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# Developing passenger car equivalents for freeways by microsimulation

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**Abstract**

In this paper a method of estimation of the passenger car equivalents for heavy vehicles on freeway is described. The variation in traffic quality was evaluated basing on a traffic demand characterized by different percentages of heavy vehicles. Aimsun micro-simulator was used to isolate traffic conditions difficult to capture on field, to replicate them to have a number of data as much as possible numerous, and to quantify the fundamental variables of traffic flow, namely the speed, flow, density, for a test freeway segment. Model calibration was accomplished by using traffic data collected at observation sections on the A22 Brenner Freeway, Italy. In order to check to what extent the model replicated reality, the validation of the calibrated model was also addressed. Simulation data were used to develop the relationships among the variables of traffic flow and to calculate the passenger car equivalents for heavy vehicles by comparing a fleet of passenger cars only with a mixed fleet characterized every time by different percentages of heavy vehicles. Despite the exploratory nature of this study, some implications can be drawn: PCE estimations are small at low flow rates and increase with increased flow rates due to at low volumes there are few passenger cars that can be influenced by heavy vehicles.



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*Keywords:* microsimulation; freeways; passenger car equivalents; heavy vehicles; calibration, Aimsun

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## 1. Introduction

Passenger car equivalents (PCEs) for heavy vehicles are used to convert a mixed vehicle flow into an equivalent flow composed exclusively of passenger cars. In transportation engineering their calculation is relevant to capacity and level of service determinations, since incorporating the impact of heavy vehicles on freeway operations make the performance analysis of a specific road infrastructure more accurate. Heavy vehicles, indeed, differ from passenger cars for size and acceleration/deceleration abilities; these different (physical and operational) characteristics can result in driving behaviour different by each vehicle class in a traffic stream where the distribution of vehicles among the classes is, in any case, influenced by location and time. Due to their larger size and manoeuvring difficulties, heavy vehicles also impose a psychological and practical impact on near drivers in adjacent lanes (Anwaar et al., 2011; Roess et al. 2014). The impact of heavy vehicles on freeway operations has been a topic of interest since the first edition of the Highway Capacity Manual (HCM). The recent versions of the HCM (2000, 2010) provide different values of passenger car equivalents for heavy vehicles depending on the percentage of heavy vehicles, different grades, and grade length for freeways and highways. Addressing heavy vehicles effect on different types of highway facilities, passenger car equivalents are intended for use in level-of-service (LOS) analyses. However, assuming the values of passenger car equivalents as the HCM (2010) suggests, underestimation or overestimation of the effect of heavy vehicles on the quality of the traffic flow may happen.

Various methodologies have been used to calculate the passenger car equivalents for heavy vehicles for different types of facilities. Definitions of equivalency based on the heavy vehicle effect on different parameters have been proposed. The determination of passenger car equivalents, indeed, include methods based on flow rates and density (John and Glauz, 1976; Huber, 1982; Krammes and Crowley, 1987; Sumner et al., 1984; De Marchi and Setti, 2003; Webster and Elefteriadous, 1999), headways (Werner and Morrall, 1976; Anwaar et al., 2011), queue discharge flow (Al-Kaisy et al., 2002), speed (Hu and Johnson, 1981), delay (Craus et al., 1980; Cunagin and Messer, 1983), volume/capacity ratio (Linzer et al., 1979), platoon formation (Elefteriadou et al. 1997; Van Aerde and Yagar, 1984; Al-Kaisy et al. 2002) and travel time (Keller and Saklas, 1984). However, significant differences can be found among the values of PCE factors from different methods especially in heterogeneous traffic environment; see e.g. Adnana (2014). Only a few studies have been based on field data; most current published studies and researches used traffic simulation to obtain equivalent flows for a wide combination of flows and geometric conditions.

