Weighing Trucks on Axle-Load and Weigh-in-Motion Scales

CLYDE E. LEE and RANDY B. MACHEMEHL

ABSTRACT

Truck weight information is used for (a) commerce, (b) statistical data, and (c) law enforcement. Single-draft weighing on a vehicle scale that meets the required basic maintenance tolerance of 0.2 percent of applied load is the only acceptable way to determine gross vehicle weight for commercial purposes. Axle-load scales and wheel-load weighers that meet basic maintenance tolerances of 0.2 and 2.0 percent of applied load, respectively, may be used to weigh trucks for the other two purposes. Tolerances and use requirements for weigh-in-motion (WIM) equipment have not yet been established by the National Bureau of Standards. Analysis of a data set from a carefully controlled field experiment in which 100 trucks were weighed statically on two different axle-load scales and at a slow speed on a WIM scale indicates that the weight of a truck is redistributed among the axles and wheels as the truck moves along the road surface and as it accelerates and stops for weighing on static scales. The variability in gross vehicle weights calculated from successive weighings of the axles or wheels of a truck on the axle-load and WIM scales that performed within small tolerances is discussed. Observed variations in axle-group weights, axle weights, and wheel weights under these conditions are also discussed. Implications of this analysis are that in establishing weight enforcement tolerances and interpreting statistical weight data consideration must be given to the fact that even though truck weight is virtually constant, it is not always distributed among the axles and wheels of the truck in the same proportions.

Trucks are usually weighed for one or more of the following purposes: commerce, statistical data, or enforcement. Commercial truck weighing requires that highly accurate determinations of the gross weight of individual loaded and unloaded vehicles be made so that weight can be relied on as the quantitative basis for buying and selling goods without risk of serious injury to either party involved in the transaction. Single-draft weighing on vehicle scales that meet acceptance and maintenance tolerances of 0.1 and 0.2 percent of applied test load, respectively, is used for this exacting purpose.

Statistical data, on the other hand, provide descriptive information on which to base decisions regarding the planning, financing, design, operation, maintenance, and management of road facilities and do not require the same degree of attention to the weight of individual vehicles or to the exact measurement of individual wheel loads because no single person or firm is at risk in using the weight information. Successive weighing of vehicle wheels, axles, or axle groups on either axle-load scales or wheel-load weighers is generally used for this purpose. Sampling techniques are employed to develop representative frequency distributions of statistical data. These data define past and present patterns of vehicular loading at selected locations with respect to time. From such information, trends in traffic loads are evaluated and forecasts of future traffic loading patterns are made. Then designs are drawn to accommodate the anticipated traffic loads during some future period of time.

To protect the designed facilities from unexpected loads, legal limits that respect engineering principles are established and enforcement weighing programs are implemented. Enforcement weighing involves checking wheel loads, axle loads, axle-group loads, and gross vehicle weights of individual vehicles to detect noncompliance with one or more of the parameters that are limited by law. These determinations must be made within reasonable tolerances because an individual is at risk when a violation of the established legal limit is detected. Vehicle scales with multiple load-receiving platforms, axle-load scales, and wheel-load weighers are all used in enforcement weighing programs. The type of device that is used in a specific enforcement program is determined by safety considerations, weigh site availability, equipment capabilities and limitations, legal limits to be enforced, time requirements, and costs. Practicable enforcement tolerances that recognize all these factors must be adopted either by law or by policy.

The purpose of this paper is to discuss the variability in truck wheel loads, axle loads, axle-group loads, and gross vehicle weights that was observed when 100 trucks were weighed in a field testing program on one weigh-in-motion scale and on two different axle-load scales. Interpretation of the information that is presented will be a valuable resource for consideration when selecting suitable equipment and weighing techniques and when defining appropriate tolerances for truck weighing operations that will be conducted either for collecting statistical data or for enforcement. Brief reviews of the basic concepts of static and in-motion weighing are given ng with analyses of the data sets that were taken each of these techniques.

STATIC WEIGHING

By definition, weight is the force with which an object is attracted toward the earth by gravitation.

It is equal to the product of the mass of the object and the local value of gravitational acceleration. To weigh a truck accurately, all wheels of the truck must be supported simultaneously on force transducers that are capable of measuring the total upward force required to balance the downward force of gravity that is acting on all components of the truck when no component is experiencing vertical acceleration. That is, no vertical external force other than gravity, nor any vertical inertial force, can be acting on any truck component at the time of weighing. The zero-vertical-acceleration condition is best approximated in practice after a truck has stopped on a weighing device and sufficient time has been allowed for any kinetic energy stored in the truck components to be dissipated. Measurement of the total upward vertical force in this condition of equilibrium is called static, single-draft weighing and is the most accurate way to determine gross vehicle weight.

Gross vehicle weight can also be determined accurately by successively measuring the downward force on the tires with all the vehicle components motionless and in exactly the same relative position to each other throughout the entire weighing sequence. This condition of juxtaposition can be approximated in practice but rarely achieved. The center of oscillation of the composite vehicle mass usually changes when the vehicle is moved; therefore the distribution of the total downward force among the tires changes. Some sacrifice in weighing accuracy can thus be expected if the vehicle is moved between successive tire force measurements as is the case when using axle-load scales or wheel-load weighers. This is especially true when the vehicle is moved several times and the weighing surface of the scales is not in the same horizontal plane as the surfaces supporting the tires that are not being weighed at the time.

A truck is made up of several interconnected components, each of which has mass. The connectors, which can be viewed as springs, hinges, and motion dampers, also have mass and serve to transmit force between the masses to which they are attached. Any external force applied to a vehicle component can be transferred to the others through the connectors and eventually to the road surface through the tires. Gravity, for all practical purposes, applies a constant downward force to each mass; therefore the total weight, or mass, of the truck does not change as the truck moves from place to place. The portion of the gross weight carried by any particular axle or wheel may change, however.

In weighing a truck, the external upward forces that are measured and summed are normally applied through the tires. The part of each such tire force that is not used to balance the gravitational force acting on the unsprung mass of each wheel suspension system assembly is transmitted to the spring mass, or body, of the truck through the connectors. Proportioning of the weight of the sprung mass to the various springs, hinges, and dampers and thence to the tires is a function of the relative positions of the various components and connectors.

