evaluate the operational effects of a TWLTL on two-
way four-lane streets.

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Effects of Trucks on Freeway Vehicle Headways
Under Off-Peak Flow Conditions

WILEY D. CUNAGIN AND EDMUND CHIN-PING CHANG

The results of a study to determine the effects of the presence of heavy trucks
on traffic flow in sections of freeway as an operational measure of total through-
put capacity are presented. The variable used to evaluate truck impacts was
time headway. Data were collected at two sites on the Houston, Texas, free-
way system during off-peak flow conditions. After each observed headway had
been classified as to types of vehicles involved in the interaction, various sta-
tistical tests were performed to analyze variations in headway due to headway
type, lane width, and traffic volume. Headway type (i.e., the types of vehicles
involved in the headway interaction) was shown to be the major determinant in
length of the headway; those that involved trucks exhibited the greatest
magnitude.

In recent years the construction of new highway fa-
cilities has not kept pace with the expansion of vehi-
cular traffic. In urban areas in particular, con-
cern with measures to increase the efficiency of
traffic operations has aroused increasing interest
as the emphasis has shifted toward making the exist-
ing system work as well as it can. The diverse mix-
ture of vehicle sizes, weights, and operating char-
acteristics has become a potential limiting factor
in trying to attain maximum efficiency and minimum
accident experience from the highway system.

Of approximately 145 million motor vehicles in
operation in this country today, nearly 7 million
are trucks with empty gross vehicle weights of
10,000 lb or more. When these trucks are involved
in accidents with the passenger cars in the traffic
stream, the results can be startling. Although
heavy trucks comprise less than 2 percent of the ve-
hicle population, they were involved in accidents
that accounted for almost 9 percent of all traffic
fatalities in 1976. Of these, 91 percent were per-
sons in other vehicles that conflicted with the
trucks (1).

The problem is further complicated by an increas-
ing polarization of the vehicle mix into very small
cars and very large trucks. The trend toward
smaller, more efficient passenger cars is undeni-
able. In 1963, automobiles made up 84.3 percent
of the total vehicle fleet and included about 8 percent
automobiles with registered vehicle weights of
3000 lb or less (2). By 1978, automobiles were down to
79 percent of the vehicle total but the small-car
portion had risen to 22 percent. By 1990, the pro-
portion of automobiles is expected to be 75 percent
while more than 50 percent of those will have regis-
tered weights of less than 3000 lb (3). Unfortu-
nately, the quest for more economical personal
transportation vehicles has been pursued through
methods that reduce the survivability of the pas-
sengers in an accident, since the smaller passenger
cars generally are characterized by reduced track
width, higher center of gravity, reduced horsepower,
reduced weight, reduced structural integrity, and
lower driver eye height.

Spurred by both demand for more fuel-efficient
vehicles due to rapidly rising gasoline prices and
mandatory standards set in the Energy Policy and
Conservation Act of 1975, gains in mileage per
gallon have been attained primarily by lowering
horsepower and increasing ratios of weight to horse-
power. These changes have tended to reduce accelera-
tion rates and therefore the vehicle performance
capabilities (3). A study by Woods and others (4)
showed that although smaller vehicles accelerated
adequately at low speeds, their acceleration capa-
bility at highway speed was substantially lower than
that of full-size cars. Indeed, at 50 mph, more
than 200 additional ft were required for the 85th-
percentile small cars to pass another automobile.
A recent study by the Institute for Highway Safety (5)
showed relative injury rates on a normalized experi-
ence basis by make and model of automobile. The
best vehicles from the standpoint of protecting oc-
cupants were full-size cars, and the worst were sub-
compacts or smaller. For example, drivers of a
Honda Civic are three times as likely to be killed
or injured in an accident as drivers of an Oldsmobile Delta 88.

Concurrent with these developments, legal gross weights for permitted vehicles are expected to reach 120,000 lb in the near future (6). Many states have already increased the weight limits to 80,000 lb with allowable lengths of 65 ft and articulated configurations (7). Truck lengths are projected to reach 94 ft with three trailers pulled by a single tractor in 1990. The large trucks are operationally limited in their ability to stop, accelerate, corner, and maneuver relative to the performance of passenger cars and other smaller trucks. As more fuel-efficient trucks are introduced, the use of engines with low revolutions per minute and low friction, low-rolling-resistance tires, aerodynamic-drag-reduction devices, and low-parasitic-power-loss accessories and lubricant will further diminish their natural direct-braking capabilities (8).

In view of the projected increase of 30 percent more vehicles and increase in miles per vehicle as well as larger percentages of heavy trucks and small cars (2) and the demonstrated serious consequences of operational conflicts between heavy commercial vehicles and passenger cars, it is worthwhile to consider the operational impacts of heavy trucks on the traffic stream.