According to Webster and Elefteriadou (1999), in operational analysis of freeways PCEs calculations should be based on density, since it is used to define LOS for freeways (HCM, 2010). On this regard, Huber (1982) proposed a framework for PCEs derivation based on finding a flow rate of a base stream of passenger cars only and a flow rate of a mixed stream $Q_M$ containing $Q_M \cdot p_T$ heavy vehicles and $Q_M \cdot (1 - p_T)$ cars, having the same level of a measure of impedance. Huber (1982), indeed, used some measure of impedence as a function of traffic flow to relate one traffic stream of heavy vehicles mixed with passenger cars and another traffic stream of passenger cars only. PCE values were related to the ratio between the volumes of the two streams at some common level of impedance (i.e. the density of both streams). Differently from Huber (1982), Sumner et al. (1984) measured the impedance by the number of vehicle-hours in the base and mixed streams, which is equivalent to density as measure of impedance; they used microscopic simulations to expand the Huber procedure to calculate the PCE of each type of subject vehicle in a mixed traffic stream taking into account the different types of heavy vehicles, in addition to passenger cars. Webster and Elefteriadou (1999), in their turn, expanded the work of Sumner et al. (1984) by including a wide range of freeway conditions and derived PCEs based on density. It is noteworthy that the HCM (2010) utilizes passenger car equivalents to estimate the effect of heavy vehicles on traffic stream behaviour under free-flow or undersaturated conditions. Moreover, these factors have been used to conduct analyses for all traffic conditions (from free-flow to congested-flow conditions). A growing body of recent empirical evidence suggests that the PCEs for undersaturated conditions can underestimate the effect of heavy vehicles after the onset of congestion (Al-Kaisy et al., 2005). One must say that the acceleration and deceleration cycles, as normally experienced during congestion or stop-and-go conditions, impose an extra limitation on the performance of heavy vehicles. On this regard, few studies have been conducted to explore the effect of heavy vehicles also for forced-flow conditions (Ahmed, 2010). Al-Kaisy et al. (2002) derived passenger car equivalents using queue discharge flow as the equivalency criterion; however, they are still far from a generalization in the results, albeit these findings were consistent with field observations as experienced by Yagar and Richard (1996).

This research proposes the methodological path to estimate the PCEs in terms of their effects on the operations of a basic freeway section. There are two objectives for this research: i) to investigate the influence of a variety of traffic, road design, and vehicle characteristics on PCEs; ii) to propose a set of PCE values to be used in analyzing the operation of basic freeway sections. Since the variation of the traffic quality had to be evaluated including different percentages of heavy vehicles in the traffic demand, a simulation model has been used to isolate traffic conditions difficult to observe on field, to replicate them to have a significant amount of data, and to quantify the fundamental variables of traffic flow, namely the speed, flow, density, for a test freeway segment. Using Aimsun software it was possible to account for the wide range of traffic conditions on the test freeway segment selected as case study. The process of finding the best model parameters was accomplished by a calibration procedure that used traffic data observed at A22 Brenner Freeway (Italy). In order to check to what extent the model replicated reality, the validation of the calibrated model was also addressed. Simulated data were then used to develop the relationships among the variables of traffic flow and to calculate the passenger car equivalents for heavy vehicles by comparing a fleet of passenger cars only with a mixed fleet, having different percentages of heavy vehicles. The paper is organized as follows: section 2 presents an overview of data collection on A22 Brenner Freeway and introduces to calibration and validation issues for the case study; section 3 describes the study methodology that uses as equivalency criteria the traffic density. Section 4 presents the modeling results; at last the conclusions are presented in section 5.

## 2. Data analysis and simulation issues for the A22 Brenner Freeway, Italy

Before explaining the study methodology here used, study efforts, made both to develop the fundamental diagram of traffic flow for the A22 Brenner Freeway, and to tackle the issues associated with calibration and validation of the simulation model parameters, will be introduced.

