

Use of Weigh-in-Motion Scale Data for Safety-Related Traffic Analysis

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So far, more than 2000 traffic lanes on North American highways have been equipped with weigh-in-motion (WIM) scales. These WIM scales provide and will continue to provide a large amount of data for individual highway vehicles, such as axle spacing and weights, vehicle length, speed, and headway. Because of their unobtrusiveness and continuous operation, WIM scales provide unbiased, statistically reliable data. The use of WIM data for investigating safety-related highway traffic flow characteristics is examined. WIM technology and its capabilities to generate traffic-monitoring data useful for transportation planning and decision making are described. Examples of data analysis that demonstrate the usefulness of WIM data for investigating safety-related traffic characteristics are provided. They include determination of truck exposure rates and evaluation of vehicle speed and headway distributions as a function of highway facility, vehicle type, daytime and nighttime conditions, and truck load. WIM data are useful in many areas of transportation planning, including safety-related traffic analysis, and should be considered corporate data and managed accordingly.

With the advent of the Strategic Highway Research Program (SHRP) and its national satellite programs, such as Canadian-SHRP, weigh-in-motion (WIM) scales have become commonplace. It is estimated that there are now more than 2000 traffic lanes equipped with WIM scales in North America, with installations in virtually all states and provinces. The Ontario Ministry of Transportation is operating nine in-highway WIM scales.

The WIM scales provide and will continue to provide a large amount of detailed data for individual highway vehicles, such as axle spacing and weights, speed, and headway. This is in addition to the traditional aggregated traffic characteristics such as daily and annual vehicle volumes and equivalent single-axle loads. Considering the effort associated with the installation and operation of WIM scales and with subsequent data retrieval and processing, the wealth of traffic-monitoring data generated by WIM scales should be properly used for as many purposes as possible.

Because of the original association with the SHRP-related pavement research effort, it is often assumed that WIM data are only applicable to pavement performance research. Many potential users of WIM-type data do not know the following:

- Traffic-monitoring capabilities of WIM technology,
- Type of data available, and
- How the data can be used within their area of interest.

Hajek et al. (1) demonstrated that WIM data are useful for a wide range of transportation planning and decision-making purposes, including

- Planning of transportation facilities,
- Pavement design and rehabilitation,
- Apportionment of pavement damage,
- Compliance with vehicle weight regulations,
- Development of geometric design standards,
- Compliance and regulatory policy development of truck dimensions,
- Traffic safety analysis,
- Traffic operation and control, and
- Analysis related to highway bridges.

The objective of this work is to make traffic safety researchers and administrators aware of the potential of WIM data in the traffic safety analysis area. Specifically, the objective is to show, by practical examples, that WIM data are also useful and indeed indispensable for fundamental safety-related traffic analysis.

The data used in this study were obtained by three Ontario WIM scales: two scales were located on a freeway (Hwy 402) and one scale on a two-lane highway (Hwy 31). All scales use piezoelectric cable technology (2). Compared with static conditions, the scales provide dimensions accurate within 2 to 3 percent, gross vehicle weights within about 5 percent, and axle loads within about 5 to 12 percent. Accuracy depends on vehicle dynamics (e.g., vehicle configuration and speed) and on pavement roughness in the vicinity of the scale.

Highway 402 is a four-lane rural freeway with a speed limit of 100 km/hr. One WIM scale is located in an eastbound right (truck) lane near Sarnia and is referred to as Location 1; the second scale spans both westbound lanes near London and is referred to as Location 2. Low traffic volumes at the two locations on Hwy 402 (about 400 vehicles during a peak daytime hour and about 75 vehicles/hr at night in the right lane) enable a large degree of traffic operational freedom. However, Location 2 is about 2 km downstream from a freeway entrance ramp. Because of highway alignment constraints, traffic may not have always reached its free-flow equilibrium at this location.

Highway 31 is a two-lane rural highway with a speed limit of 80 km/hr. The WIM scale is in both lanes; the WIM in the northbound lane is referred to as Location 3. High traffic volumes on Hwy 31 (about 3500 vehicles per day in each direction) greatly restrict traffic operational freedom, particularly passing opportunities. The highway grade is at a level for 2 or more km before all WIM scale locations.