A typical spring rate for a rear truck wheel suspension is about 3,500 to 4,000 lb per inch of displacement and each tire also has a rate of about 4,000 lb per inch. The front suspension generally has a spring rate of about 500 lb per inch. Thus, if one wheel of a vehicle is raised or lowered with respect to the others during weighing, the wheel force on the scale, or weigher, will be considerably different than when the wheel is not displaced. Particular attention must be given to this phenomenon when weighing the wheels of tandem or triple axles if reasonable accuracy is to be achieved with wheel-load weighers. The same principles also apply to weighing axles and axle groups with sets of wheel-load weighers or with axle-load scales.

The only practical way to measure gross vehicle weight accurately by successive positioning of the wheels on a scale, or a series of scales, is to maintain all wheels of the vehicle in a horizontal plane (a smooth level surface) and have no redistribution of weight during the weighing process. This means that the deflection of the scale itself must be considered and that the friction in the vehicle suspension, drive, and braking systems must be recognized. A considerable amount of weight transfer among axles occurs during acceleration and stopping of a vehicle, and the weight distribution at the time of weighing depends on the frictional forces in the suspension system at that time. In practice, efforts must be made to minimize the effects of weight transfer during successive weighings in order to make measurements within acceptable tolerances. The magnitude of these effects is illustrated in a subsequent section of this paper by data taken under carefully controlled field conditions.

IN-MOTION WEIGHING

By definition, and by common usage, the term weight means that only gravitational force is acting on an object at rest. In-motion weighing of a highway vehicle attempts to approximate the gross weight of the vehicle or the portion of the weight carried by a wheel, an axle, or a group of axles on the vehicle by measuring instantaneously, or during a short period of time, the vertical component of dynamic (continually changing) force that is applied to a smooth, level road surface by the tires of the moving vehicle. The weight of the vehicle does not change when it moves over the road, but the dynamic force applied to the roadway surface by a rolling tire of the vehicle varies from more than double its static weight when it runs up on a bump, thereby exerting a large unbalanced force on the wheel mass, to zero when the tire bounces off the road.

The pattern of wheel force for a given vehicle traveling over the same roadway surface profile at the same speed is consistent. The forces acting on the vehicle components are the same, and the response of the interconnected masses that make up the vehicle are the same. The mass of the vehicle components affects the magnitude and the frequency of the dynamic wheel forces and their variation from static weight; therefore different vehicles react differently to the same pattern of road roughness. Observation has shown that the wheels (unsprung masses) oscillate typically in the range of about 8 to 12 Hz when displaced suddenly, and that oscillations are damped rather quickly. During these vertical oscillations, the dynamic wheel force is sometimes less than static weight and sometimes greater. An out-of-round or out-of-balance tire or wheel can apply vertical forces to the rotating mass and cause large variations in dynamic wheel force. Another characteristic of truck behavior is that the sprung mass (body and payload) typically oscillates at about 0.5 to 3 or 4 Hz depending on many factors including mass. These oscillations cause variations in the proportion of the sprung mass that is transferred to a tire at any given instant.

Accurate in-motion vehicle weighing is possible only when the vertical acceleration of all vehicle components is zero. The sum of the vertical forces exerted on a smooth, level surface by the perfectly round and dynamically balanced rolling wheels of a vehicle at a constant speed in a vacuum is equal to the weight of the vehicle. None of the vehicle components will be accelerating vertically under these ideal conditions. However, such conditions never exist in practice. No road surface is perfectly smooth and level, no vehicle is perfect, and the existence of the atmosphere cannot be ignored. The nearer actual conditions approach ideal conditions, the better the approximation of vehicle weight that can be made by measuring the vertical forces applied to the roadway surface by the tires of a moving vehicle.

In practice, the adverse effects of the roadway factors can be made quite small by careful site selection and proper installation and maintenance of in-motion weighing equipment. Undesirable environmental effects can be recognized or perhaps avoided by carefully scheduling weighing operations. The vehicle factors, except possibly speed and acceleration, are largely uncontrollable at a weighing location. Legal and safety regulations restrict the range within which certain other vehicle factors occur, and economic considerations influence the vehicle operating conditions that drivers and owners are willing to tolerate. Perhaps the most significant uncontrolled vehicle factor that affects in-motion weighing is tire condition. Unbalanced or out-of-round tires rotating at high speed can cause large variations in the vertical component of force acting on the wheel mass and can therefore produce vertical acceleration of this mass. Tire inflation pressure also contributes significantly to the dynamic behavior of the tire and wheel mass. Even though the tire-condition variable cannot be controlled in in-motion weighing, observation and experience indicate that the tires on most over-the-road vehicles are maintained in reasonably good condition; therefore the results of this potentially adverse effect might also fall within tolerable limits for most vehicles and for certain types of in-motion weighing operations. Several years of experience have demonstrated that in-motion weighing is practicable. Properly designed and maintained equipment is a basic requirement. Appropriate use of the equipment and interpretation of the measurements are equally important if satisfactory results are to be achieved with the techniques. In the following section, weigh-in-motion (WIM) measurements of tire forces made at slow vehicle speeds are compared with static weights of the same wheels made when the vehicle was stopped 70 ft beyond the WIM scales.

COMPARISON OF WEIGHTS FROM THREE SCALES

On July 6, 1984, 100 trucks were selected from the normal traffic stream for weighing on three different scales at a turn-out-type weigh station on I-10 (milepost 616) near Seguin, Texas. This was part of the Texas Weigh-in-Motion (WIM) Demonstration Project that is being sponsored by the Federal Highway Administration under the Rural Technical Assistance Program (RTAP), the Texas State Department of Highways and Public Transportation, the Texas Department of Public Safety, and the Center for Transportation Research at the University of Texas at Austin. The weigh strip consists of a standard tapered exit ramp, a 500-ft straight and level section 40 ft wide, plus a tapered entrance ramp leading back into the main lanes. Special level-up work was done on the straight, level (longitudinally) section to remove all cross slope in the lane where the three scales were installed.

Three different scale configurations were arranged 70 ft apart (center to center) in the level lane so that each axle or axle group on a truck could be positioned sequentially on the load-receiving platforms of each scale. The nomenclature and operating features of each scale are given next in the order in which each truck passed over them.