### *2.1. The fundamental diagram of traffic flow for the A22 Brenner Freeway, Italy*

The speed-flow-density relationships for a traffic flow of passenger cars only were developed following the field survey activities performed on the A22 Brenner Freeway, Italy (Mauro, 2007). These relationships were built after treating and processing of traffic data collected at specific observation sections. Focusing on the development of a criterion for predicting the reliability of traffic flow by observing speed stochastic processes on A22 Freeway, a study has already been done (Mauro et al., 2013). The specification of the speed-flow-density relationships is discussed by Mauro et al. (2014). Here it will be described briefly the May's model (1990), as expressed by the following equation 1:

$$S = S_{FF} \cdot \exp\left[-0.5 \cdot \left(\frac{D}{D_c}\right)^2\right] \tag{1}$$

where $S_{FF}$ is the free-flow speed and $D_c$ is the critical density (to which is associated the reaching of the capacity). Starting from equation 1, by means of the relationship between the fundamental parameters of traffic flow, flow values were obtained; the speed-flow and flow-density relationships were also derived. Traffic flow models were calibrated for the right lane, the passing lane and both lanes of the roadway; for each observation section, the $S_{FF}$ and $D_c$ values were calculated by using the logarithmic transformation of equation 1.

Table 1 shows $S_{FF}$ and $D_c$ values for the two lanes of the roadway only. Note that for S Michele sections a fleet of cars only was observed; for the other observation sections, traffic flows were homogenized before the calibration of the May's model to consider the effects of passing heavy vehicles; for this purpose the passenger car equivalents calculated by Mauro (2007) were used.

Table 1. The May model parameters for the observation sections on A22 Brenner Freeway

| roadway | free flow speed [km/h] | critical density [veh/km/2-lanes] |
|---|---|---|
| S. Michele section – Southbound | 118.20 | 48.35 |
| S. Michele section – Northbound | 121.00 | 45.36 |
| Rovereto – Southbound | 114.30 | 49.61 |
| Adige – Southbound | 116.30 | 50.92 |
| Adige – Northbound | 112.60 | 39.20 |

### *2.2. Calibration and validation in simulation modelling*

In the context of the activities developed in micro-simulation, calibration was searched by ensuring that Aimsun gave results close to empirical data. Thus the empirical measurements of speed, flow and density and simulated data as generated by Aimsun were compared. For the fundamental core models (i.e. car following and lane changing) as implemented in Aimsun for modelling microscopic vehicle movements, the reader is referred to the relevant literature (see e.g. Barcelo, 2011; Vasconcelos et al., 2009; 2014).

The first step for executing Aimsun was to create a model network for the A22 Freeway such as to enable the geometric and functional representation of the freeway facility (having basic freeway segments, on- and off- ramps, etc.) and the related objects as traffic detectors at specific locations in the road network. Focus was then put on a basic freeway segment just a little over 2 kilometers and centered on the S. Michele observation section (Southbound); this basic freeway segment is characterized by the same cross section of A22 Freeway (Italy), having two traffic lanes, each 3.75 m wide, in each direction, and a slope of 0.09 percent. The aforesaid freeway segment was chosen outside of the influence area of ramps so that so that uninterrupted flow conditions were guaranteed. In order to test the traffic microsimulation model validity, some model parameters were changed and adjusted until the model outputs were similar to empirical data. It is noteworthy that the calibration of a microsimulation model is an iterative process which can be stopped only when the model matches locally observed conditions (Barcelo, 2011). In a previous research a statistical approach including hypothesis testing using t-test and confidence intervals was used to measure the closeness between empirical data and simulation outputs for a test freeway segment under uncongested traffic conditions (Mauro et al., 2014). The $\ln V\text{-}D^2$ regressions for simulated and empirical data were compared. Thus the microsimulation model was able to reproduce the real phenomenon of traffic flow within a wide enough range of operations, from the free flow speed conditions until almost to the critical density. However, in this study further considerations have been developed.

