing to risk a *Type 1 error*. A Type 1 error occurs when a true null hypothesis is rejected (i.e., that baseline [no enforcement] versus enforcement M.O.E. variable sets are statistically different). A level of significance of 0.05 was applied in the development of this guide.
- *Power of test* is the likelihood of making a correct statistical assessment (i.e., that the proper hypothesis is accepted). The issue is to what extent the user is willing to risk accepting an invalid change in an M.O.E. In statistical terminology, the power of test is the maximum probability with which the user would be willing to risk a *Type 2 error*. A Type 2 error occurs when a false hypothesis is accepted (i.e., that baseline versus enforcement M.O.E. variable sets are not statistically different). A power of test of 0.80 was applied in the development of this guide.

### SAMPLING OBSERVATION LEVELS

Three designated sampling observation levels are presented: (1) statewide (regional), (2) corridor (local level), and (3) location specific (spot) (Figure 1).

#### Statewide (Regional) M.O.E. Sampling

Statewide (regional) M.O.E. sampling is applied to evaluate any truck weight enforcement program that affects large geographic regions exceeding the bounds of a definable highway corridor. Sampling requirements were derived from actual observed, statewide M.O.E. distributions; however,

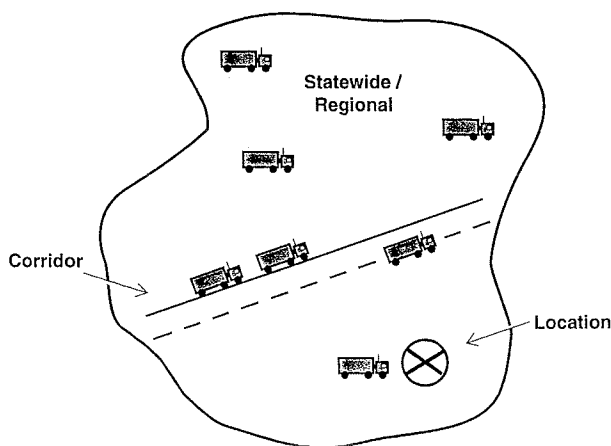


Figure 1. Illustration of sampling observation.

they are also applicable to smaller geographic regions. Site number requirements contained in this guide indicate minimum numbers to produce representative results for a designated region. Data collection site requirements are designated on the basis of regional characteristics (i.e., highway functional-class and associated truck-percentage combinations) for the area under study. Table 2 provides guidelines for site number requirements for each functional-class/truck-percentage category. Site numbers in the table are intended as a starting point for establishing final regional observation site number requirements. The TWEET software is designed to refine site number requirements on the basis of the individual user's specific data characteristics.

The statewide (regional) M.O.E. sampling procedure involves two preparatory steps. First, the geographic area (e.g., jurisdictional territory) to be affected by the enforcement program under study must be clearly defined. Second, the highway network within the defined study region must be reviewed to determine its composition, in terms of route functional classification and associated truck percentage as a function of overall traffic volume, on each affected route.

The initial number of required study sites is determined on the basis of corresponding site number designations shown in Table 2 and is subject to revision by the TWEET software. The total number of study sites in a given region will be the sum of those applied in each functional-class/truck-percentage category represented in the region. Each functional class represented in the region under study must be included in the array of designated observation sites.

For example, if the primary M.O.E. of interest is the "Proportion of Gross Weight Violations," then the number of required sites for each highway category will be derived from the numbers in the left-most column of Table 2. That is, at least three data collection sites are required to represent rural interstates with less than 15 percent trucks, six sites to represent rural interstates with 15 to 30 percent trucks, etc. The total number of sites for the study region will be equal to the sum of site numbers for all functional-class/truck-percentage categories represented in the region.

A number of cautionary factors underlie the development of site numbers contained in Table 2. First, the nationwide analysis determined that a *single* observation site, within selected functional-class/truck-percentage categories, was occasionally sufficient to statistically detect certain enforcement effects. However, application of a sound sampling strategy to a regional enforcement study requires a significant degree of generality to ensure its validity; therefore, Table 2 mandates a minimum of two sites for each functional-class/truck-percentage condition.

