



CALIBRATING THE PASSENGER CAR EQUIVALENT ON ITALIAN TWO LINE HIGHWAYS: A CASE STUDY

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Abstract. The Level Of Service (LOS) of a road infrastructure, a concept introduced for the first time in the Highway Capacity Manual (second edition), is defined as the 'qualitative measure of traffic conditions and their perception by users'. The Highway Capacity Manual, developed in the U.S., is still the most highly internationally credited reference text in the study of vehicular traffic. The method proposed by the Highway Capacity Manual is based mainly on studies and research compiled in the U.S., so in order to apply this method to other realities (e.g. Italy), research needs to be carried out at a local level. In this study, a series of studies were carried out to verify the transferability of these procedures to two roads classified as 'two-lane highways'. Two fixed RTMS (Remote Traffic Microwave Sensor) were used to record traffic data for two sections located at 3100 km on the SP30 and at 8900 km on the SP175 from 1 January to 31 December 2010. From the data, it was possible to determine not only the relationships between the basic parameters of the traffic flow, but also the (Passenger Car Equivalent) (PCE) values. The results showed that the PCEs analyzed vary significantly with vehicular flow, while they are scarcely affected by changes in speed. In particular, with respect to the vehicular flow, although they have the same range recorded in the Highway Capacity Manual (2010) (between 1 and 2), they tend to be higher than those given in the manual, and the difference tends to diminish beyond a flow rate of 400÷450 pcphpl; the PCE coefficients also tend towards 1 (i.e., the condition where a heavy vehicle is comparable to a car) with range values approaching 1000 pcphpl. In addition, for these values, the traffic-flow diagrams obtained, showed speeds (defined as the critical speed) close to 50÷55 km/h (with the exception of the study conducted on the SP175 in direction *d2*, which is considerably higher).

Keywords: traffic flow, passenger car equivalent (PCE), level of service (LOS), speed, density.

Introduction and Previous Research

The Level Of Service (LOS) of a road infrastructure, a concept introduced for the first time in the second edition of the Highway Capacity Manual (2010), is defined as a 'qualitative measure of traffic conditions and their perception by users'. The Highway Capacity Manual, developed in the U.S., is still the most highly internationally credited reference text in the study of vehicular traffic. The procedure for calculating the LOS, described in this manual, makes it possible to assign a rating for the quality of traffic flow through the application of specific procedures. In particular, it establishes the conditions and the criteria established to apply the proposed procedures. These conditions, referred to as 'base conditions' are the road's geometry, the traffic conditions on the road, and the environmental context through which the road passes.

The basic conditions include one relating to the composition of the traffic flow that considers only pas-

senger cars in the flow of traffic. Therefore, the concept of equivalence between heavy vehicles and passenger cars is introduced through the special coefficients indicated by the acronym PCE (Passenger Car Equivalent). These coefficients, however, if they are not too approximate, must be obtained experimentally, as specifically recommended by the Highway Capacity Manual, in the local area. The study recommends (declaring the approximate nature of the results) using values obtained in research carried out on the U.S. territory as equivalents (PCE coefficients) only in the absence of specific local indications. Since 1965, the estimated equivalent, and especially the definition of methods of calculation has been the subject of many international researches. The former is based on an assessment of the overtaking rate (number of overtakes per km) and the delays caused to cars by heavy goods vehicles before they could complete the overtaking maneuver.

The limits of applicability of these methods were overcome in the 80s. On this subject, the research of



Linzer *et al.* (1979) and Huber (1982) may be cited. These authors were among the first to introduce the calculation of the PCE on the basis of the comparison of a defined basis flow (consisting of only cars) and a mixed flow (consisting of both cars and heavy vehicles) which determined the level of impedance on the traffic flow. The authors defined this impedance as any measure capable of quantifying the restrictive effects on traffic flow compared with the flow in question.

Subsequently, many authors, such as Cunagin and Messer (1983), Van Aerde and Yagar (1984), and Eleftheriadou *et al.* (1997), while continuing to share the basic philosophy of the method, suggested other impedance measurements, such as density and/or the Volume/Capacity (V/C) ratio. Then, additional methods were introduced which, while based on the same impedance measurements, led to some important variations.