DESCRIPTION OF TRAFFIC-MONITORING DATA PROVIDED BY WIM SCALES

A typical WIM scale consists of magnetic loops and axle sensors embedded in the pavement and a microcomputer housed in a road-

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side cabinet. Magnetic loops and axle sensors respond to axles passing over the pavement by generating electric signals. The signals are processed by the computer and transformed into engineering parameters for each vehicle. These parameters include a time stamp, instantaneous vehicle speed, vehicle length, distances between consecutive axles, and axle weights.

The knowledge of engineering parameters for individual vehicles, and a knowledge of the impact of vehicle weight and dimension regulations on truck design, can be used to determine vehicle types for classification purposes. A judicious classification scheme using expert system techniques can pinpoint and select specific vehicle types of interest. For example, Figure 1 shows one such scheme designed for identification of fully loaded six-axle tractor-semitrailers with a liftable ("belly") axle, the most common heavy-haul truck configuration in Ontario.

Figure 1 illustrates the following criteria for truck definition:

1. Six-axle trucks;
2. Single (steering), dual (tractor), single (liftable), dual (trailer) axle arrangement;
3. Axles 2 and 3 spacing from 1.07 to 1.83 m;
4. Axles 3 and 4 spacing greater than 4.00 m;
5. Axles 4 and 5 spacing greater than 2.40 m;
6. Axles 4 and 5 spacing greater than Axle 5 and 6 spacing;
7. Axles 5 and 6 spacing from 1.07 to 3.05 m; and
8. Gross weight within 1000 kg of allowable load.

The first item simply ensures the proper number of axles. The second is descriptive and may be redundant. Item 3 covers the known range of drive axle spreads. Item 4 ensures that the filter captures semitrailers at least 10 m (32 ft) long, so it will exclude tractors pulling 7 m (23 ft) tridem container chassis. Items 5 and 6 ensure that the liftable axle is properly separated from the trailer tandem axle, according to Quebec, Ontario, or Michigan regulations. Item 7 covers the known range of trailer axle spreads. The final item ensures that the gross weight is close to the allowable limit.

Considering the variety of vehicles on Ontario's highways and the large samples of vehicles analyzed, there must be a certain level of speculation associated with any vehicle classification scheme based on WIM data. There is no reason to believe that these uncertainties have a significant effect on the observations presented.

It should be stressed that, although WIM-type data can be used to enumerate the population of trucks of any particular basic type (e.g., fully loaded six-axle trucks with one liftable axle, as outlined previously), WIM scales cannot at this time discern certain types of multi-unit trucks, the body style, commodity/load, owner, or other

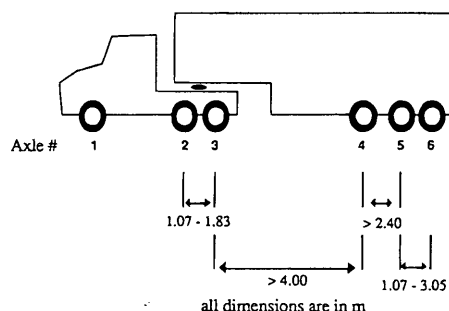


FIGURE 1 Criteria identifying six-axle tractor semitrailers with liftable axles.

information that might identify the specific nature of the truck and its owner. However, the identification of numbers of specific truck configurations is still very important because it allows infrequent or low-probability events to be examined, which is not practical with the small samples that can be garnered by manual survey methods (3).

For a more comprehensive assessment of traffic flows, WIM data should be supplemented by data from other sources. Some of these sources and sensor technologies are

- Video imaging for more specific visual vehicle classification (4),
- Radar and microwave image processing to identify vehicle shape or bulk,
- Automatic vehicle identification systems that can provide detailed vehicle descriptive data and ownership information (5),
- Vehicle height detectors (existing ones usually use a laser beam) to determine vehicle longitudinal profile (and to facilitate detailed vehicle classification),
- Automatic vehicle location systems that can provide information regarding distances traveled by individual vehicles (which can be related, for example, to travel speeds),
- Weather stations to assess weather conditions such as the rate and type of precipitation and visibility, and
- Pavement condition sensors to determine presence of snow or ice.

The use of many of these supplemental sensor technologies require appropriate communication and data integration systems. Spurred by Intelligent Highway Vehicle System needs, work is under way in many of the technology areas to obtain a more comprehensive knowledge of traffic flows.

Finally, data obtained from the individual WIM scales represent only the traffic mix at a specific highway site during a particular monitoring period and not a global picture of traffic flow.