Second, site number requirements outlined in Table 2 are based on observed M.O.E. percentage reductions found to be associated with enforcement activity. However, for situations in which an observed enforcement activity is expected to produce greater or lesser percentage M.O.E. differences, an appropriate adjustment to the number of observation sites would be required to statistically measure the effect. For

example, in a given region where seven data collection sites may be required to detect a 10-percent reduction in gross weight violations, only five sites would likely be required to detect a 20-percent reduction. The TWEET software informs the user of the level of affected M.O.E. change (and the associated number of required sites to validly observe this effect).

Third, site numbers designated in Table 2 are based on measured statistical M.O.E. distributions. By considering normal sample sizes and associated variability of these M.O.E.s, the site numbers indicate the number of observation sites required to capture representative M.O.E. distributions. However, a number of application-specific considerations are necessary in the user's interpretation of the table. Specifically, truck weight surveillance over a large geographical area may *logically* require larger site numbers than indicated in the table. For example, many cells in the table indicate the necessity of only two or three study sites, given certain highway classification and truck ratio conditions. Yet, in the case of a statewide enforcement program over a very large area, the limitation of two or three study sites may be considered inadequate.

Thus, the final designation of observation sites must consider prevalent conditions, for example, specific hauling and commodity demands that affect truck-loading operations and the subregional areas to which they apply. Specifically, the user is cautioned against combining sites characterized by

known nonhomogenous loading conditions when applying the sampling procedure.

Finally, Table 2 is a *guideline* to provide the user with the starting point for determining site number and data collection sample sizes. Its final application relies on engineering judgment in the context of specific study situations.

**Designation of Data Collection Periods.** In view of known commodity shipping patterns, both weekend and weekday data collection periods are recommended in applied regional M.O.E. sampling efforts to evaluate truck weight enforcement programs. Designated data collection periods need to be sensitive to seasonal conditions (e.g., agricultural commodity hauling patterns). A minimum 2-day data collection duration is required at each site for each observed enforcement condition. The maximum rate of violations typically occurs during the early morning hours (e.g., 3 a.m. to 7:30 a.m. on weekdays), and during the late evening hours on Sundays.

Minimum site-specific truck sample sizes are shown in Table 3 for designated combinations of highway functional class and associated truck percentages for designated M.O.E.s. Sample size estimations shown in the table are based on the requirement to detect differences in truck proportions exhibiting the array of generally applied M.O.E.s at the 0.05 level of statistical significance.

**TABLE 2 Minimum site number guidelines for selected M.O.E.s in statewide (regional) truck weight enforcement evaluations**

<b>FUNCTIONAL CLASS And Truck Percentage</b>	<b>GROSS WEIGHT VIOLATIONS</b>	<b>TANDEM-AXLE VIOLATIONS</b>	<b>SINGLE-AXLE VIOLATIONS</b>	<b>EXCESS ESALs</b>
<b>Rural Interstate</b>				
< 15% Trucks	3	3	8	9
15 to 30% Trucks	6	6	21	32
> 30% Trucks	3	3	13	32
<b>Rural Primary Arterial</b>				
< 9% Trucks	3	3	11	2
9 to 30% Trucks	7	7	24	15
> 30% Trucks	2	2	5	15
<b>Rural Minor Arterial</b>	3	3	9	9
<b>Urban Interstate</b>				
< 9% Trucks	2	2	2	10
≥ 9% Trucks	2	2	6	15
<b>Urban Primary Arterial</b>				
< 9% Trucks	2	2	7	10
≥ 9% Trucks	3	3	8	14

NOTE: The accompanying TWEET software generates site number requirements based on user's data.

**TABLE 3** Minimum site specific number of required truck observations

<b>FUNCTIONAL CLASS and Truck Percentage</b>	<b>MINIMUM* SAMPLE</b>
<b>Rural Interstate</b>	
< 15% Trucks	175
15 to 30% Trucks	300
> 30% Trucks	200
<b>Rural Primary Arterial</b>	
< 9% Trucks	225
9 to 30% Trucks	325
> 30% Trucks	100
<b>Rural Minor Arterial</b>	200
<b>Urban Interstate</b>	
< 9% Trucks	100
≥ 9% Trucks	200
<b>Urban Primary Arterial</b>	
< 9% Trucks	125
≥ 9% Trucks	100

\* Over a minimum 2-day data collection period.