In order to reproduce local traffic conditions on A22 Freeway, some trial simulation runs were performed by using the default values for the model parameters; however, outputs from simulation runs were not quite right to represent the existing traffic conditions. Thus, the iterative changing of some parameters was done, different combinations of values were explored and many simulation replications were needed until the difference between the empirical and the simulated values of the variables of interest was minimized. Table 2 shows the parameter values (default and adjusted) that were used to replicate the field conditions. For calibration purposes, a maximum allowed speed (in km/h) for the vehicles travelling through the freeway roadway was introduced on each lane; moreover, the reaction time, namely the time it takes a driver to react to speed changes in the preceding vehicle was defined as fixed, that is the same as the simulation step. Global parameters in the two-lane car-following model were also considered for calibration. This was done with the purpose to model the influence on the subject vehicle given by a certain number of vehicles driving slower in the adjacent right-side lane. These parameters included: the number vehicles, or the vehicles driving downstream of the vehicle in the adjacent slower lane; the maximum distance, representing the distance from the current vehicle within which the number vehicles are taken into account; the maximum speed difference, or the differences of speeds between two adjacent lanes. The calibration process also included the adjustments for the maximum and minimum values of the desired speed, namely the maximum speed that a certain type of vehicle can travel at any point in the network. For the freeway link, the traffic demand was defined by subsequent O/D matrices for a total time interval of 13 hours, from 7:00 am to 8:00 pm.

Table 2. The model calibration parameters

| model parameter | default value | calibrated value |
|---|---|---|
| maximum speed [km/h] - right lane | 120 | 95 |
| maximum speed [km/h] - passing lane | 120 | 125 |
| reaction time [s] | 0.75 | 0.8 |
| number vehicles | 4 | 4 |
| maximum distance [m] | 100 | 100 |
| maximum speed difference [km/h] | 50 | 50 |
| minimum desired speed [km/h] for cars | 80 | 85 |
| maximum desired speed [km/h] for cars | 150 | 125 |

An ADT of about 30,000 vehicles per day was considered and hourly modulated for representing traffic conditions on A22 Freeway. Passenger cars only were considered; their attributes were chosen within the range that Aimsun gives. Detectors were located so that they could replicate the location of field detectors. The simulated values of speed and density were verified against the corresponding empirical values as shown in Figure 1. Specifically, the graph shows the plots of empirical and simulated data for the considered link (S. Michele section - Southbound) and the corresponding speed-density relationships. The *S=S(D)* function for simulated data was obtained converting equation 1 into linear form by using the logarithmic transformation:

$$\ln(S) = \ln(S_{FF}) - \frac{1}{2 \cdot D_c^2} \cdot D^2 \qquad \text{or else} \qquad S_1 = a + b \cdot D_1 \tag{2}$$

where $S_1$ is $ln(S)$, $a$ is $ln(S_{FF})$, $b$ is $-1/(2D^2_c)$ and $D_1$ is $D^2$, with $S_{FF}$ and $D_c$ as previously defined. By using simulated data $S_{FF}$ and $D_c$ values were calculated and equation 1 was calibrated; thus, $S_{FF}$ resulted equal to 109.46 km/h and $D_c$ resulted equal to 58.77 veh/km/2-lanes, corresponding to a capacity value of 3900 veh/h/2-lanes ($R^2$= 0.88). In Fig. 1 the speed-density relationship for empirical data is also shown for both lanes of the roadway; it was built by using $S_{FF}$ and $D_c$ values reported in Table 1 for S. Michele Section – Southbound.