1. LSWIM--low-speed weigh-in-motion scale. This scale used two wheel-force transducers, each 53 x 18 in. in plan dimensions, centered transversely in each wheelpath such that the tires rolled along the 18-in. dimension. Each transducer was supplied with ±1 percent maximum tolerances in electrical output signal for a static test load placed anywhere on the load-receiving element. The analog signal was digitized and processed by a microcomputer in real time on site to convert the measured dynamic wheel force to an estimate of static wheel weight. Speed and axle-spacing computations were also made by the WIM system from inductance loop-type vehicle-presence detector signals. Each transducer was calibrated in place with ten 1,000-lb test blocks furnished by the Texas Department of Agriculture, Weights and Measures Section. The system performed within the ±1 percent tolerances under dead-weight loading.

2. AX/WHL--axle and wheel scale. This scale consisted of two scale platforms, each 4 x 6 ft in plan dimensions, arranged side by side in the lane so that the wheels rolled along the 4-ft dimension; thus each wheel on an axle could be weighed separately when the axle was positioned on the pair of scales. The design of the scale utilizes all flexure-type devices to transfer forces to the levers and finally to a single strain-gauge load cell. The load-receiving surface is supported by a tubular metal frame and deflects very little under load. The manufacturer states that one part in 5,000 (0.02 percent) tolerances are attainable with the scale. Under dead-weight calibration up to 10,000 lb, the scale always indicated within the 20-lb increment selected for use in the study.

3. AX/GRP--axle group scale. This scale had two load-receiving elements, each 30 in. x 8 ft in plan dimensions, arranged in shallow pits in the wheelpaths of the lane in such a way that the wheels rolled along the 8-ft dimension. The signals from the load cells in each scale were summed electrically to give only the total weight on both platforms; thus the weight of either a single axle or a group of axles was measured. The scales performed within the 20-lb increments under dead-load calibration even though the manufacturer normally certifies the scales as wheel-load weighers that carry 2 percent basic maintenance tolerances. The aluminum load-receiving elements of these scales deflected considerably under heavy axle-group loads.

Traffic through the weighing site was controlled by uniformed officers of the Department of Public Safety. A trooper at the exit ramp gore directed a truck onto the weigh strip when it could be processed over the scales safely; others continued on the main lanes. The driver of each truck to be weighed was stopped approximately 50 ft in advance of the LSWIM scale and instructed to proceed over the in-motion-weighing scales at a slow, steady speed and then stop with the front axle on the AX/WHL scale 70 ft beyond. A trooper instructed the driver to release the brakes after stopping each axle on the scale and wait for weighing. A weight reading was taken only after no change in the indicated weight was observed. This same procedure was also followed when each single axle or axle group was stopped on the AX/GRP scale located another 70 ft beyond. Tandem axle sets with axles that were more than about 6 ft apart, center to center, required separate weighing of each axle on the 8-ft-long AX/GRP scale. Triple axle groups were split into two weighings when necessary.

Gross Vehicle Weights

Gross vehicle weight is taken as the sum of all wheel, axle, or axle-group weights for the particular vehicle under consideration. The gross weights that were obtained for the trucks that were weighed on three different scales as described previously are presented graphically in figures. In each figure the weights of the same truck measured by two scales are plotted on the respective axes. If there were perfect agreement between the two measurements, all the plotted points would lie exactly on the 45-degree sloping line. To aid visual comparison, lines that represent plus and minus 10 percent of the values along the 45-degree line are shown in each figure. Dashed lines indicate the legal gross weight limit of 80,000 lb.

Inspection of Figure 1 indicates that there is not perfect agreement between the weights, but that all gross vehicle weights measured by the AX/WHL and the AX/GRP scales differ by considerably less than 10 percent. It is interesting to note that the gross weights of the two very heavy (special permit) vehicles, which each weighed more than 100,000 lb, were measured at virtually the same value by both scales.

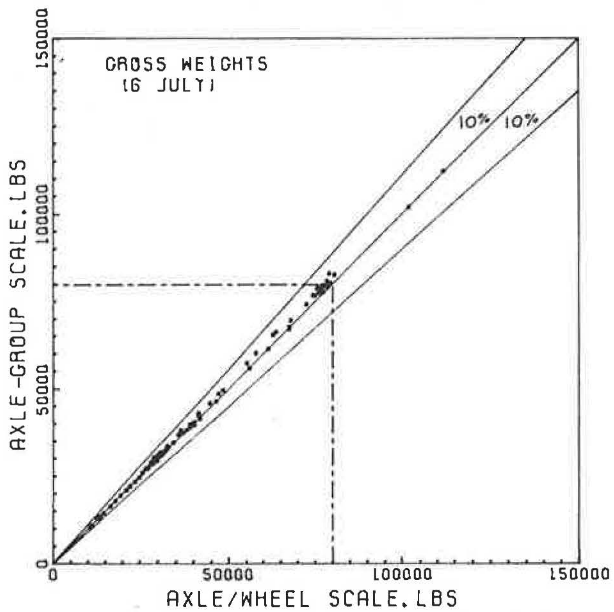

FIGURE 1 Gross weights of 100 trucks weighed statically on two axle-load scales.

Differences in the gross weight of each of the 100 trucks that were weighed on the two static scales were calculated and expressed as a percentage of the gross weight as measured by the AX/WHL scale. If the weights are considered to be a representative sample of the population of all gross vehicle weights that might occur and the observed frequency of occurrence of differences in weights measured by the two scales is assumed to be normally distributed, it can be concluded statistically that the difference in gross vehicle weight for any truck measured by the two scales will range between -1.6 and +4.5 percent 95 times out of 100. Figure 2 shows these differences graphically along with a solid horizontal line at the mean difference and a pair of dashed lines that each show two standard deviations from the mean. The observed differences in gross vehicle weight as determined by the two static axle-load scales, each capable of measuring weights to