### Corridor (Local-Level) M.O.E. Sampling

Truck weight enforcement efforts often concentrate on a corridor surrounding a specific route (e.g., commonly used for commodity hauling). Applied enforcement strategies involve monitoring primary routes as well as potential diversion routes within the corridor.

**Designation of WIM Data Collection Sites.** The corridor (local-level) M.O.E. sampling procedure first involves designation of the potentially affected roadways surrounding the primary route of interest. Routes in this area obviously need to be targeted, and WIM data sampled, by the corridor-specific enforcement program. Second, the highway network within the diversion area must be examined to determine the functional classification and associated truck percentage on each affected route. Initial numbers of required data collection sites on each functional class of highway within the region can then be determined via the application of guidelines in Table 4. Although Table 4 is similar in appearance to Table 2, it does indicate routes on which a single observation site is suitable for collection of designated M.O.E.s. Unlike wider-area, regional weight enforcement efforts, a single observation site may be suitable for the evaluation of a corridor-specific enforcement activity. The

**TABLE 4** Recommended minimum site numbers for selected M.O.E.s in corridor (local-level) truck weight enforcement evaluations

<b>FUNCTIONAL CLASS And Truck Ratio</b>	<b>GROSS WEIGHT VIOLATIONS</b>	<b>TANDEM-AXLE VIOLATIONS</b>	<b>SINGLE-AXLE VIOLATIONS</b>	<b>EXCESS ESALs</b>
<b>Rural Interstate</b>				
< 15% Trucks	3	3	8	9
15 to 30% Trucks	6	6	21	32
> 30% Trucks	3	3	13	32
<b>Rural Primary Arterial</b>				
< 9% Trucks	3	3	11	2
9 to 30% Trucks	7	7	24	15
> 30% Trucks	1	1	5	15
<b>Rural Minor Arterial</b>	3	3	9	9
<b>Urban Interstate</b>				
< 9% Trucks	1	1	2	10
≥ 9% Trucks	2	2	6	15
<b>Urban Primary Arterial</b>				
< 9% Trucks	2	2	7	10
≥ 9% Trucks	3	3	8	14

TWEET software is designed to refine site number requirements based on an individual user's specific data characteristics.

**Designation of Data Collection Periods.** The data collection period sampling principles of the statewide (regional) M.O.E. level also apply to the corridor (local-level) M.O.E. application. That is, truck observation periods should include both weekday and weekend periods, with emphasis given to pre-dawn weekday and Sunday evening observation times. In addition, scheduled data collection periods need to be sensitive to seasonal commodity hauling; a minimum duration of data collection of 2 days is required for each enforcement condition. Finally, minimum, site-specific, sample size requirements are the same as those in Table 3.

### Location-Specific M.O.E. Sampling

M.O.E. sampling to evaluate a specific enforcement activity can involve data collection at a single observation site. The site would be designated as a feasible permanent or portable WIM installation at a highway location affected by trucks subjected to the enforcement procedures under study. A minimum data collection duration of 2 days is required for each enforcement condition. Care must be taken to install and operate WIM instrumentation in an unobtrusive manner so as not to interfere with an objective evaluation procedure.

Ideally, such an evaluation will be conducted at a location where no potential overweight-truck diversion route is possible. However, enforcement agencies are advised to monitor any parallel highways for increased truck volume. Furthermore, as an internal validity check with regard to the enforcement evaluation effort, user agencies are advised to compare truck volumes, time-of-day flow rates, and violation percentages between enforcement and non-enforcement data collection periods. The TWEET software will perform these validity checks.

### M.O.E. SOFTWARE (DATA ANALYSIS) TOOL

TWEET is a Windows-based software tool designed to aid in determining the effectiveness of truck weight enforcement policies. It calculates and statistically compares M.O.E. values between two observed enforcement conditions. It also allows users to conduct an automated pavement design life analysis, estimating the theoretical pavement-life effect resulting from differences in the two observed enforcement activities. More details on TWEET, including a description of the HELP screens, are presented in the final report.

TWEET works by reading WIM data that has been collected under different enforcement conditions and comparing the data from each condition to determine the most effective method of enforcement. It provides a series of "dialog boxes" (i.e., pop-up screens) that enable the user to provide required input to run the software and obtain the results of the analysis.

There are three discrete steps to the analysis process: (1) user input, (2) calculation, and (3) output.