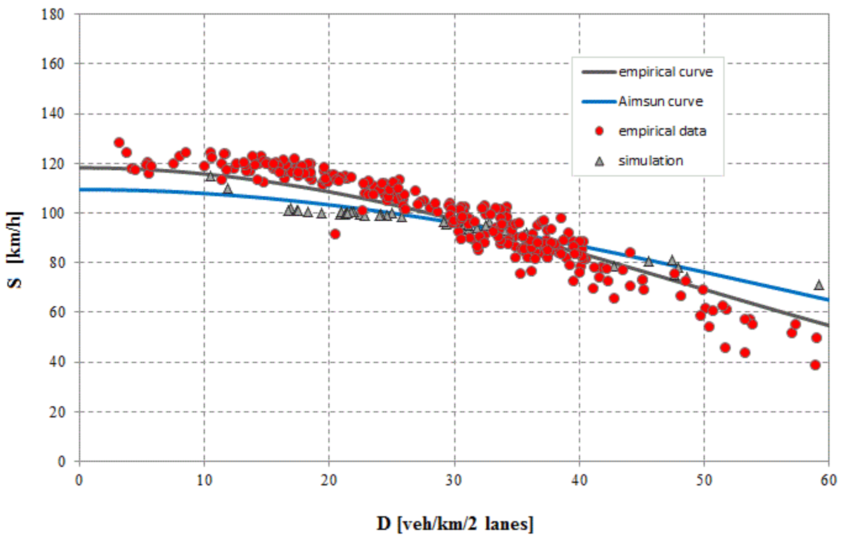


Fig. 1. Speed-density graphs with plots of field and simulated data.

For the examined case study, the GEH index was calculated as criterion for acceptance, or otherwise rejection, of the model (Barceló, 2011). The GEH statistic calculates the index for each counting station:

$$GEH_i = \sqrt{\frac{2(x_i - y_i)^2}{x_i + y_i}} \tag{3}$$

where $x_i$ is the $i^{th}$ simulated speed and $y_i$ is the $i^{th}$ observed speed. Since the deviation of the simulated values with respect to the measurement was smaller than 5 in 96% of the cases, the model was accepted as significantly able to reproduce local conditions and traffic behaviour.

Once the global parameters were adjusted to produce a good fit between observed and simulated data, i.e. they began to have little further influence on the model outputs, the validation of the calibrated model was also addressed. In this first step of analysis, simulation outputs were compared with two empirical data sets that were not used in the calibration process. Fig. 2 shows the comparison among the simulation data and the empirical equation *S=S(D)* for two observation sections on A22 Brenner Freeway in Table 1. For performing the comparison, each observed speed was calculated from the speed-density equations, as specified by the values in Table 1 for Rovereto (Southbound) and Adige (Southbound) sections, by using the simulated values of density. Since the deviation of the simulated values with respect to the measurement was smaller than 5 in 96% of the cases for Adige Section (Southbound) and smaller than 5 in 94% of the cases for Rovereto Section (Southbound), the model validation could be accepted. It is noteworthy that field data did not exceed (or just in few cases) the critical density and not cover sufficiently oversaturated conditions; by consequence, in this study we retained to be able to explore under capacity conditions only.

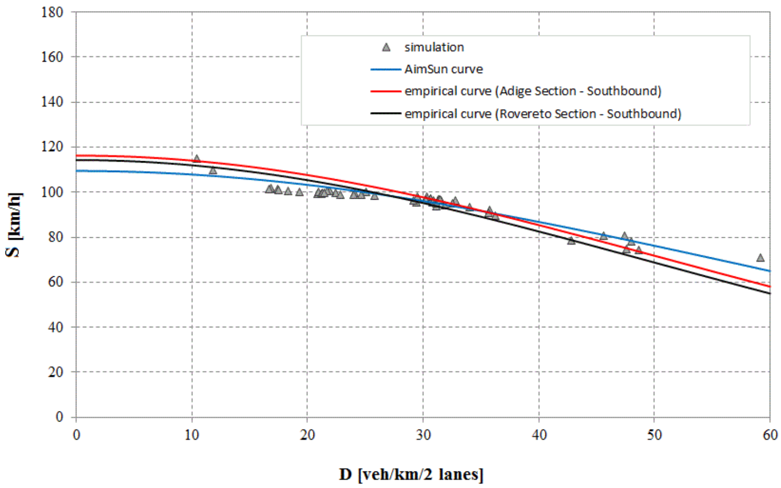


Fig. 2. Speed-density graphs with plots of simulated data.