The effect of grade on heavy-truck performance has long been a subject of concern (9-17). On twolane roadways in particular (18), climbing lanes are often provided on steep and/or long grades. Current practice generally calls for climbing lanes (or vertical profile modification) when the truck speeds are expected to fall 15 mph below the average passenger-car speeds. A joint study by the Texas Transportation Institute and the Center for Highway Research (19) showed that the distance required for a full-size car to pass a 95-ft triple-bottom truck is about 330 ft more than that to pass a 65-ft double-bottom truck.

Lower-performance small cars will simply compound this problem. The operational effects of trucks on grades are addressed in the Highway Capacity Manual (20). In this guide, for a freeway on level terrain, one truck is the equivalent of two passenger cars. On rolling terrain, one truck is equivalent to four passenger cars generally, but more precise (and much higher) equivalents are given by percent and length of grade. Obviously, these guidelines must be reevaluated. Two recent research studies sponsored by the Federal Highway Administration are addressing the relative performance of different types of cars and trucks and three recreational vehicles.

The operational problems of trucks on downgrades have also been addressed (21). Consequently, many states have implemented emergency escape ramps for runaway vehicles; these include both gravity ramps and arretor beds.

The disparity in operational characteristics between heavy commercial vehicles and passenger cars is aggravated by geometric design practices, which often have not addressed the problem. Heavier, longer trucks on grades will introduce speed differentials that were not expected when the facilities were designed and may cause impatient motorists to attempt to pass in unsafe situations. Further, previously safe passing zones may no longer be adequate for heavier performance automobiles. Consequently, the design driver eye height of 3.75 ft is much higher than that which the majority of drivers enjoys (22,23).

OBJECTIVE

Although various aspects of freeway truck operations have been examined elsewhere (24), the impact of heavy trucks on the capacity of urban freeways has not been satisfactorily ascertained. This paper presents the results of a study of heavy trucks on the freeway in Houston, Texas. A significant program of increasing the capacities of freeway bottlenecks has been conducted in this urban area by the Texas State Department of Highways and Public Transportation (TSDHPT) with support from the Texas Transportation Institute. The variable chosen to indicate traffic flow performance was time headway, defined as the time in seconds for the front bumper of two successive vehicles in the same lane to pass a single datum point.

DATA COLLECTION

Data were collected by photographic means. A total of 2 h of data was collected at each of two urban freeway locations in Houston, Texas. One study site was the westbound lanes of the Southwest Freeway (US-59) east of the loop IH-610 West Interchange. The other location was the eastbound lanes of IH-610 South at the new IH-610 interchange which, at the time of construction, fifteen-minute traffic volumes were recorded by lane. Super-8 movie films were taken for one 5-min period in each of the quarter hours. The data were collected between the hours of 10:00 a.m. and noon at each site. The study was conducted at the Southwest Freeway sites on Tuesday, July 31, 1979, and at the IH-610 site on Monday, August 5, 1979. Physical measurements of roadway features such as lane widths and offsets from landmarks were obtained on site from each location. Although the film speed was set at 9 frames/s, a test car was driven through the study area during each study to confirm the camera speed.

MEASUREMENT Technique

At both locations, the procedure followed was to set up the data-collection station above and to the right of the traveled way. In the case of the site on the Southwest Freeway, permission was obtained from the operator of a parking garage to set up on the top floor. At the IH-610 site, the contractor constructing the interchange and TSDHPT authorized setting up the data-collection site on an overpass. A Kodak XL55 Super-8 movie camera with a telephoto lens was used to collect the photographic data. Two research assistants collected the 15-min lane-count data on each of the five lanes on the Southwest Freeway and three lanes on IH-610 South. Physical measurements at each site were made about 6:00 a.m. on Sunday mornings following the studies. This was necessary due to the almost constantly high volumes on the Houston Freeway system. The test car was driven through the study area at a constant speed of 50 mph to obtain calibration data for the film speed.

ANALYSIS

The vehicle headways were obtained from the Super-8 movie films by using a time-lapse projector. The raw headway data were recorded in terms of frames between successive passages of a datum point on the projection screen. Conversion from frame headway to time headway was achieved by considering the test-vehicle data. From physical measurements of the lane stripes, it was known that there was a distance of 260 ft between the ends of lane stripes at either end of the study area visible on the film. The test vehicle traversed this distance in 15.5 frames at 50 mph to yield the following frame rate:

Frame rate = 260 ft/(15.5 frames)(50 mph)(1.467(ft· h)/(s·mile)) = 0.229 s/frame.
The headways were classified into one of the following types:

Type 1: car following car (automobile/automobile),
Type 2: car following single-unit truck (automobile/truck),
Type 3: single-unit truck following car (truck/automobile),
Type 4: car following tractor with trailer (automobile/truck),
Type 5: tractor with trailer following car (truck/automobile), and
Type 6: truck following truck (truck/truck).

Table 1. Sample sizes by headway type and lane for Southwest Freeway and IH-610 data.