1. The *user input* phase of the program requires the user to enter information, such as the type of units the program is to use (English or metric), enforcement condition description, and data file format.
2. During the *calculation* phase, TWEET performs the necessary calculations on the data, including violation levels, Bridge Formula calculations, and M.O.E. calculations. This activity is entirely automatic; during calculations a graphical percentage meter is displayed to indicate the program's progress.
3. During the *output* phase, calculated results are displayed to the user. The data is displayed on-screen in a series of dialog boxes, each of which can be printed by the user. The program will automatically display the calculated values after finishing the calculations. Once the program has performed the calculations, the output can be viewed again by pressing the "View Results" button on the main window.

### Starting the Analysis

To start a truck weight enforcement analysis, the user activates the program from the *Main Window* dialog box (Figure 2) and selects the button marked "Start Analysis."

The dialog box labeled *Select Units* appears first (Figure 3). The user selects the system of units of measure to be used by the program (English or metric) and presses "Next." (This dialog box defaults to English units.)

The *Set Legal Weight Limits* dialog box appears next (Figure 4). The user enters the maximum allowable weights as defined by local regulations. There are five fields presented: Gross, Single Axle, Tandem Axle, Tridem Axle, and Steering Axle Weights. Defaults may be adequate for most users, although modification of these defaults may be necessary depending on prevailing legal regulations.

The *Select Truck Classification* dialog box allows selection of the user's choice of truck classification system. Choices are FHWA 13-Type or Custom (Figure 5). The 1995 FHWA *Traffic Monitoring Guide* 13-Type scheme is a standard, 13-Type vehicle classification system that should be adequate for most users. If the data are in the FHWA Card-7 format, the user can click on the default standard, 13-Type classification option and the program will run normally.

The *File Conversion* dialog box is designed to assist agencies whose data format does not conform to either the 1995 FHWA *Traffic Monitoring Guide* 13-Type scheme or Card-7 classification formats (Figure 6). If the user's data are not in either of these formats, the "Convert" button is clicked to display the *TWEET Conversion Utility* dialog box. This utility provides an efficient way to convert data files from other formats to the 1995 FHWA Truck Weight Record format. An associated dialog box will then prompt the user for specific information regarding customized input and

output information that is required for operating the software given the user's unique data format requirements.

The user then defines the observed enforcement conditions through the *Enforcement Condition 1 of 2* dialog box (Figure 7). For each condition, the user is asked to enter

the name, location, and dates of the enforcement effort. Similar information is provided in response to the *Enforcement Condition 2 of 2* dialog box.

For each designated enforcement condition, a *Number of Files for Condition* dialog box asks for the identification of

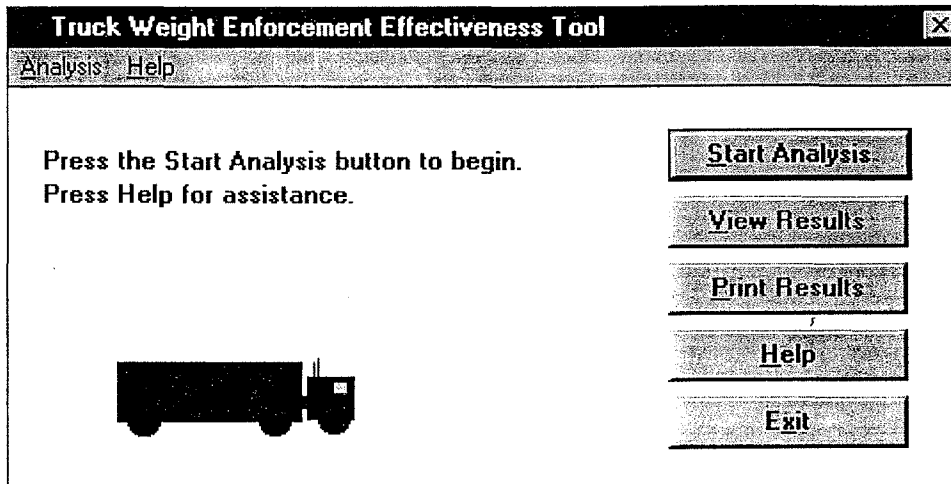


Figure 2. The "Main Window" on M.O.E. application software.