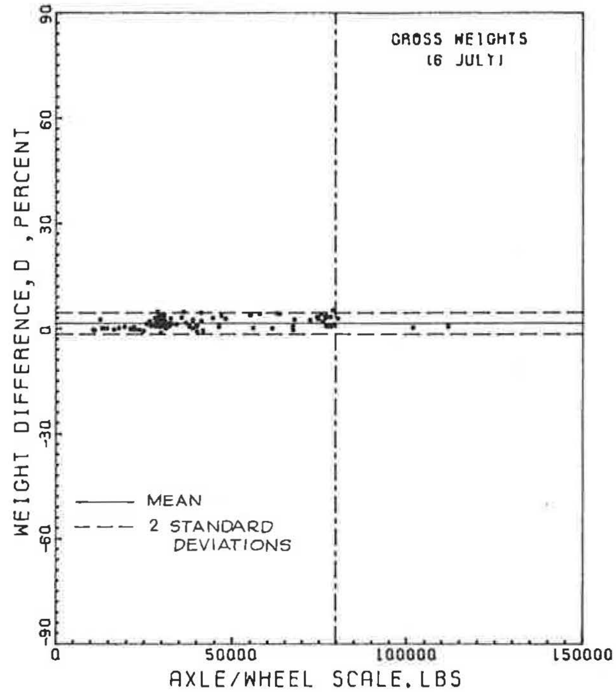

FIGURE 2 Difference in gross vehicle weight for each truck weighed on the AX/GRP scale shown as a percentage of the gross vehicle weight of the same truck measured on the AX/WHL (100 trucks).

within 0.2 percent of an applied test load, can be attributed almost certainly to the transfer of weight among the various axles as the truck moved into position for successive weighing of the axles or groups of axles.

Because more than half the trucks on I-10 at this location are the tractor-semitrailer type (3-S2) and a proportional sample was attempted, 66 trucks of this type were weighed. Gross vehicle weights from the two static scales are shown in Figure 3. Statistical analysis of these data indicates that a dif-

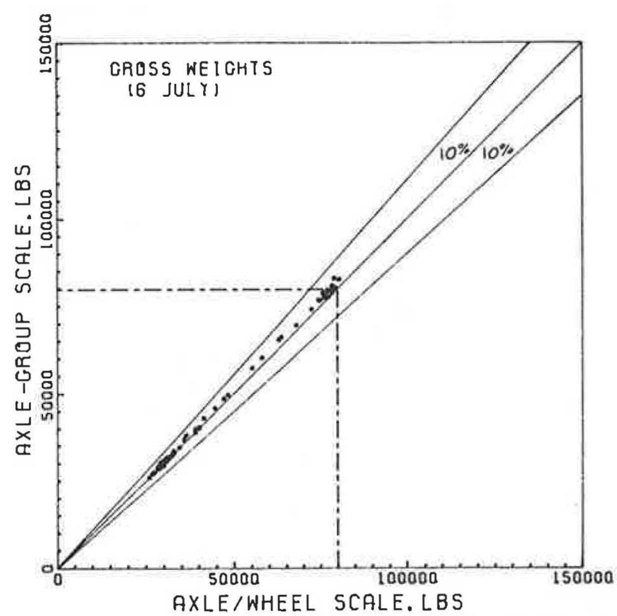

FIGURE 3 Gross weights of 66 tractor-semitrailer (3-S2) trucks weighed statically on two axle-load scales.

ference in gross weight between -0.6 and +4.9 percent may result when weighing any 3-S2-type truck on the two scales 95 times out of 100. Figure 4 shows the observed differences in gross vehicle weights of 3-S2-type trucks as determined by weighing on the two axle-load scales. Weights from the AX/GRP scale were in general slightly heavier than those from the AX/WHL scale. Deflection of the 8-ft-long scale platforms under heavy loads will pitch weight toward the lowered axles and tend to cause differences of this kind. The tractor drive tandem axle group and then the trailer tandem axle group were each weighed in a separate stop on the AX/GRP scale; therefore the scale platforms of this scale received all the weight on each tandem axle set. Each axle was weighed one at a time on the AX/WHL scales that deflected only negligibly.

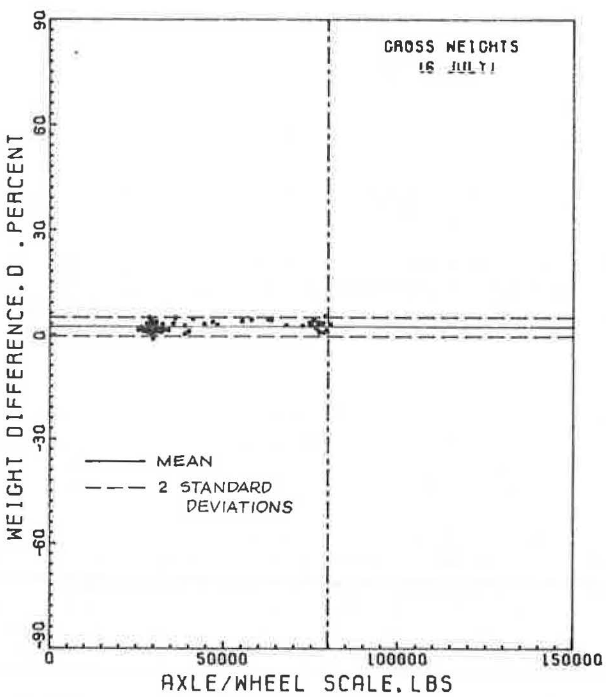

FIGURE 4 Percentage difference in gross vehicle weights of 66 tractor-semitrailer (3-S2) trucks by AX/GRP scale versus AX/WHL scale.

Gross vehicle weights from the LSWIM scale are plotted versus those from the AX/WHL scale in Figure 5. Compared with the data in Figure 1, there is somewhat more scatter in the weights, particularly for the lighter trucks, but all differences are less than 10 percent. The scatter of data shown in Figure 5 is, however, more evenly distributed about the 45-degree line of equality with no pronounced tendency for weights from either scale to be consistently higher or lower. Statistical analysis indicates that the gross weight of an individual truck weighed on each of these scales would differ between -6.7 and +5.9 percent 95 times out of 100. Figure 6 shows the distribution pattern of these differences. Note that the mean difference is virtually zero.