<table>
<thead>
<tr>
<th>Lane No.</th>
<th>Headway Type</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Southwest Freeway Data</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>51</td>
</tr>
<tr>
<td>2</td>
<td>64</td>
</tr>
<tr>
<td>3</td>
<td>146</td>
</tr>
<tr>
<td>4</td>
<td>179</td>
</tr>
<tr>
<td>5</td>
<td>74</td>
</tr>
<tr>
<td>Totala</td>
<td>514</td>
</tr>
<tr>
<td>IH-610 Data</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>197</td>
</tr>
<tr>
<td>2</td>
<td>154</td>
</tr>
<tr>
<td>3</td>
<td>60</td>
</tr>
<tr>
<td>Totalb</td>
<td>411</td>
</tr>
</tbody>
</table>

Table 2. Lane volumes.

<table>
<thead>
<tr>
<th>Quarter Hour</th>
<th>Southwest Freeway Lane</th>
<th>IH-610 Lane</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>1</td>
<td>258</td>
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<tr>
<td>2</td>
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<td>3</td>
<td>230</td>
<td>300</td>
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<tr>
<td>4</td>
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<td>299</td>
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<tr>
<td>5</td>
<td>274</td>
<td>344</td>
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<tr>
<td>6</td>
<td>302</td>
<td>330</td>
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<tr>
<td>7</td>
<td>317</td>
<td>274</td>
</tr>
<tr>
<td>8</td>
<td>321</td>
<td>189</td>
</tr>
<tr>
<td>Total</td>
<td>2200</td>
<td>2313</td>
</tr>
</tbody>
</table>

Note: Statistical analyses were performed after coding for each headway site number, quarter-hour period number, lane number, headway in seconds, lane width in feet, and quarter-hour total traffic volume.

RESULTS

Duncan's multiple-range test was applied to compare mean headways for different headway types. The test results are shown below (note that mean headways...
Figure 2. Frequency histogram for automobile/truck headways.

Figure 3. Frequency histogram for truck/automobile headways.
underlined as a group are not significantly different):

1. All freeway data \((a\text{-level} = 0.05,\) degrees of freedom = 1287, mean square = 1.46341):

<table>
<thead>
<tr>
<th>Headway Type</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2.297</td>
<td>2.297</td>
<td>3.005</td>
<td>3.288</td>
<td>3.834</td>
<td>4.041</td>
</tr>
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</table>

2. Southwest Freeway data \((a\text{-level} = 0.05,\) degrees of freedom = 592, mean square = 1.5421):

<table>
<thead>
<tr>
<th>Headway Type</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2.189</td>
<td>2.778</td>
<td>2.874</td>
<td>3.212</td>
<td>3.596</td>
<td>4.153</td>
</tr>
</tbody>
</table>

3. IH-610 data \((a\text{-level} = 0.05,\) degrees of freedom = 687, mean square = 1.3343):

<table>
<thead>
<tr>
<th>Headway Type</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2.383</td>
<td>2.971</td>
<td>3.147</td>
<td>3.416</td>
<td>3.864</td>
<td>4.237</td>
</tr>
</tbody>
</table>

Figure 4. Frequency histogram for truck/truck headways.

Figure 5. Headway means by headway type versus lane volume.
The results clearly show that the automobile/automobile headways are significantly less than all other headway types that involved trucks with automobiles or with each other. The type of truck also seemed to have an effect, since the mean headways of cars following trucks and of a single-unit truck following a car, taken as a group, are significantly less than those of tractors with semitrailers following either cars or other trucks. Examination of the histograms of the frequencies of headways by 1-s intervals for the automobile/automobile (Figure 1), automobile/truck (Figure 2), truck/automobile (Figure 3), and truck/truck (Figure 4) headway types reveals obvious differences in the shapes of the distributions. Indeed, the automobile/automobile headway type is skewed strongly to the right, whereas the automobile/truck and truck/automobile headway types are skewed only slightly to the right. The truck/truck headway type appears to be skewed slightly to the left.

Note that the headway data include only headways less than 9 s in length, whereas the traffic volume data include all vehicles passing during the study period. Figure 5 is a plot of headway means by headway type versus lane volume. Although all headway types indicate a reduction in headway with increasing volume, the truck/truck interaction again appears to be the most profound.

CONCLUSIONS

The presence of trucks in the traffic stream is accompanied by an increase in the mean headway. Although this phenomenon is not critical at the flow rates observed in this study, the reduction in capacity (predicted by the Highway Capacity Manual) might become significant during the peak hours. Data collected in this effort were not sufficient to quantify the expected reduction in capacity due to heavy truck interactions during the peak period.

Contrary to complaints often expressed by automobile drivers, truck drivers did not appear to operate their vehicles unnecessarily close behind other vehicles. Indeed, they seemed to allow more room to the front than did automobile drivers.

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The contents of this paper reflect our views and we are responsible for the facts and accuracy of the data presented herein.

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