In this regard, Chandra *et al.* (1995) is worthy of mention. According to Chandra, calculation of the equivalent is based on the relationship between the speed ratio (measuring the impedance representative of the traffic conditions) and the space ratio (representative of the performance characteristics of vehicles). An important criticism regarding the use of PCE for conditions of forced flow (beyond capacity), and in particular in the dispersal of a queue has been raised by Al-Kaisy *et al.* (2002).

According to Al-Kaisy *et al.* (2002), the use of PCE in the above traffic conditions underestimates the effects of the presence of heavy vehicles in the flow, since no account is taken of the reduced performance in terms of acceleration and deceleration that heavy-duty vehicles produce under 'stop and go' conditions (typical traffic conditions beyond capacity). All calculation methods identify the PCE based on the range, length and grade of the vertical alignment and the type of heavy vehicles in circulation. These correspondences have been confirmed in numerous scientific papers related to applications to case studies conducted in contexts different from those studied as a basis for the calculation methods, aiming to test the transferability of the methods themselves.

Examples include applications in China (Fan 1990), Canada (Sun *et al.* 2008) and a more recent one developed and introduced in Brazil (Cunha, Setti 2011), etc.

Other important studies have been conducted by Werner and Morrall (1976), who have adopted the temporal spacing method for calculating the PCE of vehicles traveling at a low speed and the impedance method for heavy vehicles traveling at a high speed.

Similarly Krammes and Crowley (1986) conclude in one of their articles that the spatial distancing method not only takes into account the impact of heavy vehicles in terms of size and performance, but also the psychological impact on the drivers of other vehicles. This impact, for example, manifests itself in the form of aerodynamic disturbance, spray and splashing in rainy conditions, and the obstruction of the visibility of road signs. Lastly, in another important relationship (Webster, Eleftheriadou 1999) regarding highway traffic (where

simulation models were used to calculate the correlation between flow and density) the correspondence between PCE and the flow of traffic is calculated, taking into consideration the percentage of heavy vehicles in the flow, the type of heavy vehicle, the length and grade of the vertical alignment, and the number of lanes.

1. The Data Set and Data Processing

1.1. Survey of Data

The traffic data were collected on two different roads located in the south of Italy (Dell'Acqua *et al.* 2011): the Eboli–Mare SP30 and the Salerno–Paestum SP175 (Fig. 1).

Both roads are classified as 'two-lane highways', level terrain, without posted speed limit, Annual Average Daily Traffic (AADT) 13000 veh/day (SP30) and 15000 veh/day (SP175), 1 access per km, long distance (in terms of prevailing trips), dense asphalt carriageway characterized by lanes 3.50 m wide and a shoulder width of 1.5 m. The traffic data were obtained using two fixed Remote Traffic Microwave Sensor (RTMS) devices that collect the data continuously (Fig. 2). The two continuous traffic detection devices were placed (in a fixed location) in two sections, located at distance 3100 m on the SP30, and at the distance 8900 m on the SP175, from 1 January to 31 December 2010.

The Electronic Integrated Systems Inc. (EIS, Ontario, Canada) radar antenna is made up of the following main elements:

- RTMS traffic analyzer Model K3;
- RTC (Remote Traffic Counter) Data storage unit;
- GSM Terminal Module MC35T.