SAFETY-RELATED TRAFFIC ANALYSIS

Safety is a major issue in all debates about changes in highway traffic regulations and in vehicle weights and dimensions. Invariably, it is concluded that adequate information about safety implications of the proposed changes is lacking (6). WIM data can contribute to analysis of these issues by providing unique and detailed information on the following:

- Frequency of different vehicle types using highway facilities,
- Driver and vehicle behavior on highway facilities, and
- Truck payload and its distribution.

Frequency of Vehicle Types Using Highway Facilities

The knowledge of accident rates for different truck types is instrumental in identifying the influence of vehicle design parameters on highway safety. The accident rate is defined as the number of accidents divided by the number of kilometers traveled (exposure rate to risk of accident). Because trucks are registered once but may travel in several jurisdictions, vehicle registration systems usually do not provide adequate information for estimating vehicle kilometers traveled by different truck classes, which would help to obtain accident rates for different truck types. Moreover, such estimates

are only general and not for specific highway types or locations. WIM data can help establish truck exposure measures, particularly for facilities where WIM scales have been installed. For example, five-axle trucks, consisting of a three-axle tractor with one dual axle semitrailer or 3S2, made up about 60 percent of the total truck volume on Hwy 402 (Location 1) (Figure 2). It would be possible to relate the volume percentage of 3S2s to the percentage of accidents involving the 3S2s on this facility.

Driver and Vehicle Behavior on Highway Facilities

Although highways are designed to serve a mix of vehicle types, the effects of various types of vehicles on traffic operations and safety are not uniform. In this context, factors such as acceleration, speed, headway, passing, merging and other lane changing maneuvers, splash and spray, aerodynamic buffeting, blockage of view, and lateral placement are clearly different among vehicle classes and influence the interaction of the vehicles. Inherent vehicle performance factors related to highway safety are vehicle handling, stability and braking capabilities, and load and load distribution (7).

WIM data alone can be used to evaluate driver and vehicle behavior in terms of speed and headway distributions as a function of axle (vehicle) weight and time of day (daytime versus night time). For a more comprehensive assessment, WIM data should be supplemented by data from other sources described previously. In this paper data from a nearby weather station were used to select WIM data for periods when the pavement was likely to be dry.

Vehicle Speed Distribution

Excessive vehicle speed, and particularly speed differentials between different vehicles, is considered a main cause of accidents (8). When different vehicle types exhibit different speeds (loaded trucks may travel more slowly than the prevailing traffic, particularly on upgrades), the speed variance of the traffic flow increases. The difference in speed variance has been linked to the increase in overall accident rates (9). The primary vehicle characteristic affecting acceleration and speed performance of trucks is the weight/power ratio. Overloaded and speeding trucks may constitute an additional safety hazard.

Examples of vehicle speed distribution for cars and trucks, obtained by the WIM scales during daylight hours and at night, are shown in Figures 3 and 4. Figure 3 shows data for Location 1 (right

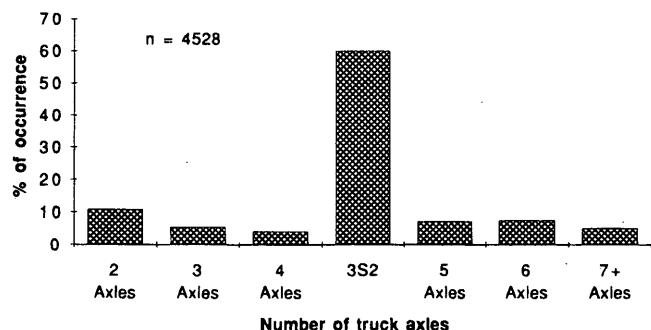


FIGURE 2 Occurrence of different truck types, Hwy. 402, March 19 to 22, 1991.

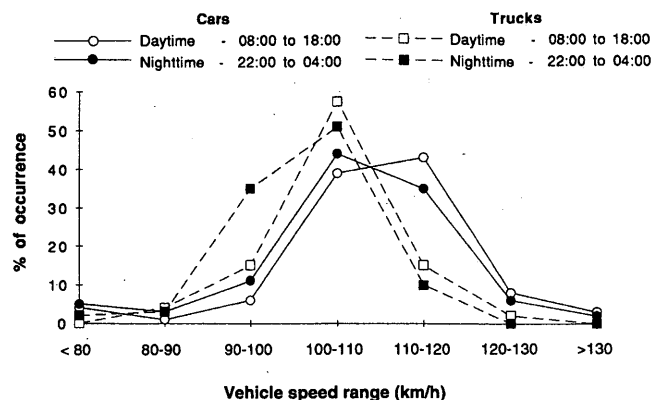


FIGURE 3 Vehicle speed distribution, Hwy. 402, truck lane, March 19 to 22, 1991.

lane on a four-lane freeway); Figure 4 shows data for Location 3 (northbound lane of a two-lane highway).