Because of the expense involved, a vehicle scale capable of single-draft weighing was not made available to determine the correct gross weight of the trucks that were weighed on the axle-load and wheel-load scales used in the study. The ability to determine gross vehicle weight correctly by successive weighing of wheels, axles, or axle groups on axle-

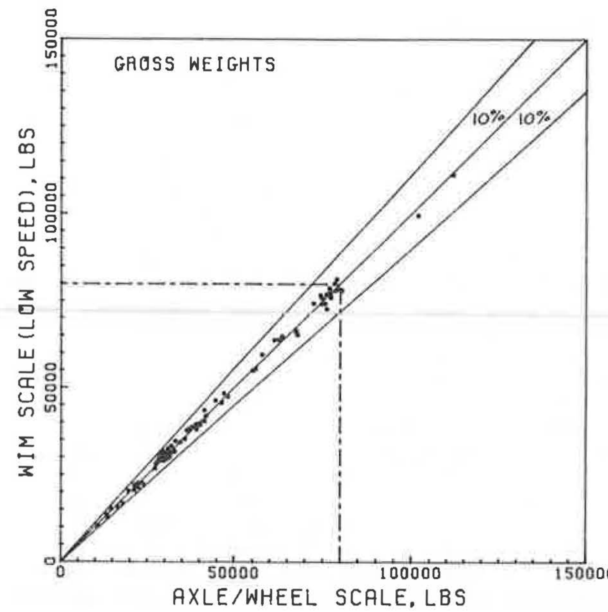

FIGURE 5 Gross weights of 86 trucks weighed on axle/wheel static scale and on low-speed weigh-in-motion scale.

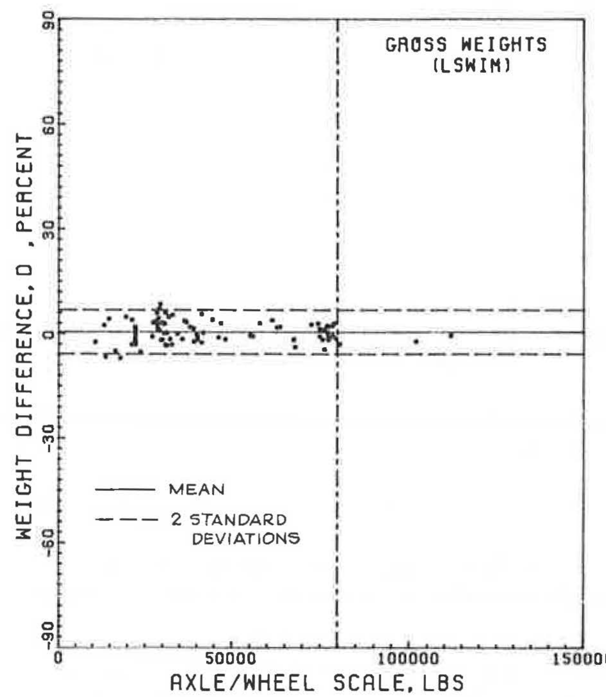

FIGURE 6 Percentage differences in gross vehicle weights by LSWIM scale versus AX/WHL scale.

load or wheel-load scales cannot, therefore, be evaluated directly from the data obtained. The data can, however, be compared to determine whether the three scales gave consistent estimates of gross vehicle weight, but consistency is not to be confused with correctness. There is no way to quantify from the measurements available the amount of weight transfer that occurred as the truck wheels moved into successive positions for weighing. The magnitude of this effect on the calculated gross vehicle weight is, however, indicative of the kind of variability that can occur and should therefore be considered in setting tolerances for enforcement weighing and for interpreting statistical data when axle-load and wheel-load scales are used.

Axle-Group Weights

The total weight on a group of closely spaced axles is important in the engineering design of pavement and bridge structures and also in enforcement weighing. In this study the AX/GRP scale was configured to indicate only the total weight of all wheels on two axles that were spaced less than about 6 ft apart. Axles in a group with greater spacing were weighed separately and summed, and axle groups with an overall spacing between extreme axles in the group greater than this were weighed in separate stops of the truck before summing. The AX/WHL and LSWIM scales indicated the weight of each wheel. Axle-group weights were calculated from these scales by summing the weights of all wheels on the axles in the group.

The observed and calculated values for all axle-group weights are plotted in figures along with a 45-degree line of equality and lines showing 10 percent difference. Weights for all axle groups from the two static axle-load scales are shown in Figure 7. The AX/GRP scale weights are generally somewhat

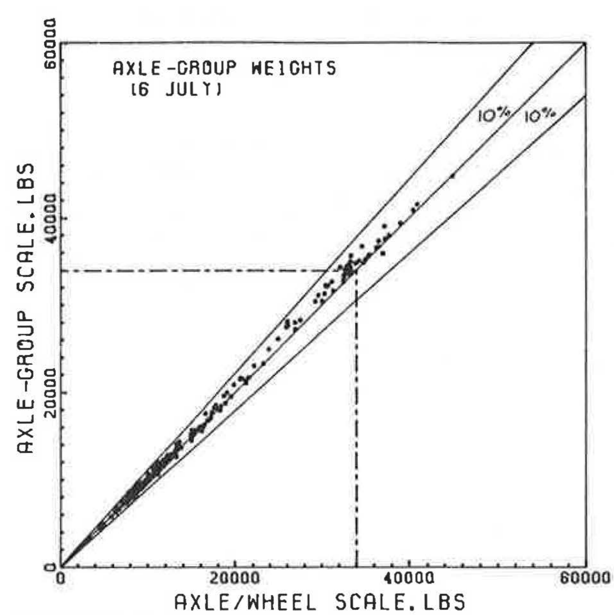

FIGURE 7 Static weights of 287 axle groups from two axle-load scales.

higher (mean value = ±1.3 percent) than the AX/WHL scale weights, especially for the heavier axle groups. The extreme difference ranges from +9.7 to -5.0 percent of the observed differences lying between -4.8 and +6.4 percent as shown in Figure 8. It is interesting that the gross vehicle weights calculated by summing the applicable axle-group weights have a smaller percentage of variation than the individual axle-group weight observations. There appears to be an averaging effect due to the weight redistribution among axle groups during successive weighings of axles on axle-load scales.