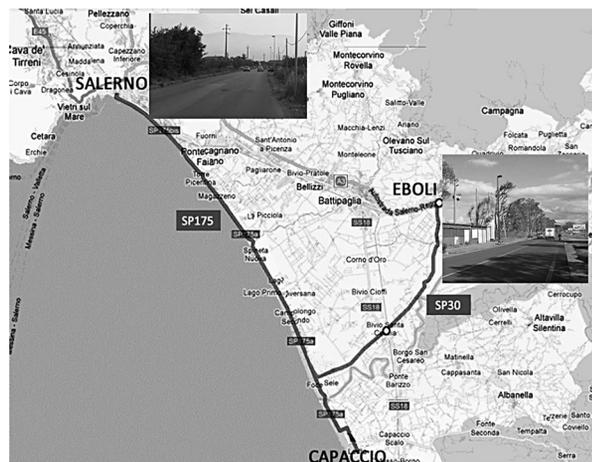


Fig. 1. Analyzed roads: SP175 and SP30

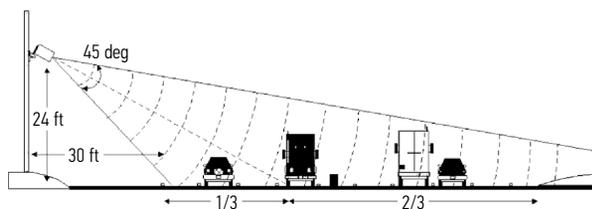


Fig. 2. RTMS aiming

Table 4. PCE for SP175 road, directions *d1* and *d2*

<i>q</i> [veh/h/ln]	Direction <i>d1</i>					Direction <i>d2</i>				
	PPCE _{MS1}	PPCE _{MS2}	PPCE _{LV1}	PPCE _{LV2}	PCE _{XLV}	PPCE _{MS1}	PCE _{MS2}	PPCE _{LV1}	PPCE _{LV2}	PCE _{XLV}
≤120	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
180	1.96	1.96	1.99	2.00	2.00	1.95	1.91	1.97	2.00	2.00
240	1.81	1.94	1.97	1.99	1.99	1.79	1.94	1.98	2.00	1.99
300	1.68	1.87	1.88	1.97	1.97	1.78	1.84	1.85	1.94	1.94
360	1.64	1.79	1.79	1.88	1.87	1.75	1.76	1.76	1.82	1.84
420	1.51	1.75	1.74	1.77	1.80	1.55	1.70	1.71	1.74	1.77
480	1.47	1.63	1.70	1.70	1.70	1.46	1.60	1.67	1.67	1.67
540	1.50	1.57	1.58	1.61	1.61	1.52	1.58	1.55	1.57	1.58
600	1.49	1.58	1.59	1.61	1.62	1.43	1.59	1.60	1.61	1.62
660	1.46	1.49	1.50	1.50	1.57	1.45	1.49	1.50	1.51	1.52
720	1.38	1.45	1.42	1.42	1.52	1.34	1.43	1.42	1.42	1.52
780	1.22	1.25	1.24	1.25	1.41	1.25	1.26	1.26	1.27	1.42
840	1.24	1.27	1.33	1.33	1.38	1.25	1.24	1.33	1.34	1.38
900	1.19	1.23	1.24	1.29	1.26	1.19	1.24	1.25	1.30	1.26
960	1.14	1.17	1.21	1.24	1.30	1.14	1.17	1.21	1.25	1.30
1020	1.14	1.24	1.24	1.25	1.30	1.14	1.24	1.25	1.24	1.24
≥1080	1.12	1.13	1.14	1.14	1.14	1.13	1.15	1.14	1.15	1.20