Data for Location 1 were obtained on four consecutive weekdays without any precipitation in March 1991. Overall, data in Figure 3 indicate that truck drivers are more disciplined than car drivers. Some specific observations are

- Highway speed limit is 100 km/hr, and most cars were speeding. During daytime, about 53 percent of all car drivers exceeded 110 km/hr; at night 42 percent of all car drivers exceeded this speed. The corresponding numbers for truck drivers were 16 and 10 percent, respectively.
- Compared with cars, the truck speed distribution is more uniform. Looking at the extremes, during daytime, 1.3 percent of cars had speeds lower than 80 km/hr compared with only 0.3 percent of trucks. At the high end, 1.3 percent of cars (in the right lane) exceeded 130 km/hr compared with 0.1 percent of trucks.
- The more uniform speed distribution observed for trucks is reflected in their lower speed variance. A reduction in speed variance has been linked empirically to a reduction in accident rates (7).

Data for Location 3 (Figure 4) were obtained on seven consecutive weekdays in October 1992. It should be noted that the data are only for the northbound lane. Any passing northbound vehicles use

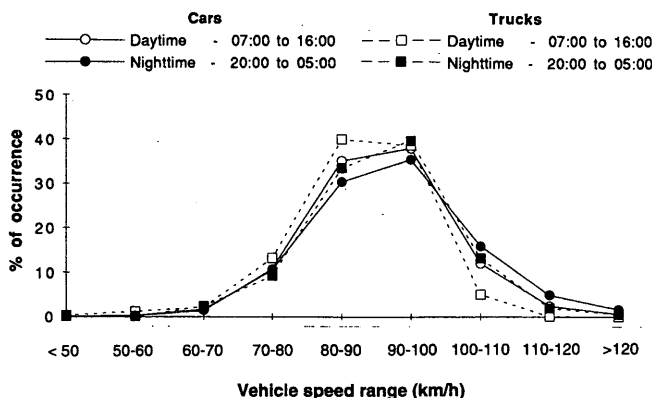


FIGURE 4 Vehicle speed distribution, Hwy 31, northbound lane, October 1 to 5, 1992.

the southbound lane, and their passage is treated as an error by the WIM scale in the southbound lane. There are some similarities between the data in Figures 3 and 4. Most cars are again speeding (about 87 percent of cars exceed the 80 km/hr speed limit during daytime), and truck drivers are again more disciplined than car drivers. However, the differences in the speed distribution attributable to the vehicle type and the time of day are considerably attenuated by the lack of operational freedom caused by the large traffic volumes. In fact, because of the large daytime traffic volumes and contrary to the results given in Figure 3 for Location 1, the daytime (7:00 to 16:00) car and truck speeds on Location 3 are smaller than the night-time (20:00 to 05:00) speeds. For example, the mean night-time truck speed was 91.0 km/hr, and the corresponding daytime speed was only 87.7 km/hr. The higher night-time speeds may be one of the contributing factors to the often-encountered higher night-time accident rates.

Headway Distribution

According to Ontario's Highway Traffic Act (10), maintaining "reasonable and prudent" headway (the time or distance between successive vehicles) is mandatory for all drivers. There is an extra stipulation for drivers of commercial vehicles (trucks) who, while driving at speeds exceeding 60 km/hr, "shall not follow within 60 m of another motor vehicle."

Vehicles traveling at 100 km/hr (27.8 m/sec) would have a front-bumper-to-front-bumper spacing of only 28 m with 1-sec headway. This results in the actual space between vehicles of about 24 m for an average car and, of course, considerably less space for even small trucks. Clearly, headways less than 2 sec do not meet the "reasonable and prudent" stipulation at highway speeds.

Figures 5, 6, and 7 compare the difference in headway distributions of cars and trucks. Figures 5 and 6 are for Location 1 and use the same data set as that used for Figure 3; Figure 7 is for Location 3 and uses the same data set as that used for Figure 4.