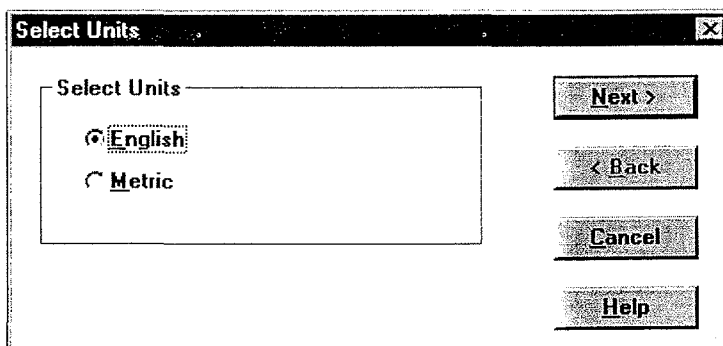


Figure 3. The "Select Units" dialog box.

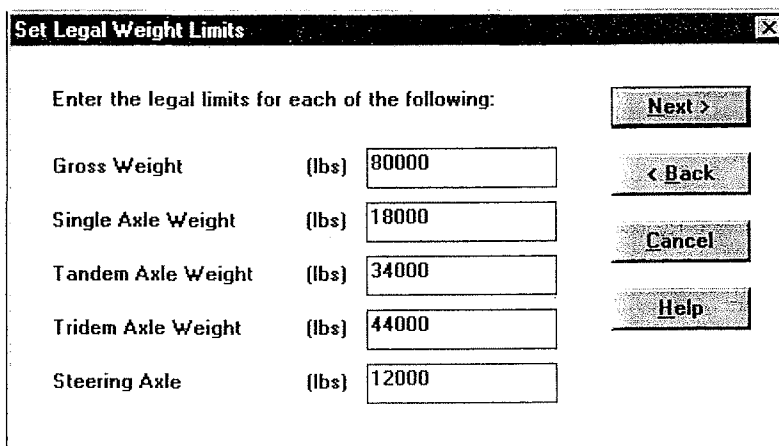


Figure 4. The "Set Legal Weight Limits" dialog box.



WIM data files that pertain to each condition. Up to four files can be used for each condition. Following this step, the *File 1 of 1 for Condition 1* dialog box asks the user to select a particular data file for the current condition (Figure 8).

The program, in turn, asks the user to select (or name) the data files pertaining to each condition. The user is presented with a series of dialogs requesting the path of each data file labeled "Select Data File 'X' for Enforcement Condition 'Y'." 'X' represents sequentially numbered data files, and 'Y' is the number of the enforcement condition to which the data files pertain.

The *Pavement Analysis* box gives the user an option to analyze the effects of pavement design life enforcement (Figure 9). The program asks for detailed pavement design data. Because of the complexity of the pavement design life analysis, the user may skip the pavement analysis by clicking the "Skip pavement analysis" option.

Depending on whether the user selects "Flexible" or "Rigid" pavement, different variables appear in the "Pavement Characteristics" section of the dialog box. This box prompts the user for appropriate pavement design parameters. A comprehensive "Help" screen associated with the *Pavement Analysis* dialog boxes explains the design theory, including the AASHTO design equations, underlying the computations used in the software.

The program then reads the WIM data files and performs the calculations. Unless data files are extraordinarily large, these calculations should take no more than a few seconds. An animated graphic *Status* dialog box tracks the program's progress on the computational process (Figure 10). The truck on the screen moves from left to right on the roadway as the calculation is completed.

### Viewing Results of the Calculations

When the calculations are complete, a series of "output" dialog boxes displays the calculated values based on input data. The first M.O.E. output dialog box, *Severity of Violations*, also reports summary information (i.e., enforcement condition, highway type, total vehicle, and truck sample) (Figure 11). The first part of the dialog box displays the observed number of violations (i.e., gross vehicle weight, single-axle weight, tandem-axle weight, tridem-axle weight, and Bridge Formula violations). The second part displays the average number of overweight pounds (or metric equivalent) for each grouping noted above.

The *Calculated Percentages of Overweight Trucks* dialog box displays calculated percentages of overweight trucks in the sample (Figure 12). It lists five calculations based on the data files: (1) percentage of trucks over the legal gross weight limit, (2) percentage of trucks over the single-axle weight limit, (3) percentage of trucks over the tandem-axle weight limit, (4) percentage of trucks violating the tridem-axle weight limit, and (5) percentage of trucks violating the Bridge Formula.