Axle-group weights for all 3-S2-type tractor-semitrailer trucks weighed on the two static scales are plotted in Figure 9. Visual inspection of Figure 10 or statistical analysis of this data set indicates that the difference in the axle-group weights

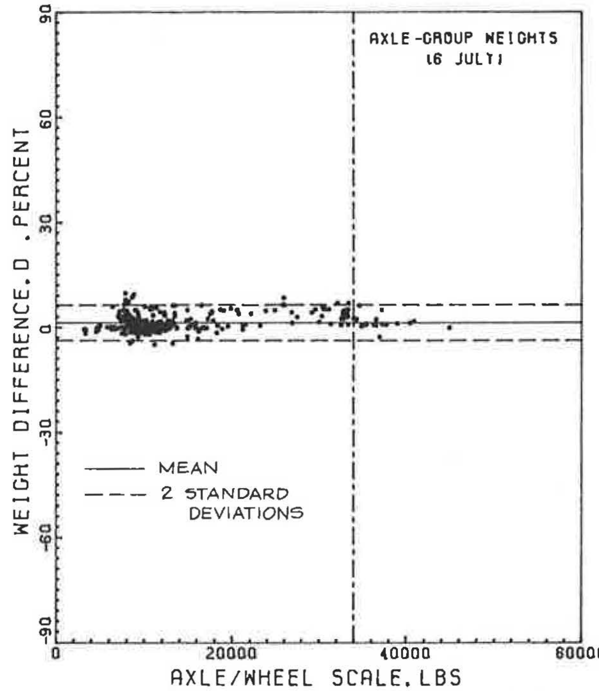

FIGURE 8 Percentage difference in axle-group weights for AX/GRP versus AX/WHL scale weights.

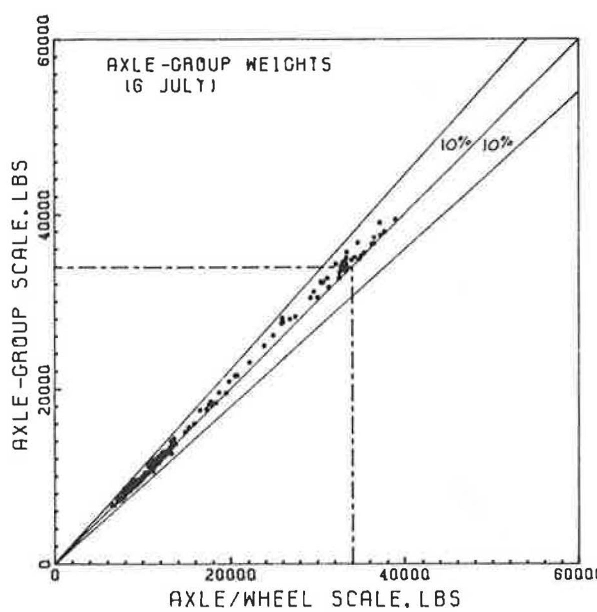

FIGURE 9 Weights of 198 axle groups on 66 tractor-semitrailer (3-S2) trucks by static weighing on two axle-load scales.

was between -3.5 and +7.2 percent in 95 percent of the cases. This difference is slightly larger than that for the axle-group weights of all truck types.

Weights for the 242 axle groups that were measured by both the LSWIM and the AX/WHL scales are shown graphically in Figure 11. Several vehicles had axle weights less than the 2,000-lb threshold set on the LSWIM scale; therefore these axle weights were not recorded. Thus the number of observations plotted in Figure 11 is fewer than the number shown in Figure 7. The scatter in the plotted weight measurements is larger in magnitude than for those in Figure 7, but the pattern of the scatter is more evenly

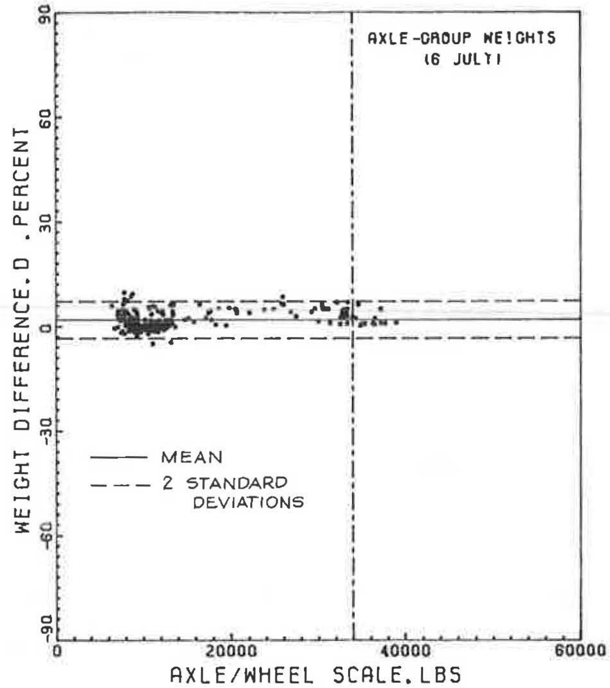

FIGURE 10 Percentage difference in AX/GRP versus AX/WHL scale weights for axle groups on 66 tractor-semitrailer (3-S2) trucks.

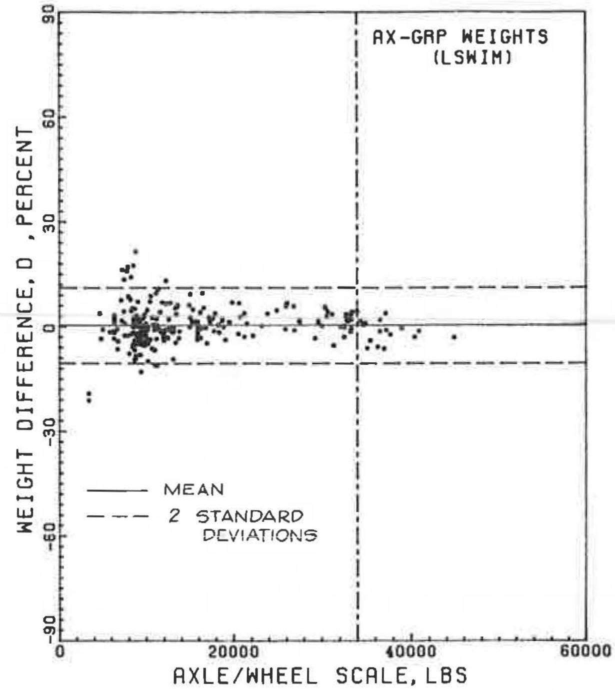

FIGURE 12 Percentage difference in 242 axle-group weights measured statically on the axle/wheel scale and at low speed on the weigh-in-motion scale.