Examining first the results for the freeway location (Figures 5 and 6), the greater discipline of truck drivers, as shown by the speed distribution, is also indicated by the headway distribution. Some additional observations are

- During daytime, 7 percent of all cars followed other cars with a headway of 1 sec or less; only 2.5 percent of trucks did so. Nev-

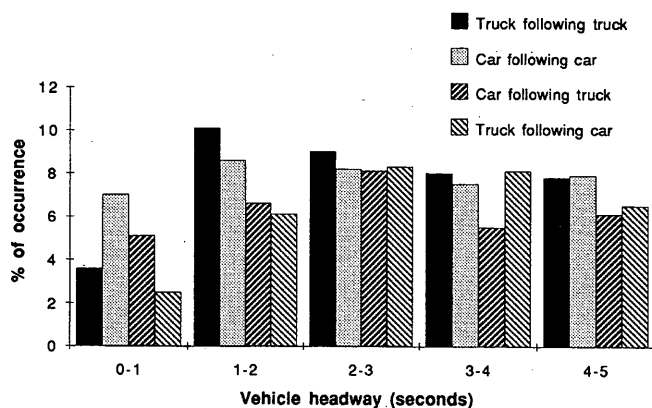


FIGURE 5 Daytime vehicle headway distribution, Hwy. 402, truck lane, March 19 to 22, 1991.

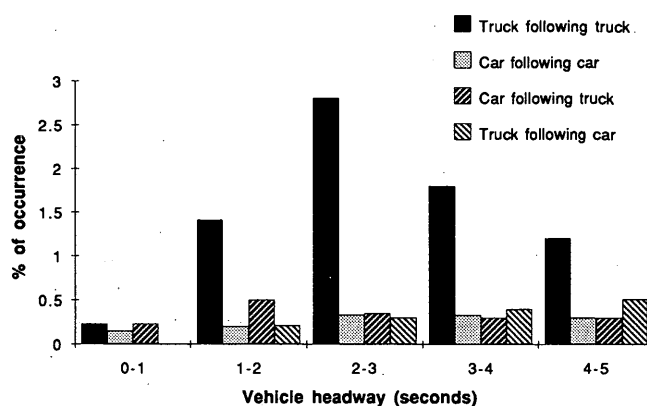


FIGURE 6 Nighttime headway distribution, Hwy. 402, truck lane, March 19 to 22, 1991.

ertheless, considering an average truck speed of 100 km/hr, more than 2.5 percent of all trucks appear to be in violation of the Ontario Highway Traffic Act headway requirement.

- Also during daytime, 3.5 percent of all trucks were following other trucks with a 1-sec headway or less and only 2.5 percent of trucks were following cars with this headway. The difference in the headway distribution for these two cases was found to be statistically significant.

- Trucks tend to travel in convoys. This is particularly evident at night when 7.5 percent of all trucks had headway of less than 6 sec compared to only 1.1 percent for cars.

The headway distribution on the two-lane highway during daytime (Figure 7) shows even more pronounced tendency of cars to follow other vehicles with short, unsafe headways.

- About 36 percent of cars followed other vehicles with the headway of 1.5 sec or less; only 8 percent of trucks did so.
- Compared with the headway distribution obtained for the freeway location, there is a pronounced tendency of trucks to follow other trucks with headway in the range of 1.5 to 5 sec. This can be attributed to the inability of trucks to pass other trucks, thus form-

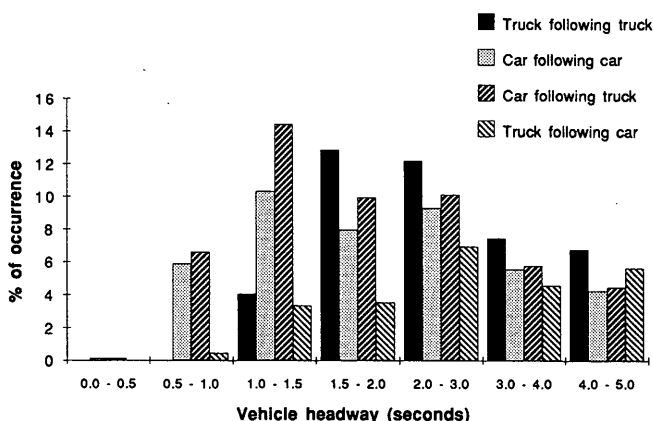


FIGURE 7 Daytime vehicle headway distribution, Hwy. 31, northbound lane, October 1 to 15, 1992.

ing truck convoys. Passing opportunities for cars that follow such convoys may be limited.

