

Weigh-in-Motion Sampling Plan for Truck-Weight Data in Texas: Method and Plan Development

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ABSTRACT

A statewide data collection plan for truck weights using weigh-in-motion equipment was developed for Texas. The plan was aimed at obtaining truck-weight data that may represent the state. This was accomplished by a probability sample of weigh stations by major road classes, varying levels of truck traffic, and regions of the state. Criteria for selecting preliminary locations for weigh stations were also developed to capture maximum variability in truck types and weights. Twenty-six weigh stations were recommended for Texas. These cover 4 road classes (Interstate system, U.S. system, Texas highway system, and farm-to-market) and 3 levels of percent truck traffic (less than 8 percent, 8 to 16 percent, and over 16 percent). Different levels of truck traffic are likely to reflect degree of urbanization, land use, and other ambient traffic characteristics. The methodology is general enough to be applied to other states with minimal or no modification.

Contained in this paper is a description of a data collection plan of truck weights using weigh-in-motion (WIM) equipment for Texas. The methodology used is documented together with the actual development of the plan. The plan is based on a probability sampling framework, aimed at capturing maximum variability of truck weights and types within the state. The method can be applied to any state, region, or district with minimal or no modification.

INTRODUCTION

The State Department of Highways and Public Transportation (SDHPT) has expended a great deal of effort collecting traffic data to satisfy internal and external data requirements for analysis, evaluation, and planning purposes. The data collected include traffic volume, vehicle classification, and weight. The data collection program can be divided into 3 broad categories: the Continuous element, the Highway Performance Monitoring System (HPMS) element, and the Special Data Collection element (1).

The HPMS element, which includes statewide samples of vehicle counts and classification as well as truck weight data, is aimed at providing a statewide representation of the traffic characteristics. There are currently 206 manual count stations and 6 weigh stations in Texas.

A detailed study of the Texas truck weighing program (1) was conducted to analyze and evaluate the existing program, and current and future data needs. The study revealed a number of improvements that could be made to the existing truck weight program. In particular, it suggested that the number of weigh stations should be increased. A need was also indicated to be able to link truck weight data to truck classification data so that the usefulness of both may be fully realized.

Described in this paper is the development of a data collection plan for truck weights using WIM equipment. The plan was especially designed for

Texas but the methodology used can be directly applied to any area of interest. The plan was developed based on traffic volume information from the 206 manual count stations and relatively limited truck weight information from the six weigh stations.

METHODOLOGY AND PLAN DEVELOPMENT

The purpose of the truck-weight data collection scheme is to capture, as much as possible, the variability in truck weights and types on various functional road classes across the state. In this way, the weight data collected may yield representative results for all parts of Texas. The critical sample size for truck weight data, therefore, is the number of sampling sites rather than the number of trucks that are to be sampled. This is so because the latter is easy to obtain once the weigh stations are selected. The issues addressed in developing the plan include (a) the number of weigh stations required statewide, (b) the locations of the weigh stations, and (c) the regional subplans for data collection and planning.

These tasks are to ensure that the truck weight data collected may yield reasonably accurate weight estimates for the truck population in Texas, as well as to provide data that may eventually be used with the classification data from existing manual count stations. Task (c) also facilitates the planning for data collection. It allows each region the flexibility to plan their data collection as frequently as needed during the course of a year to account for temporal variation in truck traffic, which may be dictated by the regional industries and their levels of production throughout the year. This is particularly desirable for Texas where a number of industries are concentrated only in certain parts of the state. Timber, cattle, produce, coal, and iron ores are typical examples of such industries.

Specific tasks involved in developing a data collection plan for truck weights are as follows:

1. The determination of the number of weigh stations required statewide (based on existing knowledge of truck weight variability in the state);

2. The definition of regions for data collection purposes;

3. The determination of the number of weigh stations required by road class, percent truck traffic, and region;

4. The development of criteria to select preliminary locations of the weigh stations; and

5. The selection of preliminary locations for the weigh stations.

These tasks are fully described below.