## 3. Study methodology

PCEs will be estimated as a function of variables that are found to have a critical effect on PCE values. In this explorative study, the influence of the following traffic and road design characteristics on PCEs will be investigated: grade and length of grade, percentage of heavy vehicles in the traffic stream, and traffic flow rate. According to Elefteriadou et al. (1997), the effect of a heavy vehicle on the quality of traffic flow, and then its PCE, is also related to the performance characteristics of the heavy vehicles. In this paper, the heavy vehicles mix included single trucks and single trailer trucks having the following characteristics: the maximum length was assumed equal to 12 m; the maximum desired speed was equal to 80 km/h (with a minimum and a maximum value of 70 km/h and 90 km/h, respectively). For the heavy vehicles mix a maximum acceleration of 1 $m/s^2$ (with a range 0.6-1.8 $ms^2$) and a maximum deceleration of 5 $m/s^2$ (with a range 4-6 $m/s^2$) were assumed. For the other heavy vehicle attributes, default values as proposed by Aimsun (version 8.0.4) were assumed. The dynamics of interaction between passenger cars and heavy vehicles during overtaking and the driving behaviour in the neighborhood of heavy vehicles is handled internally by the Aimsun model (Barcelò, 2011). Simulation data were used to develop the relationships among the variables of traffic flow and to calculate the passenger car equivalents for heavy vehicles by comparing a fleet of cars only with a mixed fleet characterized every time by different percentages of heavy vehicles.

### *3.1. Method of PCE estimation*

In this study PCE values were estimated basing on the method developed by Huber (1982). The method consists of the steps as explained in the following:

- a Q = Q(D) curve has to be generated by simulating a passenger-car-only traffic stream from free flow up to critical density. Since the passenger car is the base vehicle, this curve is called the base curve (see Fig. 3);
- using a vehicle mix, which includes passenger cars and heavy vehicles, another flow-density curve (the mix curve) should be generated (see Fig. 3);
- Q = Q(D) functions in presence of different percentages of heavy vehicles can be developed; O/D matrices must be assigned to reproduce a wide range of operational conditions on the roadway, from free-flow to critical density;
- estimation of passenger car equivalents for a given percentage of heavy vehicles should be made comparing (being equal the density value) the flow rate obtained for entering traffic flows with passenger cars only ($Q_B$) with the flow value ($Q_M$) corresponding to a traffic demand characterized by a percentage $p_T$ of heavy vehicles; the estimation can be developed considering:

$$E_T = \frac{1}{p_T} \cdot \left( \frac{Q_B}{Q_M} - 1 \right) + 1 \tag{4}$$

  This equation starts from $Q_B=Q_M\cdot (1 - p_T)+Q_M \cdot p_T \cdot E_T$, where $Q_B$ is a heterogeneous flow including the share referable to passenger cars $Q_M \cdot (1 - p_T)$ and the share of heavy vehicles ($Q_M \cdot p_T$), multiplied by $E_T$ for obvious reasons of homogeneity.
- Q = Q(D) functions $Q_B$ and $Q_M$ for different flow percentages (that is 100% passenger cars, 10%, 20% , 30%, heavy vehicles) for the freeway roadway can be now developed. In order to apply this criterion for calculating $E_T$, lnV-$D^2$ regressions on simulated data are necessary.

Base and mix curves were developed for combinations of freeway grade and length of grade, and percentages of heavy vehicles; it is to be expected that each set of conditions results in potentially different flow-density values for the base and mix curve point.

## 4. Modeling Results

As an example of the above proposed method of PCE estimation, the investigation of the effect of traffic flow rate and road design variables on PCE is shown here. Table 3 shows the resulting PCE values for the subject types of heavy vehicles and for the explored combinations of traffic and road design variables considered in the base and mix curves. PCE values are limited to $Q_M$ < 3000 veh/h/2 lanes in order to avoid saturated conditions for which simulation model has not been calibrated. In this explorative study estimations in Table 3 show that PCEs are sensitive, to some degree, to all variables here examined:

- the effect of heavy vehicles tend to increase with traffic flow rate for upgrades as well as downgrades;
- increasing the flow rate, the effect of heavy vehicles increases even at level grades;
- having the same value of grade length, there is an increasing effect of heavy vehicles at an increasing flow rate;
- having the same value of freeway grade, there is a higher effect of heavy vehicles at high flow rate values;
- increasing the percentage of heavy vehicles, the effect of heavy vehicles on traffic operations slightly decreases, especially when traffic flow rates is higher than 2,000 veh/h/2 lanes.