The *Violation Data by Truck Classification* dialog box indicates violators, by number of trucks and percentage, for each class of truck (Figure 13). This dialog box displays violation information, broken down by truck classification. This information is useful in determining violation distributions according to truck type.

The *ESAL Data* dialog box indicates average ESAL calculations using the FHWA *Traffic Monitoring Guide* procedure according to the number of axles (Figure 14). This dialog box also indicates computed excess ESAL violations by truck axle count.

Finally, the results of the data analysis are presented. The *Comparison of Enforcement Conditions* dialog box shows the user whether or not the observed M.O.E. differences are statistically significant (Figure 15). This dialog box contains the results of the statistical significance tests applied to the computed M.O.E.s; it indicates to the user whether or not the observed differences are significant. Separate tests of statistical significance are applied to M.O.E.s depending on whether the measure was calculated as a mean (i.e., average gross weight violation) or a proportion (i.e., proportion of gross weight violators). Significance tests are applied at a 0.05 level of statistical confidence.

The *Sampling Guide* dialog box is an aid to determine how many sites should be surveyed to detect regional changes for designated M.O.E.s, given specified levels of statistical confidence (Figure 16). The "Sampling Guide Options" table allows the option of specifying two parameters (discussed above) related to the precision of the statistical estimate: *level of significance* and the *power of test*. The main feature of the *Sampling Guide* dialog box is a table indicating the number of sites required for data collection in order to detect specified differences (i.e., 5, 10, 15, or 20 percent) in M.O.E.s. These numbers are based on TWEET's analysis of the measured statistical characteristics (e.g., variance) of the observed M.O.E.s. More sites are necessary to detect smaller differences because such differences in real-world, truck weight enforcement compliance are subtler and therefore require more statistical rigor to detect.

The final dialog box presents results of the *Pavement Effects Analysis*, if this option was selected (Figure 17). Results contained in this dialog box are based on a theoretical pavement design life effect, associated with differential enforcement-related ESAL loading conditions. The calculated pavement ESAL capacity, the estimated pavement life under both observed enforcement conditions, and estimated percentage pavement-life change due to the observed ESAL-loading difference associated with the enforcement activity are displayed.

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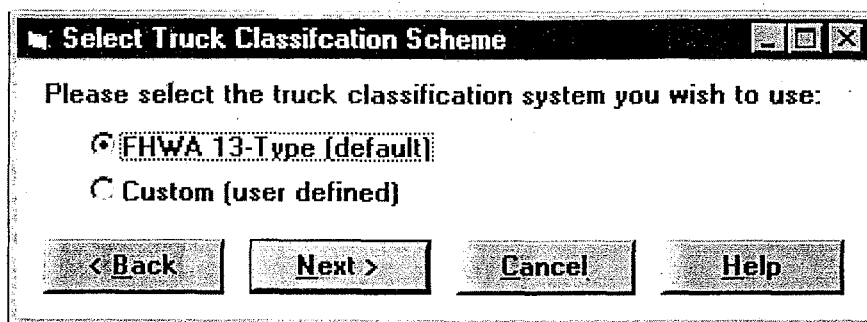


Figure 5. The "Set Select Truck Classification" dialog box.

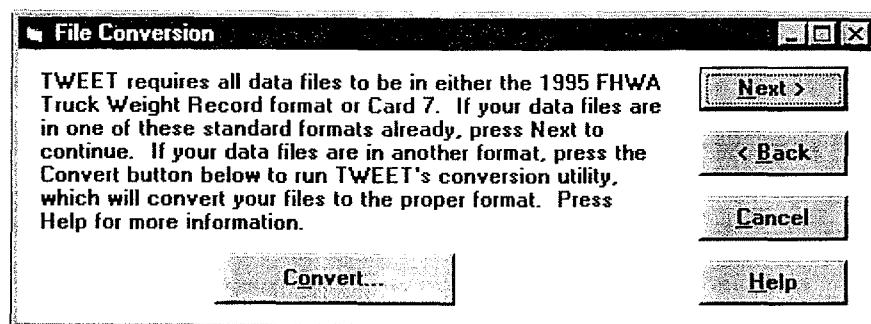


Figure 6. The data "File Conversion" dialog box.