Task 1: The Determination of Optimal Number of WIM Stations

The number of weigh stations required statewide is a function of (a) the variability in the mean truck weights among different locations across the state, (b) a desired level of accuracy in estimating the mean truck weight, and (c) a desired confidence limit $(1 - \alpha)$ of the estimated mean truck weight. The formula for determining the optimal number of truck weigh stations is as follows (2):

$$a = (1 - f) S_a^2 / v \quad (1)$$

where

a = the optimal number of weigh stations required statewide,

f = a sampling fraction or a ratio of the number of sampled trucks to total trucks in the population,

S_a^2 = the known variability in the mean truck weights among different locations across the state, and

v = the desired variance that is directly related to desired accuracy in estimating the eventual mean truck weight.

Because f is usually a small fraction, Equation 1 can be approximated by the following:

$$a = S_a^2 / v \quad (2)$$

The desired variance of the estimated mean truck weight, v , is related to a desired accuracy level and a confidence limit as follows:

$$v = (\bar{d}/z)^2 \quad (3)$$

where \bar{d} is a desired error margin (or allowance) in estimating the mean truck weight in pounds, and z is the normal variate corresponding to the $(1 - \alpha)$ confidence limit. The formula for S_a^2 was derived by Kish (2) as follows:

$$S_a^2 = 1/(n - 1) \sum_{i=1}^n \left[x_i / (x/n) (\bar{y}_i - \bar{y}) \right]^2 \quad (4)$$

where

n = the number of weigh stations with available truck weight data ($n = 5$ here),

x_i = the sample size of the i th station,

$x = \sum_{i=1}^n x_i$,

\bar{y}_i = the observed mean truck weight of the i th station, and

\bar{y} = the overall mean truck weight from the 5 stations.

Truck weight data available from the 5 weigh stations in Texas were used to calculate S_a^2 . The 5 weigh stations were located at Lubbock, Nacogdoches, San Marcos, Seguin, and Sweetwater. The value of S_a^2 based on the available truck weight data was found to be 1.512×10^7 .

Figure 1 and Table 1 show the optimal number of weigh stations required for different error margins based on Equations 2 and 3. From this figure, it was recommended that 26 weigh stations be adopted for an error margin in the mean truck weight of $\pm 1,500$ lb.

Note that if truck weight data by road class are available, the number of weigh stations required should be determined separately for each road class in a similar manner. If not, the number of weigh stations by road class will have to be obtained by some other means as shown below.

The statewide number of weigh stations required was allocated to four major road classes. The four road classes are Interstate system, U.S. system, Texas highway system, and farm-to-market (FM) roads. Because there are no truck weight data available by road class, these numbers of stations by road class were determined based on a general notion that heavy trucks tend to travel more on the Interstate, U.S., and Texas highway systems, but less frequently on FM roads. It is therefore desirable to allocate proportionally more weigh stations to the first 3 highway

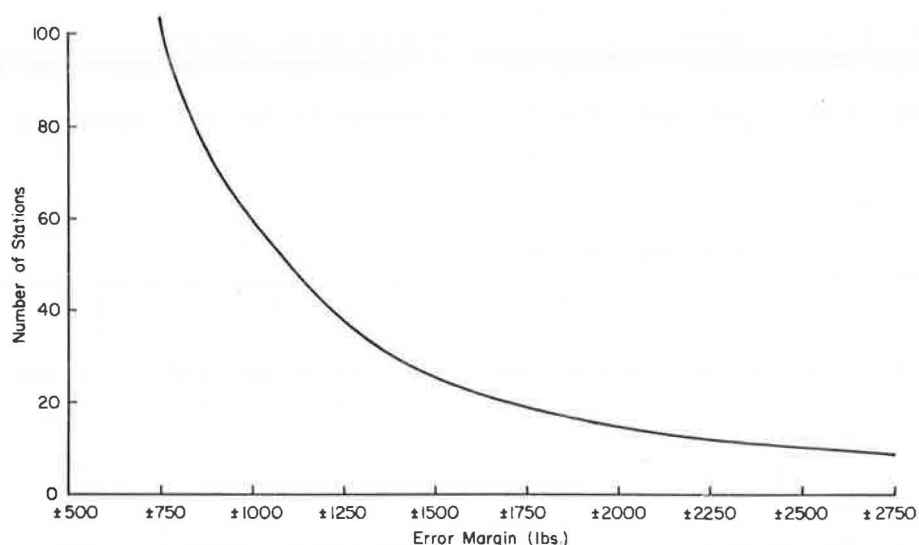


FIGURE 1 Optimum number of weigh stations by desired accuracy levels.