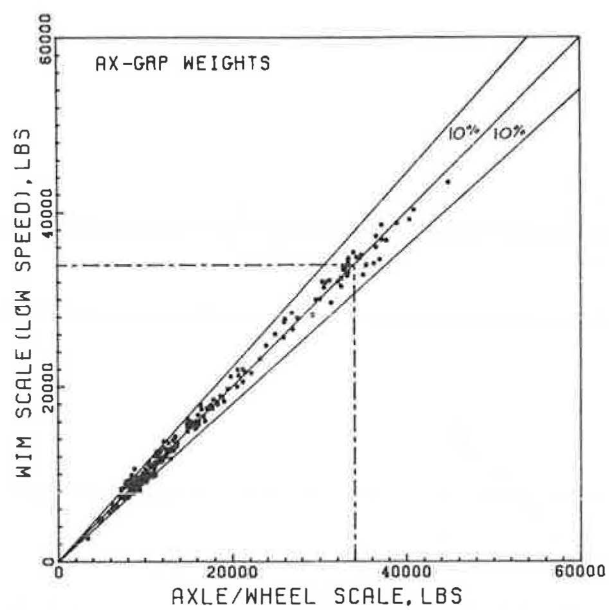

FIGURE 11 Weights of 242 axle groups measured statically on axle/wheel scale versus weights from low-speed weigh-in-motion scale.

distributed about the line of equality. Statistically, 95 percent of the differences in axle-group weights indicated by the AX/WHL and by the LSWIM scales were between -10.6 and +11.0 percent. Figure 12 shows the scatter of these percentage differences.

Axle Weights

Values for the 367 individual axle weights that were determined on both the AX/WHL and the LSWIM scales are shown in Figure 13. Several of the plotted points lie outside the 10 percent difference lines, and standard statistical analyses of the data or visual inspection of Figure 14 indicate that differences ranging from -12.3 to +14.1 percent can occur if 95 percent of all possible comparisons are considered. This data set can be viewed as evidence that the distribution of weight among the axles of a vehicle changes as the vehicle moves over the road surface and stops for successive weighing of axles and wheels on static scales.

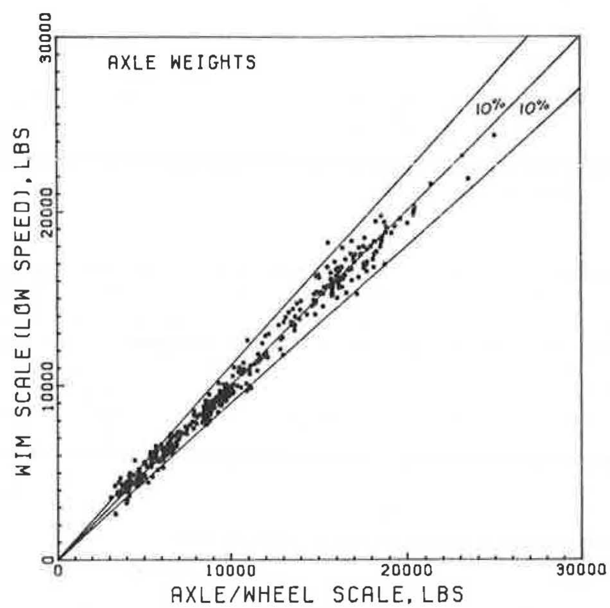

FIGURE 13 Weights of 367 individual axles measured statically on axle/wheel scale and on weigh-in-motion scale.

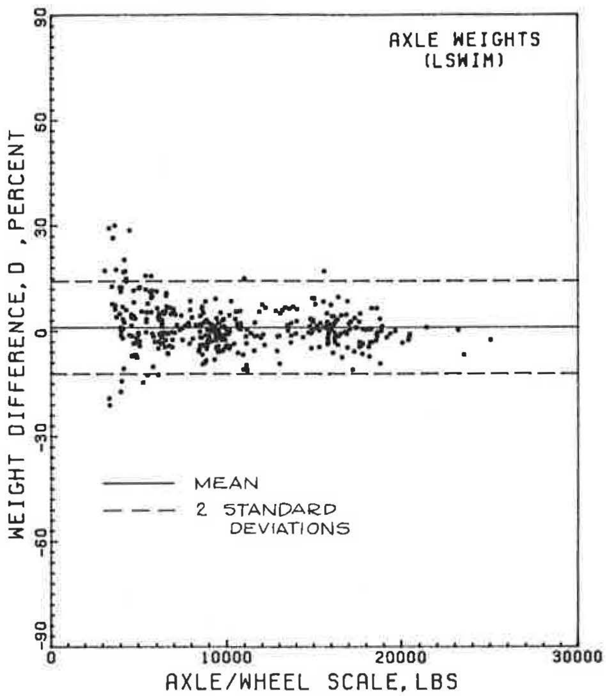

FIGURE 14 Percentage difference in 367 individual axle weights from measurements on axle/wheel scale and on weigh-in-motion scale.

Wheel Weights

The 734 wheel weights that were summed to give the respective axle weights shown in Figure 13 are plotted individually for the AX/WHL and the LSWIM scales in Figure 15. A few observed wheel weights lie well outside the 10 percent difference lines, particularly the lighter wheel weights. Statistically, differences in wheel weights lying between -16.4 and +18.3 percent can occur when a truck is weighed on both these scales and 95 out of 100 weighings are considered. Figure 16 shows the scatter pattern of these percentage differences.

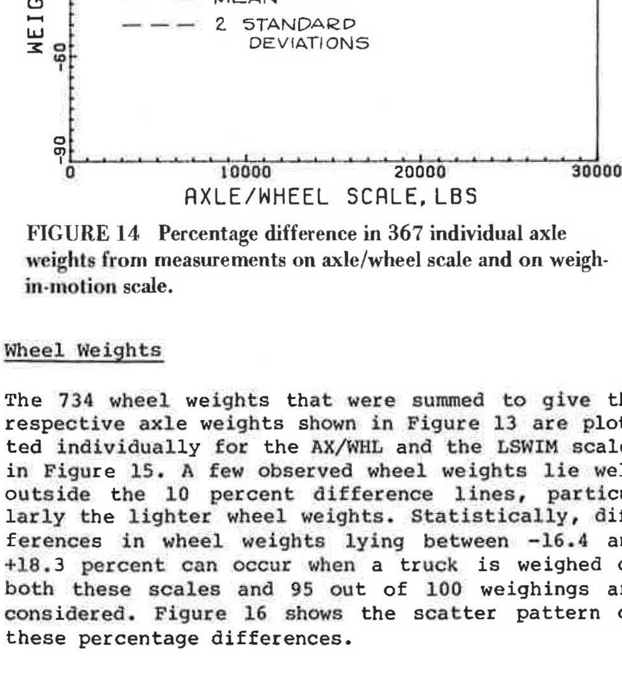

FIGURE 15 Weights of 734 wheels from weigh-in-motion scale versus static axle/wheel scale.