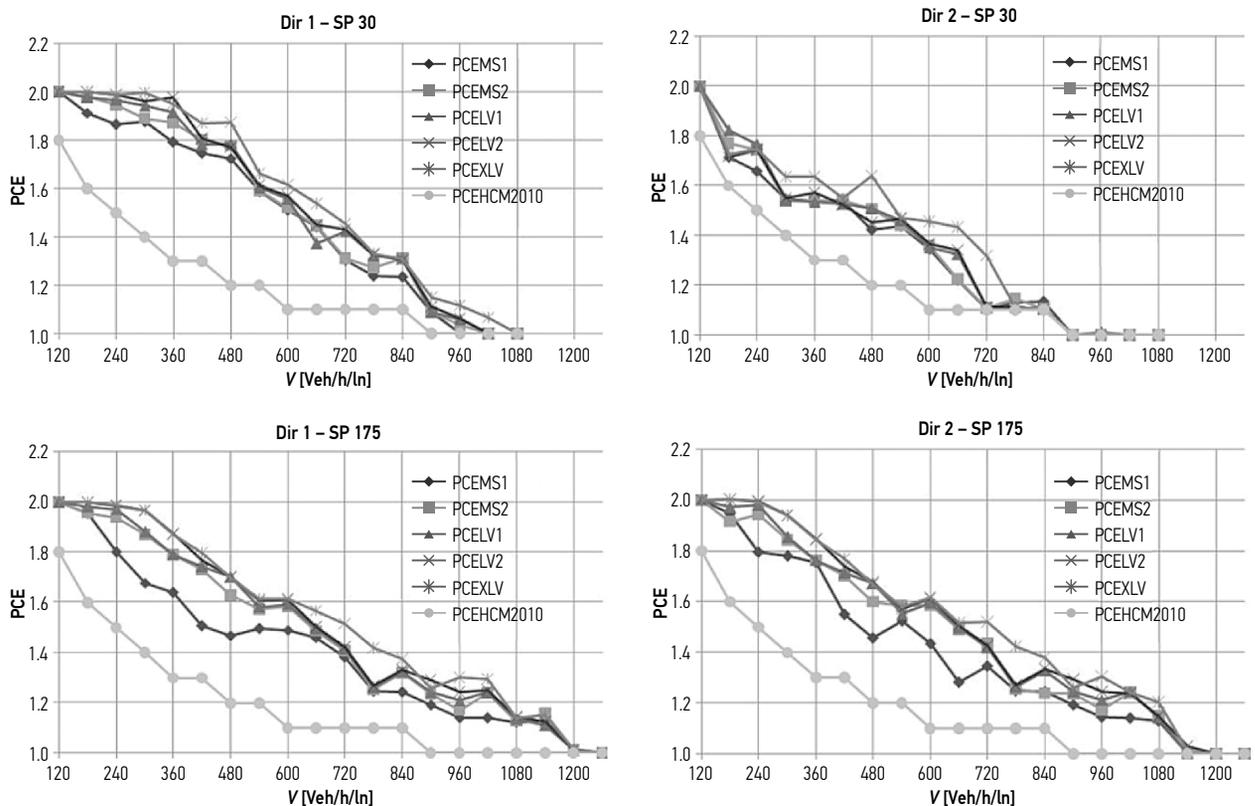


Fig. 4. PCE for different ‘traffic volume’ classes

‘flow rate’ through the PCE coefficients discussed in the previous chapter.

It has been observed that experimental data are well interpreted by the Greenshield model for roads with an uninterrupted flow. This model predicts, of course, a linear ‘*S-D*’ (De Luca, Dell’Acqua 2012) relation and a

parabolic ‘*V-D*’ and ‘*V-S*’ relation. In particular, to determine the relationship between the three ‘traffic flow’ parameters, the following procedures were used:

- to construct the diagram ‘*V-S*’, flow classes *V* were constructed with an range of 60 pcphpl and the average speed was determined for each class.

- to construct diagram 'V-D', classes of flow V were constructed, with a width of 60 pcphpl, and for each class the average vehicle density was determined.
- to construct diagram 'S-D', classes of density, D , with a width of 0.2 pc/km/ln (passenger car per kilometer per lane) were constructed, and for each class, the average speed was determined (Dell'Acqua *et al.* 2011).

Again, given the large number of records analyzed (about 500000), it was necessary to construct the appropriate support procedures for performing calculations in a reasonable time. Figs 5 and 6 show the results obtained for the two different directions on the two roads analyzed (SP30 and SP175). From the flow diagrams obtained experimentally, there are speeds (defined as the critical speed) close to 50÷55 km/h (excluding the survey conducted on the SP175 for direction $d2$, which is considerably higher). This speed, defined as 'critical speed', is the speed at which a heavy vehicle is equivalent to a car.

Conclusions

The method of calculating the LOS, and in particular of determining the PCE coefficients proposed by the Highway Capacity Manual, is based mainly on studies and research developed in the USA. To transfer this method to another reality (for example, Italy), it is necessary to conduct evaluations locally. In this work a series of experimental studies were carried out to assess some of these procedures.

The data were collected using two fixed RTMS (Remote Traffic Microwave Sensor) devices measuring traffic flow in two sections located at 3100 km on the SP30 and 8900 km on the SP175, from 1 January to 31 December 2010.

The PCE coefficients were determined together with the relationship between the fundamental parameters of traffic flow (V , S and D) using the procedures set out in the Highway Capacity Manual (2010). Using the data, it has been possible to obtain not only the relations