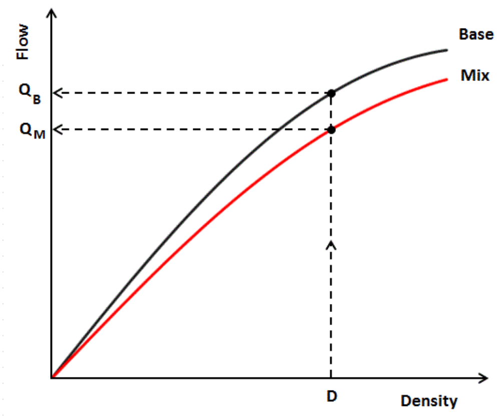

Fig. 3. Method of PCE calculation.

PCE values obtained in this research are similar than those shown in the HCM (2010) at level and slight upgrades (≤3%) especially at low values of flow rate (< 2000 veh/h/ lanes); increasing the flow rate, at high grade, HCM PCE values, in turn, are greater when the flow rates increase for steep and long upgrades as well as downgrades.

Table 3. PCE estimations for different grade level and flow rates

| Grade | length of grade [km] | Flow rate [veh/h/2 lanes] and percent heavy vehicles [%] | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | $Q_M$≤1000 | | | 1000<$Q_M$≤2000 | | | 2000<$Q_M$≤3000 | | |
| | | 10 | 20 | 30 | 10 | 20 | 30 | 10 | 20 | 30 |
| level | 1 | 1.1 | 1.4 | 1.4 | 1.2 | 1.5 | 1.5 | 1.8 | 1.7 | 1.6 |
| | 2 | 1.1 | 1.4 | 1.4 | 1.2 | 1.5 | 1.5 | 1.8 | 1.7 | 1.6 |
| up-grade 2% | 1 | 1.2 | 1.5 | 1.3 | 1.3 | 1.5 | 1.5 | 1.6 | 1.6 | 1.6 |
| | 3 | 1.2 | 1.5 | 1.5 | 1.4 | 1.6 | 1.6 | 1.8 | 1.7 | 1.7 |
| | 5 | 1.2 | 1.6 | 1.6 | 1.4 | 1.6 | 1.6 | 1.8 | 1.8 | 1.7 |
| up-grade 3% | 1 | 1.3 | 1.5 | 1.5 | 1.4 | 1.5 | 1.5 | 1.8 | 1.7 | 1.6 |
| | 3 | 1.3 | 1.5 | 1.5 | 1.4 | 1.6 | 1.6 | 1.9 | 1.7 | 1.6 |
| | 5 | 1.4 | 1.5 | 1.6 | 1.6 | 1.6 | 1.6 | 1.9 | 1.8 | 1.7 |
| up-grade 5% | 1 | 1.3 | 1.5 | 1.5 | 1.4 | 1.5 | 1.5 | 2.0 | 1.7 | 1.6 |
| | 3 | 1.4 | 1.5 | 1.7 | 1.5 | 1.6 | 1.6 | 2.0 | 1.8 | 1.8 |
| | 5 | 1.5 | 1.6 | 1.7 | 1.6 | 1.6 | 1.7 | 2.0 | 1.8 | 1.8 |
| downgrade 3% | 2 | 1.1 | 1.4 | 1.5 | 1.3 | 1.5 | 1.5 | 1.8 | 1.6 | 1.6 |
| | 3 | 1.0 | 1.3 | 1.4 | 1.2 | 1.5 | 1.6 | 1.8 | 1.8 | 1.7 |
| downgrade 5% | 2 | 1.1 | 1.4 | 1.5 | 1.3 | 1.5 | 1.6 | 1.9 | 1.8 | 1.7 |

These difference are due to the different definition of PCE applied in this research, compared to the definition applied in obtaining the HCM PCEs. According to Linzer et al. (1979) indeed, the PCEs in the HCM were based on equivalent effect on traffic speed, while the PCEs in this research were obtained using the definition of PCE as equivalent effect on traffic density. Moreover, heavy vehicles considered in this study (having a length less than 12 m) are only a part of those considered in the simulation model used to estimate the PCEs provided in the HCM (2010).