Truck Payload and Distribution

Another descriptive parameter useful in accident studies (and provided by WIM data) is the gross vehicle weight and its distribution among axles and, in the case of multiple truck units, between truck units. Braking performance of trucks is not as good as that for cars—braking distances of trucks are significantly longer. A recent investigation (11) analyzed braking capabilities of different truck types for unloaded, partially loaded, and fully loaded vehicles. It appears that braking distances can increase substantially when trucks are partially loaded or unloaded and that the magnitude of this degradation in braking capabilities depends on the truck type. A comprehensive analysis of truck accidents in Ontario (12) indicated that, except for twin trailers, the highest accident rates were for unloaded straight trucks, semi-trailers, and bobtail tractors. This suggests a link between braking capabilities of unloaded, partially loaded, and fully loaded trucks and accident frequencies, which should be addressed in part by the introduction of antilock brake systems.

Payload distribution can also affect truck operating characteristics. Billing and Hajek (3) show how WIM data can be used to evaluate payload distribution on six-axle trucks with one liftable axle. Systematic evaluation of WIM data for loaded and unloaded trucks can provide valuable insights into their operating characteristics. In this work, the loaded trucks were defined as trucks with a payload estimated to be at least one-half of the total allowable load.

Figure 8 uses data obtained on a passing lane at Location 2 (freeway location) to compare the speed distributions for unloaded and loaded six-or-more-axle trucks during daytime. Although the difference in mean speed between unloaded and loaded trucks is only 1.5 km/hr, the corresponding speed variance, with its safety implications, differs by 10 (km/hr)².

The differences in speed distributions for unloaded and loaded three-or-more-axle trucks during daytime obtained for Location 3 are illustrated in Figure 9. The differences may be attenuated by the relatively high traffic volumes on this highway. Nevertheless, the difference in the mean speed of the unloaded and loaded trucks is

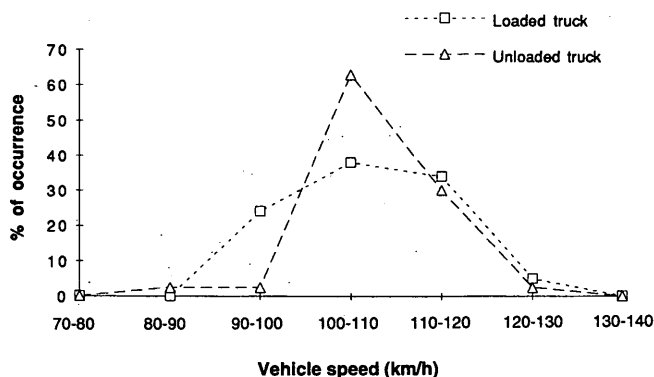


FIGURE 8 Daytime vehicle speed distribution for six-axle trucks, Hwy. 402, passing lane, March 1992.

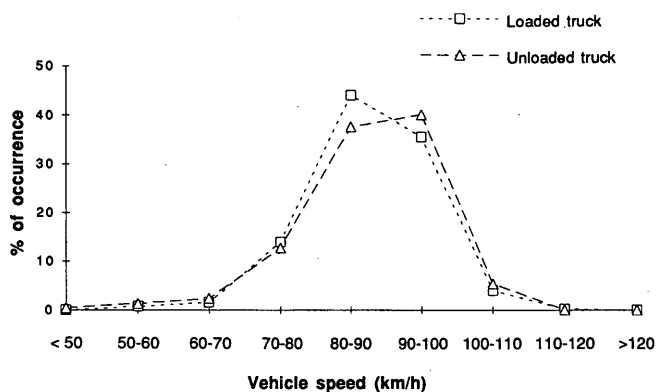


FIGURE 9 Daytime vehicle speed distribution for three-or-more-axle trucks, Hwy. 31, northbound lane, October 1 to 15, 1992.

1.4 km/hr, while both loading conditions have a similar speed variance.

Examples of headway distribution for loaded and unloaded trucks with six-or-more axles, obtained for the right lane at Location 2 and for the northbound lane at Location 3, are given in Figures 10 and 11, respectively. The headway distribution is different on the two facilities.