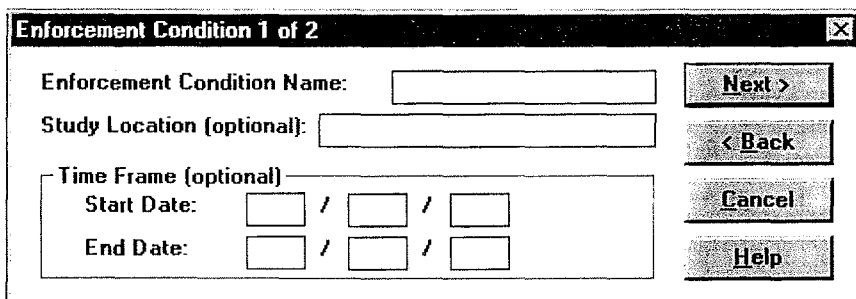


Figure 7. The "Enforcement Condition" dialog box.

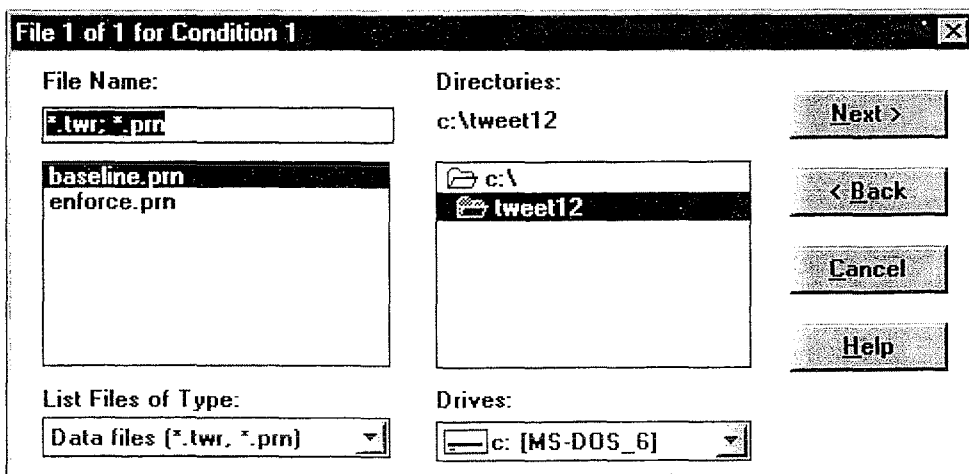


Figure 8. The "Data File for Enforcement Condition" dialog box.

**Pavement Analysis**

Please enter information about the characteristics of your pavement. If you are unsure about any of these, you may use the default values.

☐ Skip pavement analysis.

Select Pavement Material

☒ Flexible (i.e., Asphalt)  
☐ Rigid (i.e., Portland Cement Concrete)

Flexible Pavement Characteristics

Please enter values for each of the following pavement variables. If you do not know one or more of the values for your particular pavement use the defaults, as they were chosen as the most probable values for a flexible pavement. If you do not know the value of SN, but you do know the materials which comprise your pavement, press the "Calculate SN..." button, and TWEET will compute SN based on the material composition of the pavement.

SN:	5	M <sub>R</sub> :	5000
P <sub>O</sub> :	4.2	Z <sub>R</sub> :	-1.64
P <sub>t</sub> :	2.5	S <sub>O</sub> :	.35

Calculate SN...

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Figure 9. The "Pavement Analysis (Flexible Example)" dialog box.

**TWEET 1.2**

Calculating...

71% done

0% 100%

Figure 10. The "Calculation Status" dialog box.

**Severity of Violations**

Enforcement Condition: Baseline Condition

Number of overweight trucks

Gross Vehicle Weight:	33	out of	266	trucks total
Single Axle Weight:	82	out of	266	trucks total
Tandem Axle Weight:	47	out of	266	trucks total
Tridem Axle Weight:	0	out of	266	trucks total
Bridge Formula Violations:	13	out of	266	trucks total

Average lbs overweight

Gross Vehicle Weight:	6872	lbs overweight
Single Axle Weight:	1304	lbs overweight
Tandem Axle Weight:	3393	lbs overweight
Tridem Axle Weight:	0	lbs overweight
Bridge Formula Violation:	2307	lbs overweight

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Figure 11. The "Severity of Violations" dialog box.