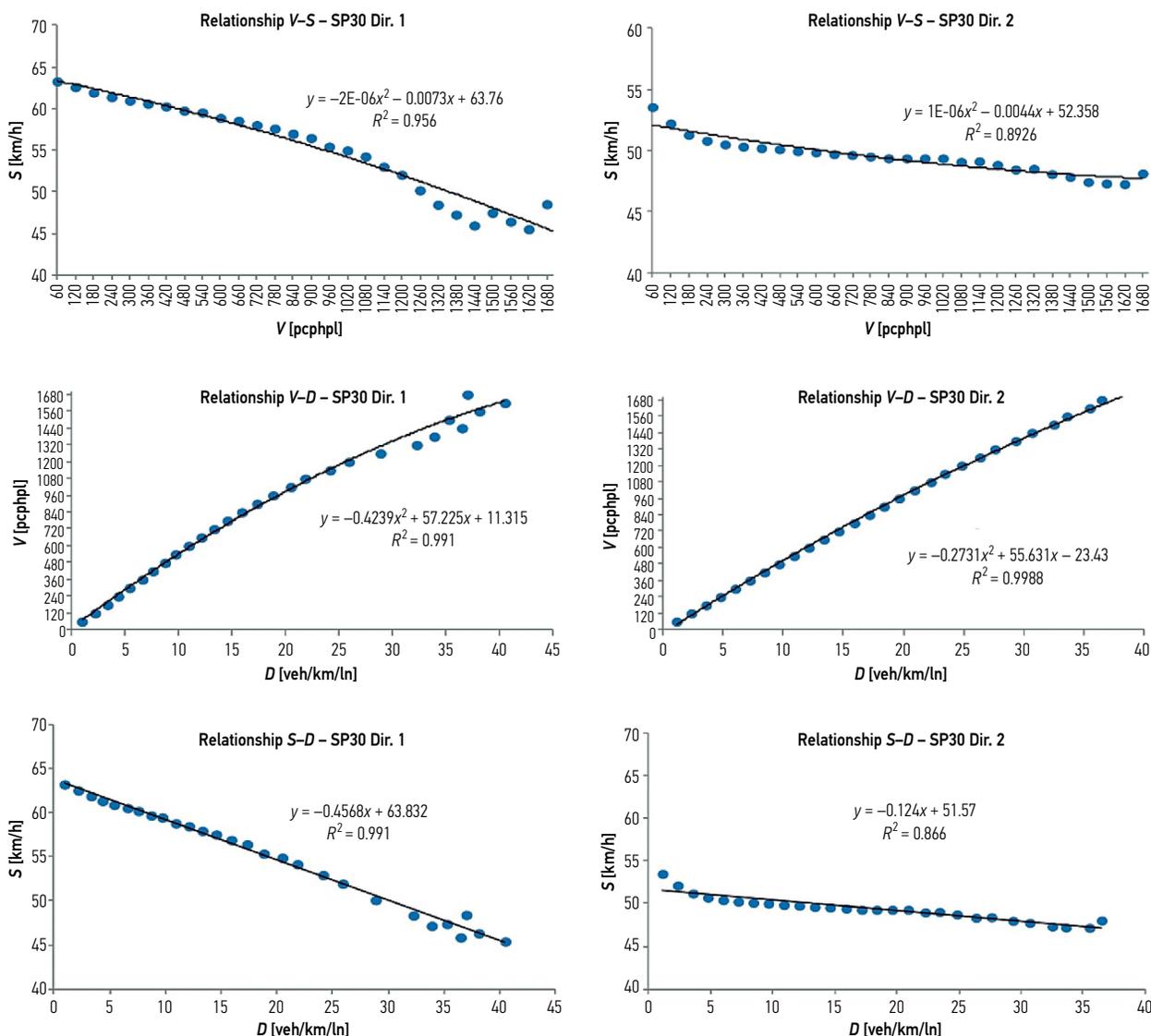


Fig. 5. Relationship between S, V and D for SP30 road

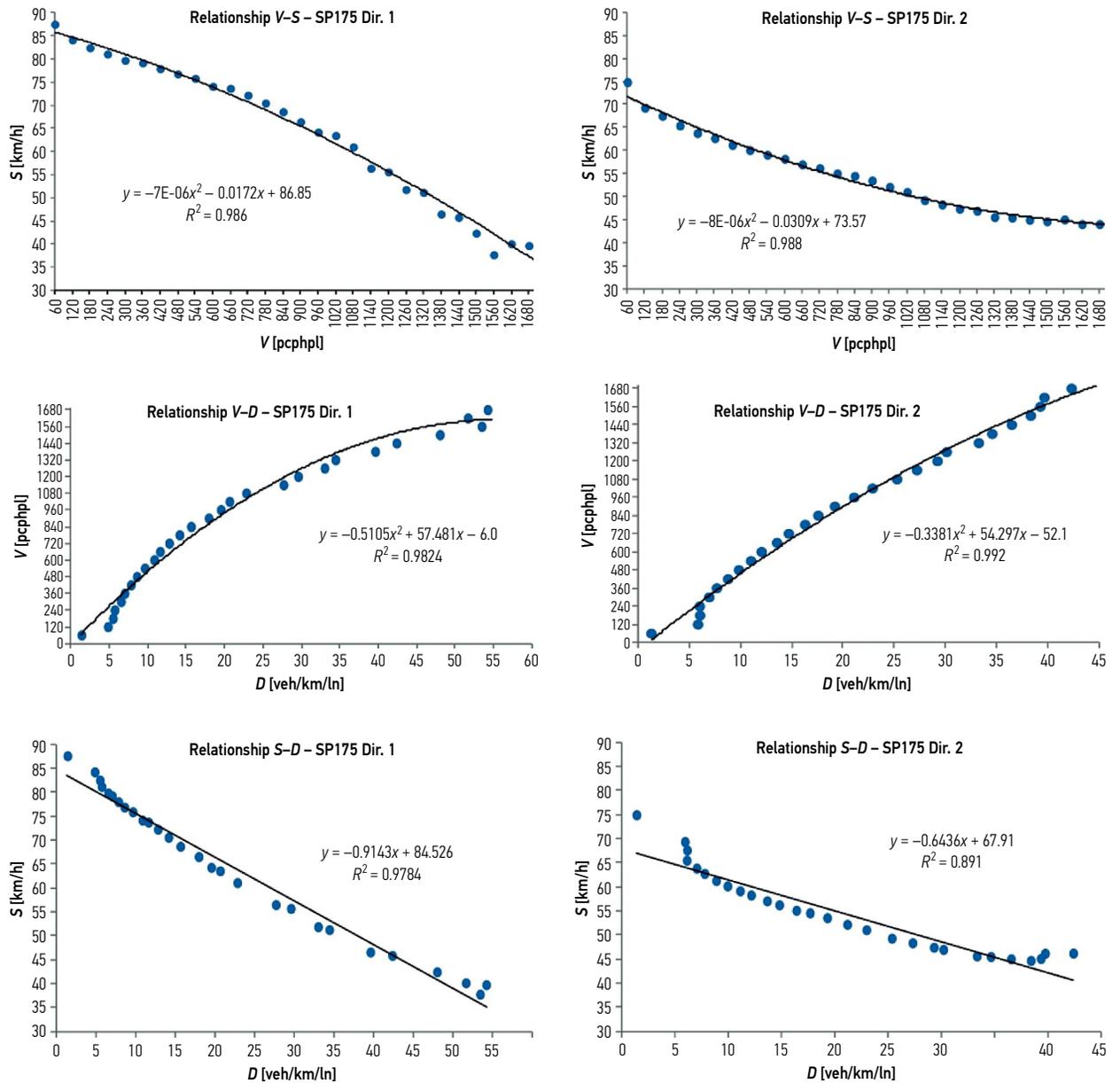


Fig. 6. Relationship between S, V and D for SP175 road

between the basic parameters of the flow, but also the PCE values in some traffic conditions.

The results showed that while the PCE analyzed have the same range as recorded in the Highway Capacity Manual (2010) – values between 1 and 2 – they are on average greater than those indicated by the manual, with a difference that tends to diminish beyond a flow rate of 400÷450 veh/h/pl (Fig. 4). Furthermore, the PCE coefficients tend towards 1 (i.e. the condition in which a heavy vehicle is comparable to a car) for flow values approaching 1000 pcphpl; for these values, as may be seen from this first analysis, carried out under these traffic conditions, it can be concluded that, in terms of size and performance, PCE values, while varying within the same range indicated in the Highway Capacity Manual (2010), are generally higher and tend to 1 for values higher than the flow rate.

Furthermore, the relationship between the runoff values (V, D, S) were in line with the contents of the Highway Capacity Manual (2010); in particular it was found that the experimental data analyzed are well interpreted by the Greenshield model for roads with an uninterrupted flow. To consolidate these results, the research is proceeding with other experimental studies concerning different infrastructures on which tests are being carried out also in different traffic conditions.

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