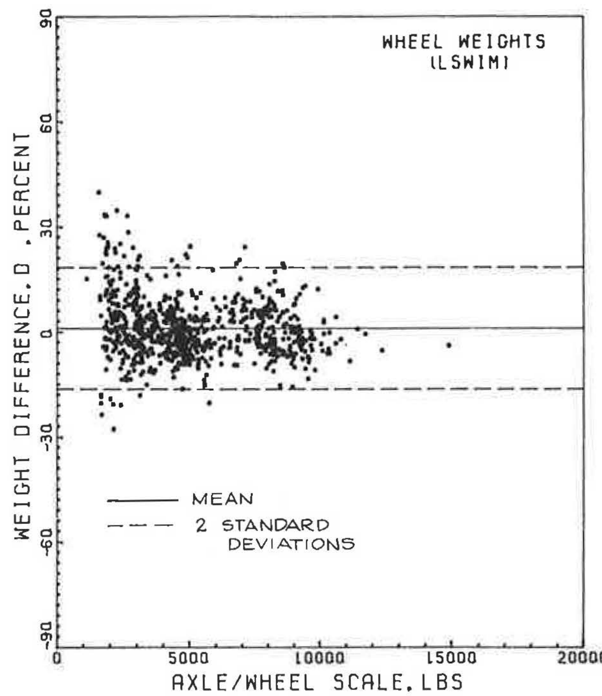

FIGURE 16 Percentage difference in 734 wheel weights measured on weigh-in-motion scale and on axle/wheel scale.

Distribution of Weight Among Wheels of an Axle Group

The weight on an axle group is implicitly assumed to be equally distributed among all wheels in the group. It is possible to evaluate the validity of such an assumption by examining the wheel-weight data from the AX/WHL scale. The drive and trailer tandem-axle groups on 3-S2 trucks are of particular interest because this truck type is predominant on many highways.

Drive and trailer tandem-axle groups on 54 trucks of the 3-S2 type were analyzed for weight distribution among the wheels. Measures of the distribution were computed by finding the deviation of each measured wheel weight from the mean weight of the four wheels in the tandem-axle group. Root mean square (RMS) deviations were then calculated for each wheel position as given in Table 1 for drive and trailer tandems, respectively. If all wheels in the tandem-axle had carried the same share of the tandem-axle group weight, the RMS deviations would all be zero. The values in Table 1 show that none of the RMS deviations approaches zero and that differences in wheel weights from the mean wheel weight of all wheels in the trailer tandem-axle sets are larger than for wheels in the drive tandem-axle groups. When RMS deviations of wheel weights are expressed as a percentage of the grand mean of all wheel weights on tandem-axle sets, the RMS values range from 7.4 percent for the left rear wheel in the drive-tandem group to 21.4 percent for the right rear wheel in the trailer-tandem set. The analysis indicates that the weight carried on the tandem-axle group is not equally distributed among all four wheels in the group.

A similar type of analysis was used to evaluate the distribution of weight between the front and rear axles of the drive and trailer tandem-axle groups on 3-S2 trucks. The results of this analysis are summarized in Table 2. The tabulated values indicate that the weight is not equally shared by the two axles in the tandem group and that the vari-

TABLE 1 Deviation of Individual Wheel Weights from the Mean Weight of All Wheels in a Tandem-Axle Group on 3-S2 Trucks

Tandem-Axle Position on Truck	RMS Deviation* From Mean Wheel Weight for Tandem-Axle Group (lbs)			
	Left Front Wheel	Left Rear Wheel	Right Front Wheel	Right Rear Wheel
Drive	445	398	428	439
Trailer	595	532	829	998

Tandem-Axle Position on Truck	RMS Deviation* From Mean Wheel Weight for Tandem-Axle Group (Percent of Grand Mean of AH Wheel Weights in Tandem-Axle Groups)			
Drive Axles	8.2	7.4	7.9	8.1
Trailer Axles	12.7	11.4	17.8	21.4

$$\text{* RMS Deviation}_j = \sqrt{\frac{\sum_{i=1}^{n} (X_{ij} - \bar{X}_i)^2}{n-1}}$$

where $\bar{X}_i$ = mean of four wheel weights in drive or trailer tandem-axle group on truck i

X_{ij} = measured weight of wheel in position j in drive or trailer tandem-axle group on truck i

n = number of trucks included in sample

j = index of wheel position: left front, left rear, right front, or right rear

i = index of truck on which wheel was weighed

TABLE 2 Deviation of Individual Axle Weights from Mean of the Two Axles in the Tandem-Axle Group on 3-S2 Trucks

Tandem-Axle Position on Truck	RMS Deviation From Mean Weight of the Two Axles in Tandem-Axle Group (lbs)	
	Front Axle	Rear Axle
Drive	623	611
Trailer	1288	1328

Tandem-Axle Position on Truck	RMS Deviation From Mean Weight of Axles in Tandem Group (Percent of Grand Mean of All Axle Weights in Tandem-Axle Groups)		Grand Mean
	Front Axle	Rear Axle	
Drive	5.8	5.7	10,807
Trailer	13.8	14.2	9,342

ability in the weight on each axle in a tandem-axle set is approximately twice as great for the trailer tandems as for the drive tandems.

The RMS deviation values given in Tables 1 and 2 may be interpreted statistically in roughly the same manner as standard deviations. Thus deviations from the mean wheel or axle weight in a tandem-axle group larger than those tabulated for the various conditions shown might be expected to occur approximately 30 times in 100 weighings of wheels or axles in tandem-axle groups on 3-S2 trucks.

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