**Calculated Percentages of Overweight Trucks**

Enforcement Condition: Baseline Condition

Percentage of trucks over the legal gross weight limit:	12.41%
Percentage of trucks over the legal single axle weight limit:	30.83%
Percentage of trucks violating the legal tandem axle weight limit:	17.67%
Percentage of trucks violating the legal tridem axle weight limit:	0.00%
Percentage of trucks violating the Bridge Formula:	4.89%

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Figure 12. The "Calculated Percentages of Overweight Trucks" dialog box.

**Violation Data By Truck Classification**

Enforcement Condition: Baseline Condition

Select truck classification:

- Motorcycles
- Passenger Cars
- Other Two-Axle, Four-Tire Single Unit Vehic
- Buses
- Two-Axle, Six-Tire, Single Unit Trucks
- Three-Axle Single Unit Trucks
- Four or More Axle Single Unit Trucks
- Four or Less Axle Single Trailer Trucks
- Five Axle Single Trailer Trucks

Violation Data for Selected Classification:

Total Number of Trucks:	211
Number of Violators:	78
Percentage Violating:	36.97%
Proportion of total violations committed by this type:	87.64%

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Figure 13. The "Violation Data By Truck Classification" dialog box.

**ESAL Data**

Enforcement Condition: **Baseline Condition**

Average Number of ESALs:

Truck Type:	Average ESALs:	Average Excess ESALs:
2-axle trucks	.2468189	0
3-axle trucks	.4756302	0
4-axle trucks	.2083355	0
5-axle trucks	1.622841	1.573099
6-axle trucks	0	0
7-axle trucks	0	0
All Trucks:	1.413015	1.573099

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Figure 14. The "ESAL Data" dialog box.

**Comparison of Enforcement Conditions**

This dialog allows you to determine the effectiveness of your enforcement activity by comparing the differences in the calculated violation data for each enforcement condition. For each MOE, a check has been placed in either the "Significant" or "Non-significant" column. This shows whether the difference in the calculated value of that MOE between the first and second enforcement condition is statistically significant. Press Help for more information.

Significance of Proportions and Means

MOE	Significant	Non-significant
Percentage of Gross Weight Violators	✓	
Percentage of Single Axle Weight Violators		✓
Percentage of Tandem Axle Weight Violators	✓	
Percentage of Tridem Axle Weight Violators		✓
Percentage of Bridge Formula Violators		✓
Average Pounds over the Gross Weight Limit		✓
Average Pounds over the Single Axle Limit		✓
Average Pounds over the Tandem Axle Limit	✓	
Average Pounds over the Tridem Axle Limit		✓
Average Pounds over the Bridge Formula Limit		✓
Average ESALs	✓	
Average Excess ESALs	✓	

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Figure 15. The "Comparison of Enforcement Conditions" dialog box.

**Sampling Guide** [X]

This guide is intended to assist you in determining the number of data collection sites required to detect specified levels of change for various MOEs. You can change the following options to control the creation of the sampling guide.

**Sampling Guide Options**

Level of Significance: 0.05 [v] Current number of sites: 40 [v]

Power of Test: 0.80 [v]

**Number of Required Data Collection Sites**

MOE	Percent change to be detected			
	5	10	15	20
Percentage of Gross Weight Violators	26	7	3	2
Percentage of Single Axle Wt. Violators	12	3	1	1
Percentage of Tandem Axle Wt. Violators	26	6	3	2
Percentage of Bridge Formula Violators	25	6	3	2
Average Pounds Over Gross Weight Limit	82	41	27	20
Average Pounds Over Single Weight Limit	77	38	26	19
Average Pounds Over Tandem Weight	78	39	26	20
Average Pounds Over Bridge Weight Limit	106	53	35	27
Average ESALs	369	185	123	92
Average Excess ESALs	246	123	82	61

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Figure 16. The "Sampling Guide" dialog box.

**Pavement Effects Analysis** [X]

Calculated pavement ESAL capacity: 4,162,490

Estimated pavement life BEFORE enforcement activity (years): 21.5

Estimated pavement life AFTER enforcement activity (years): 23.4

Percentage increase in pavement life due to enforcement activity: 8.81%

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Figure 17. The "Pavement Effects Analysis" dialog box.