TABLE 1 Optimal Number of Weigh Stations Required by Various Error Margins

Error Margin	Number of Stations
±500	233
±750	104
±1,000	59
±1,200	38
±1,500	26
±1,750	19
±2,000	15
±2,250	12
±2,500	10

systems than to FM roads. The number of weigh stations allocated to each road class is as follows:

Road Class	Number of Stations
Interstate	10
U.S.	6
Texas	6
FM	4
Total (N)	26

Next, these 26 weigh stations were distributed by various traffic characteristics within the same road class and different regions of the state.

Task 2: Defining Regions Within State for Data Collection

Different regions of Texas are usually characterized by different industries, the products of which are transported by trucks. These products may give rise to seasonal variation in truck-trip generation. For example, the timber industry is predominantly located in eastern Texas, where timber production usually goes on year-round. Fruit and vegetables are predominantly grown in the south and the level of production is influenced by seasons of the year. Division of the state into smaller regions allows appropriate seasonal plans for data collection to be developed for different regions as needed.

Identification of regions was based on broad geographical characteristics and regional industries. The region's boundary was made to coincide with boundaries of current highway districts. Five regions were defined as shown in Figure 2, each containing a number of highway districts.



FIGURE 2 Regions for truck weight data collection.

Task 3: The Determination of the Number of Weigh Stations by Percent Truck Traffic, Road Class, and Region

The purpose of this task is to ensure that all regions and the varying traffic characteristics within the same road class will be well represented in the sample. Given a road class, percent truck traffic may be a good indicator of many traffic characteristics because it is likely to reflect a degree of urban-rural, land use served by the route, and other ambient traffic-related elements.

The 26 weigh stations determined in Task 1 were allocated to each road class, percent truck traffic, and region, in proportion to (a) regional highway mileage of a given road class, and (b) a distribution of percent truck traffic for a given road class. This task involves the following steps:

1. Three levels of percent combination-truck traffic were defined to represent high, medium, and low truck traffic as follows (note that a percent truck traffic is a proportion of total traffic that is combination trucks):

- Low = 8 percent combination trucks or less,
- Medium = 8 to 16 percent combination trucks, and
- High = over 16 percent combination trucks.

2. Mileage distribution was obtained by road class, percent truck traffic, and region. Information from the 206 manual count stations was used to first establish the distribution of percent truck traffic by road class and region. This was then combined with the highway mileage, which was compiled from the district map for those routes subject to the 55 mph speed limit to yield the mileage distribution.

TABLE 2 Distribution of Road Class by Percent of Truck Traffic and Region

Region and Percent of Truck Traffic	Road Class			
	Interstate	U.S.	Texas	FM
Northwest				
High	.062	.090	.036	.046
Medium	.046	.106	.036	.023
Low	.015	.016	.072	.139
West				
High	.225	.048	.028	.059
Medium	^a	.108	.083	.029
Low	^a	.072	.028	.059
South				
High	.101	.061	.044	.010
Medium	.101	.081	.094	.058
Low	.017	.092	.143	.164
East				
High	.135	.028	.033	—
Medium	.054	.077	.059	.017
Low	.027	.065	.145	.205
North				
High	.078	.026	.017	—
Medium	.062	.085	.059	.028
Low	.047	.042	.122	.163
Total	1.000	1.000	1.000	1.000

^aNo information, assumed empty.

bution by road class, percent truck traffic, and region.

3. For each road class, the proportions of mileage by percent truck traffic and region were computed as shown in Table 2. These proportions can be expressed as

$$r_{ijk} = m_{ijk} / \sum_j \sum_k m_{ijk} \quad (5)$$

where

- $i = 1, 2, 3, \text{ or } 4$ (indexes for Interstate, U.S., Texas, or FM),
 $j = 1, 2, \text{ or } 3$ (indexes for the three levels of percent truck traffic), and
 $k = 1, 2, 3, 4, \text{ or } 5$, (indexes for the 5 regions).