## 5. Conclusions

The effect of highway and traffic variables on the equivalency between heavy vehicles and passenger cars was investigated in this research. Technical literature still presents few studies related to the calculation of passenger car equivalents for heavy vehicles in Italian context. The reasons for this are due to time, resources and efforts to be faced for a PCE estimation study based on data collected on field. As a consequence, microsimulation can be a useful tool for the functional analysis of freeway and highways, and for the estimation of the impact of heavy vehicles on the quality of traffic flow. Starting from an overview of data collected on A22 Brenner Freeway, Italy, the issues associated with calibration and validation of the simulation model for the selected case study were described. The study methodology that used the traffic density as equivalency criteria for the estimation of passenger car equivalents for heavy vehicles was then presented. Starting from the Huber criterion, passenger car equivalents for heavy vehicles on basic freeway sections were estimated using the densities of the mix flow generated by Aimsun. Using Aimsun software it was possible to evaluate the variation in the traffic quality on freeway, varying the percentage of heavy vehicles in the traffic demand. Thus traffic conditions difficult to capture on field were isolated and replicated to have a huge amount of empirical data. Simulations have permitted to obtain values of the fundamental variables of traffic flow (namely speed, flow, density) for different percentages of heavy vehicles. Data simulated by Aimsun were used to develop the relationships among the variables of traffic flow and to calculate the passenger car equivalents for heavy vehicles by comparing a fleet of cars only with a mixed fleet, characterized every time by different percentages of heavy vehicles.

Despite the exploratory nature of this study, some implications can be drawn from the application of the proposed procedure. PCE values of a heavy vehicle changes with change in traffic volume and composition. The PCE values here estimated resulted sensitive, to some degree, to all variables examined: increasing the flow rate, the effect of heavy vehicles increased for upgrades and downgrades, as well as at level grades; moreover, increasing the flow rate, an increasing effect of heavy vehicles on segments having the same value of length occurred. Analogous considerations could be made for segments characterized by the same grade value, for which there was an increasing effect of heavy vehicles at an increasing flow rate. At last, decreasing the percentage of heavy vehicles, the effect of heavy vehicles on traffic operations slightly increased, especially for traffic flow rates higher than 2,000 veh/h/2 lanes. The differences between the values of PCEs estimated in this study and the HCM values for PCEs were briefly described; reasons for the difference between these two set of values were also discussed. However, at this stage of the research, the methodological path followed for estimating the PCEs of heavy vehicles in terms of their effects on the operations of a basic freeway section has been described. Two objectives were pursued: i) to investigate the influence of a variety of traffic, road design, and vehicle characteristics on PCEs; ii) to propose a set of PCE values to be used in analyzing the operation of basic freeway sections.

More research is still needed to better understand and confirm these findings. Results, indeed, could be improved by using an automated procedure in the calibration process in order to include the effect of further parameters on the model outputs. Moreover, PCEs should be calculated for other types of heavy vehicles such as multi-trailer trucks and buses, as well varying the traffic scenarios and/or considering other geometric variables (for example exploring situations in which a segment of freeway consists of composite grades). Collection of typical vehicle distribution in real field would be also needed. Only afterwards, a validation study of the PCE values estimated for A22 Brenner Freeway could be done using data collected on the field. It should be noted that such a field data collection effort was already conducted (Mauro, 2003, 2005, 2007); however data updating and integration could be hindered by difficulties both in the selection of vehicle types for the data collection, because it can be difficult to obtain typical vehicle performance characteristics, and in the selection of a time period for collecting typical traffic volumes on basic freeway sections.

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