On the freeway, the loaded trucks are more likely to follow cars with short headways than are the unloaded trucks. The difference in the headway distribution was found to be statistically significant. The higher occurrence of shorter headways observed for the loaded trucks may be attributed to the lack of engine power available to pass slower moving cars. The unloaded trucks are able to pass these cars using the left (passing) lane.

In contrast, on the two-lane highway, the unloaded trucks are more likely to follow cars with short headways than the loaded trucks. For example, about 8 percent of unloaded six-or-more-axle trucks followed cars with the headway in the 1.5 to 2.0 sec range, and only about 1.5 percent of the loaded trucks did so. It appears that the drivers of the unloaded trucks, because of the availability of spare power, are positioning their trucks to pass slower moving cars. Alternatively, they may simply be better able to maintain the speed with the more nimble cars.

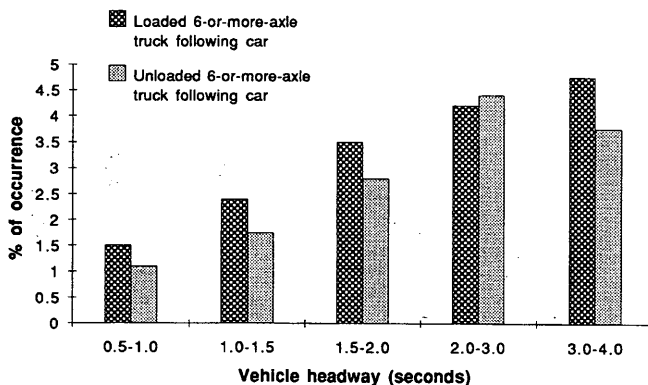


FIGURE 10 Daytime truck headway distribution for six-or-more-axle trucks, Hwy. 402, Lane 1.

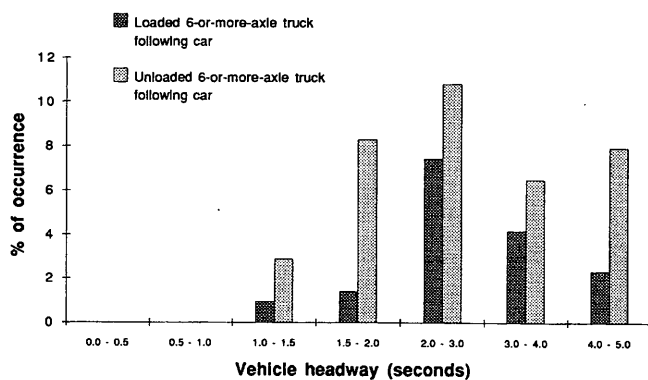


FIGURE 11 Daytime vehicle headway distribution for six-or-more-axle trucks, Hwy. 31, northbound lane, October 1 to 15, 1992.

DISCUSSION OF RESULTS

The discussion on extracting specific information from WIM data to provide insights into safety-related highway traffic characteristics is not exhaustive. It simply illustrates possible use of WIM data in traditional application areas. It is also possible, for example, to study more complex functions of traffic flow such as the relationship among vehicle speed, headway, payload, and weather conditions for different vehicle categories and to provide data to develop and manage police strategies for enforcing traffic regulations.

WIM scales have been also used as a main component of speed advisory systems for truck drivers approaching potentially hazardous conditions, such as

- Long steep downgrades, or steep downgrades with traffic signals or stop signs—The system advises truck drivers, particularly drivers of loaded trucks, of a recommended speed to negotiate the grade safely.
- Freeway ramps with small turning radii—The system advises truck drivers, such as drivers of loaded tanker trucks, of a recommended speed to prevent a rollover (13).

Although this work addresses application of WIM data and WIM scales in the traffic-safety area, their use for transportation planning and decision making is much larger and cuts across the organizational structure of any highway agency (1).

CONCLUSIONS

1. WIM data are useful for a wide range of transportation planning and decision-making purposes including traffic safety-related applications.

2. Using examples, WIM data have been demonstrated to provide previously unavailable insights about a range of safety-related highway traffic flow characteristics.

3. WIM scales, because of their unobtrusiveness and continuous operation, can provide truly unbiased statistically reliable data, yielding a realistic long-term picture of exposure rates for specific vehicle types and other safety-related traffic flow characteristics. Both concerns are important for identification of relative influence of vehicle design parameters and driver behavior on highway safety.

4. It is imperative that those working in the traffic safety area are made aware of the potential of WIM data for traffic-related safety analysis, and that this potential is further pursued.

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