4. The probability of selecting a weigh station from any one road class with a certain level of truck traffic in a certain region was computed using the following formula:

$$P_{ijk} = r_{ijk} (N_{i..}/N) \quad (6)$$

where $N_{i..}$ = the number of weigh stations for the i th road class, and N = the total number of weigh stations for the state. (Table 3 gives the values of P_{ijk} .)

TABLE 3 Values of P_{ijk}

Region and Percent of Truck Traffic	Road Class				$\sum_i P_{ijk}$
	Interstate	U.S.	Texas	FM	
Northwest					
High	.024	.021	.008	.007	.060
Medium	.018	.024	.008	.004	.054
Low	.006	.004	.017	.021	.048
West					
High	.098	.011	.006	.009	.124
Medium	^a	.025	.019	.004	.048
Low	^a	.017	.006	.009	.032
South					
High	.039	.014	.010	.002	.065
Medium	.039	.019	.022	.009	.089
Low	.007	.021	.033	.025	.086
East					
High	.052	.006	.008	^a	.066
Medium	.021	.018	.014	.003	.056
Low	.010	.015	.033	.032	.090
North					
High	.030	.006	.004	^a	.040
Medium	.024	.020	.014	.004	.062
Low	.018	.010	.028	.025	.081
Total Values $\sum_j \sum_k P_{ijk}$.386	.231	.230	.154	1.000

^aNo information, assumed empty.

5. The random allocation indices by level of truck traffic and region were defined as follows:

$$Q_{.jk} = N \times \sum_{i=1}^4 P_{ijk} \quad (7)$$

The random allocation numbers ($N_{.jk}$) by level of truck traffic and region were obtained by rounding $Q_{.jk}$ to the nearest integers. (The values of the allocation indices and numbers are given in Table 4.)

6. The 26 weigh stations were assigned to different regions and levels of truck traffic within each road class by the following procedure (3). A square (26 x 26) allocation matrix was constructed as shown in Table 5. The allocation numbers were used to assign the rows to each combination of region and percentage of truck traffic. For each column (1-26), one row was selected at random. In this way, each column and each row of the allocation matrix eventually contained one selection unit. The 26 selection units are marked by an X in Table 5.

TABLE 4 Allocation Indices and Allocation Numbers by Percent of Truck Traffic and Region

Region and Percent of Truck Traffic	Allocation Index	Allocation Number
Northwest		
High	1,560	2
Medium	1,404	1
Low	1,248	1
West		
High	3,224	3
Medium	1,248	1
Low	0,832	1
South		
High	1,690	2
Medium	2,314	2
Low	2,236	2
East		
High	1,716	2
Medium	1,456	2
Low	2,340	2
North		
High	1,040	1
Medium	1,612	2
Low	2,106	2
Total	26	26

7. The number of weigh stations required for each level of truck traffic, road class, and region is summarized in Table 6. The table was obtained by tallying the selection units from Table 5.

Task 4: The Development of Criteria for Selecting Preliminary Locations for Weigh Stations

Preliminary locations for the weigh stations summarized in Table 6 can be selected in a systematic manner. There are a number of ways to do this. The simplest method is to randomly select from existing manual count locations until the required number (in Table 6) is met. This random selection involves an initial cross-classification of existing manual count locations by road class, percent truck traffic, and region (as given in Table 7). The locations for weigh stations are then randomly selected from these count locations in circled cells of Table 7, until the numbers specified by Table 6 are satisfied. The circled cells correspond to the nonempty cells of Table 6. Table 7 lists a total of 474 manual count locations for 206 count stations. This is so because if a station was located near an intersection of more than one route, traffic counts usually took place on all routes for that station. The random-selection method is not recommended for this study.

The recommended method for selecting preliminary sites for the weigh stations here is one that aims at capturing maximum variability of different truck types on all road classes. The vehicle classification counts available from existing manual count stations provided basic input to develop the site selection criteria as follows.

A truck diversity index, based on the Shannon Entropy Function, was used to compare the relative abundance of various types of trucks at different locations. This diversity index at a site can be expressed as:

$$\text{Truck Diversity Index (TDI)} = - \sum_i P_i \log P_i$$

TABLE 5 Random Allocation Matrix and Selection Units

Region	Percent Truck	Road Class																									
		Interstate						US						Texas						FM							
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
Northwest	High	1					X							X													
	Medium	2								X										X							X
	Low	3																									
	Low	4																									
West	High	5									X								X								
	Medium	6																									
	Low	7			X																			X			
	Low	8																									
South	High	9																									
	Medium	10	X								X																
	Low	11																									
	Low	12																									
East	High	13																									
	Medium	14																									
	Low	15																									
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	Medium	18																									
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	Low	20																									
North	High	21																									
	Medium	22																									
	Low	23																									
	Low	24																									
North	High	25																									
	Medium	26																									
	Low	27																									
	Low	28																									

X denoted selected cells

where $i = 1, 2, 3$, or 4 (the indexes for four different truck configurations: single-unit, truck and trailer, semitrailers, and double-trailers). The truck diversity index (TDI) at a site is a maximum when all 4 truck types are observed in similar proportions. It is a minimum (TDI = 0) when only one truck type is represented at the site. In general,

the TDI is always a positive quantity as long as more than one truck type is observed at a site. The more diverse a site is in terms of the availability of different truck types, the larger the magnitude of the TDI.

Task 5: The Selection of Preliminary Locations for Truck Weigh Stations

This task involves the following steps:

1. TDI values for the existing manual count locations in the circled cells of Table 7 were computed. The TDI values within the circled cells were then ordered from the largest to the smallest.

2. Preliminary sites for the weigh stations were selected from the manual count locations in the circled cells of Table 7, which showed the highest values of TDI, until the number of weigh stations in Table 6 were satisfied. These selected locations represent the sites with maximum diversity of truck configurations. These preliminary locations are listed in Table 8.

3. Site investigation of these preliminary truck weight locations can be conducted for field feasibility. If a location is considered infeasible as a site for a weigh station, another preliminary location is selected within the appropriate cell of Table 7, which shows the next largest TDI value.

CONCLUSIONS

The preceding data collection plan for truck weights in Texas was aimed at achieving the following:

1. The development of a plan that may result in representative truck weight data for the state,

TABLE 6 Number of Weigh Stations Required by Road Class, Percent of Truck Traffic, and Region

Region and Percent of Truck Traffic	Interstate	U.S.	Texas	FM
Northwest				
High	2	1	a	1
Medium	a	a	1	a
Low	a	a	a	a
West				
High	1	1	1	1
Medium	a	a	a	a
Low	a	a	a	a
South				
High	2	a	a	a
Medium	a	1	1	a
Low	1	a	1	1
East				
High	a	a	a	a
Medium	1	1	a	a
Low	1	a	1	a
North				
High	a	1	a	a
Medium	1	a	1	a
Low	1	1	a	1
Total	10	6	6	4

aNone.

TABLE 7 Number of Existing Manual Count Stations by Percent of Truck Traffic, Road Class, and Region

Region	% Truck Traffic	Road Class				Total
		Inter-state	U.S.	State	FM	
Northwest	High	(4)	(11)	2	(2)	19
	Medium	3	13	(2)	1	19
	Low	1	2	4	6	13
West	High	(6)	(4)	(2)	(2)	14
	Medium	-	9	6	1	16
	Low	-	6	2	2	10
South	High	(6)	12	9	1	28
	Medium	6	(16)	(19)	6	47
	Low	(1)	18	(29)	(17)	65
East	High	5	7	5	-	17
	Medium	(2)	(19)	9	1	31
	Low	(1)	16	(22)	12	51
North	High	5	(10)	4	3	19
	Medium	(4)	32	(14)	4	54
	Low	(3)	(16)	29	(23)	71
Total		47	191	158	78	474

- denotes no information available

TABLE 8 Preliminary Locations Selected for Truck Weigh Stations in Texas

Region and Highway Number	Percent Truck	Station Code	District	County	Remarks
Northwest					
IH 40	31	M 1083	4	Oldham	IH 40—west of Adrian
IH 40	30	MS 1	1	Wheeler	IH 40—east of Shamrock
US 82	20	L 149	25	King	US 82—south of Guthrie
SH 350	15	M 1105	8	Howard	SH 350 and FM 820 northeast of Big Spring
FM 1057	23	M 1094	4	Deaf Smith	US 385, FM 1057 and 1062 south of Vega
West					
IH 10	35	MS 152	24	Hudspeth	IH 10 west of Van Horn
US 277	21	M 1003	7	Edwards	US 277 and SH 35 south of Sonora
US 137	21	M 1103	7	Glasscock	SH 158 and 137 west of Garden City
FM 181	23	M 1100	6	Ector	SH 302, SH 158, and FM 181 northwest of Odessa
South					
IH 37	22	L 371	16	Live Oak	IH 37 north of Three Rivers
US 83	7	M 1159	15	Zavala	US 83 and FM 1025—north of Crystal City
IH 10	24	MS 164	3	Fayette	IH 10 east of Schulenburg
US 57	14	M 1130	15	Frio	US 57 and FM 140 northwest of Pearsall
SH 123	9	M 1498	15	Wilson	SH 123 and FM 1681 north of Stockdale
SH 71	6	M 904	14	Bastrop	SH 21 and 71 west of Bastrop
FM 140	8	M 1130	15	Frio	US 57 and FM 140—northwest of Pearsall
East					
IH 10	10	M 1200	12	Harris	IH 10 west of SH 6 Houston
IH 45	7	MA 16	12	Harris	IH 45—north of Houston
US 59	15	L 72	11	Nacogdoches	US 59—south of Nacogdoches
SH 155	7	M 72	10	Smith	US 271 and SH 155—northeast of Tyler
North					
IH 35	15	M 1149	18	Denton	IH 35W north of SH 114 Interchange
IH 20	7	M 1181	18	Dallas	IH 20 west of Dallas
US 82	22	M 278	3	Baylor	US 82 and 183 west of Wichita Falls
US 277	6	M 167	3	Wichita	US 287 Wichita River Bridge
SH 14	14	M 1144	17	Robertson	SH 6 and 14 south of Bremond
FM 407	8	M 1089	2	Wise	US 287 and FM 407—southeast of Decatur

Note: IH = Interstate highway, US = U.S. highway, SH = state highway, and FM = farm-to-market road.

2. The collection of truck weight data for all major road classes and for various traffic characteristics within each road class,

3. The capture of maximum variability of truck types, and

4. The selection of locations for the weigh stations so that the weight data can be used with the state's current classification data.

The methodology and plan for truck WIM stations were developed based on the amount of the available information on truck weights and truck classification counts for Texas. The method, however, can be directly applied to any other area of interest with some or no modification.

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This paper is based on a study that was sponsored by the Texas State Department of Highways and Public Transportation. The views, interpretations, analyses, and conclusions expressed or implied in this paper are those of the authors and not necessarily those of the sponsor.

Publication of this paper sponsored by Task Force on Weigh-In-Motion.

The South Dakota Bridge Weigh-in-Motion System

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ABSTRACT

Following completion of Federal Highway Administration (FHWA)-sponsored research in high-speed weighing of vehicles using instrumented bridges as the load-sensing element, the South Dakota Department of Transportation became interested in the technology as an appropriate means for gathering truck weight information. After unsuccessful efforts to obtain a prototype system from the FHWA, the Department decided in late 1982 to develop its own bridge weigh-in-motion system. Electronic equipment was purchased, weighing software was designed and written, and a motorhome was purchased to house and transport the system. Two bridges were permanently instrumented and used for weighing in 1983. Although it was based on research published during the FHWA-sponsored contracts, the system has been developed independently and differs from the prototype systems. Permanently bonded strain gauges are used instead of removable transducers, and photocells are used rather than tapeswitches to sense axles. Calibration procedures are also different. As of fall 1985, eighteen bridge weigh-in-motion sites in South Dakota are being used to conduct the state's Truck Weight Study on interstate, main rural, secondary and urban highways.

In 1982, research sponsored by the Federal Highway Administration (FHWA) in weigh-in-motion technology--a method of weighing vehicles as they pass over instrumented highway structures--was being completed. One aspect of the research contracts involved development and delivery to the FHWA of three prototype systems that would later be made available to state

agencies for purposes of evaluation and demonstration.

When the South Dakota Department of Transportation became aware of the prototype systems, an evaluation of the concept was made. Bridge weigh-in-motion appeared appropriate for use in South Dakota because of its portability, the large number of potential sites available throughout the state, and the relatively low traffic volumes of the state, which were consistent with the system's limitations at that time. The decision was made to pursue acqui-