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AUTOMATED HIGHWAY SYSTEMS AND HARD-SHOULDERS RUNNING: A CASE STUDY

Marco Guerrieri and Raffaele Mauro
Department of Civil, Environmental and Mechanical Engineering, University of Trento, Italy
E-Mail: marco.guerrieri@tin.it

ABSTRACT

The purpose of this research was to evaluate the increase of capacity of existing motorway resulting from the implementation of relatively new traffic control strategies, as the automated highway systems (AHS) and the hard-shoulder running (HSR). Was examined the Italian motorway A22, belonging to Trans-European Road Network, corridor Helsinki - La Valletta. Many traffic surveys were done (year 2014) in several road sections. For each of them have been carried out the flow diagrams, the traffic flow parameters (capacity C, free flow speed v_f, jam density k_{jam}) and the relationship between flow rate of lane (right lane Q_{right} and passing lane Q_{pass}) and total flow rate Q_t. The current carriageway capacities are in the range 2.703 veh/h ÷ 3.621 veh/h. To improve the capacity, a hard-shoulder running is planned, in both directions of the A22, for a total length of 128 km. This type of traffic control strategy allows an increase of the capacity up to 35%. Instead, for the hypothesized safety conditions of the platooned automated vehicles, a single lane with an AHS gives rise to a capacity of about 5.500 veh/h (reaction time $\delta = 0,1$ s).

Keywords: automated highway systems (AHS), hard shoulders running (HSR), capacity.

1. INTRODUCTION

The Intelligent Transportation Systems (ITS) have been developed with the aim to improve the capacity and safety of transportation systems by means of new technologies that allow the implementation of novel and decision-making techniques. Among others, ITS cover the following areas [1]:

- *Advanced Traffic Management Systems (ATMS).* ATMS covers dynamic traffic control systems, ramp metering, arterial signal control, etc.;
- *Advanced Traveler Information Systems* (ATIS). ATIS supports travelers to arrive at their chosen destination (i.e. on-board navigation systems);
- *Advanced Vehicle Control Systems* (AVCS). AVCS includes all the systems used for helping the driver's control of the vehicle (traction control, automatic braking and/or automatic steering, etc.);
- *Commercial Vehicle Operations* (CVO). This area includes the use of the ITS technologies to commercial vehicles like as buses, trucks, taxis, and emergency vehicles, etc.;
- *Advanced Public Transportation Systems (APTS). APTS* concerns the applications of the ATIS, and AVCS technologies to ameliorate the operation of high-occupancy vehicles (i.e. transit buses, van- and car pools, etc.).

Automated Highway Systems (AHS) is an area of the ITS that could improve radically the capacity and safety of the current highways and motorways systems. In the AHS, instrumented vehicles with ITS technologies flow out in platoons on pre-selected lanes of highways. The use of instrumented vehicles (semi-automatic or automatic vehicles) equipped with electronic sensors, computers, and actuators can provide quicker and more accurate responses than human drivers. In fact, drivers' ability to identify changes in vehicle gaps, accelerations, trajectories, etc. decreases speed and precision of response. For this reasons, in the case of uninterrupted flow conditions, the lane's capacity generally is below 2.200 vehicles per hour under manual control [2]. In addition, driver errors are answerable of 90% of the crashes that occur today [1].

The Automated Highway Systems have a multi-level control structure, as follows [3]:

- *the vehicle controllers* (VC) installed in each vehicle receive commands from the platoon controllers (for example: trajectories, speeds, headway, etc.) and convert these information into control signals for the vehicle actuators such as braking, throttle and steering actions;
- *the platoon controllers* (PC) obtain commands from the roadside controllers and are accountable for coordination and control of the interplatoon and intraplatoon maneuvers;
- *the roadside controllers* (RC) control the highway sections in which AHS technologies are installed. RC order platoon's speeds, safe distances to prevent collisions between platoons, appropriate platoon sizes, and ramp metering at the on-ramps, etc.;
- *the higher-level controllers* (HLC) (regional, and/or supraregional controllers) provide network-wide coordination of the lower-level and middle-level controllers. HLC give area-wide dynamic route guidance for the platoons, and they supervise and coordinate the activities of the roadside controllers.

Under uninterrupted flow condition, the lane's capacity C is $C = 1/\tau_m$, where τ_m is the mean of the headways.

For increasing lane capacity, it is necessary to operate vehicle sat closer average spacing (for the same speed). To do this is required the platoon mode of

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operation. If in AHS the platoons inter-vehicle spacing are known, the capacity of one lane can be evaluated, for example, by means of the following relation [4]:

$$C = 3600 \cdot \frac{v \cdot N}{[(L \cdot N) + i \cdot (N - 1) + I)]}$$

where: C is the lane capacity [veh/h], L is the vehicles length [m], N is the number of vehicles in one platoon, i is the spacing between vehicles in a platoon (intra-platoon spacing, generally 1÷2 m) [m], I is the spacing between platoons (inter-platoon spacing, generally 30÷60 m) [m], v is the speed [m/s].

The values calculated with the previous equation are in accordance to the capacity-speed curves obtained by Shladover [5], in which the maximum capacity for a lane it is reached in the case of 20-vehicle platoons and speed around 30 m/s [1]: C = 8.500 veh/h.

Many international researches on Automated Vehicle Control Systems and AHS were conducted in USA, Europe and Japan since the mid-1960s. Some of the most important studies in this filed are [1, 6, 7, 8]: MIT Project METRAN, Program on Advanced Technology for the Highway (PATH) in 1986, DRIVE (Dedicated Road Infrastructure for Vehicle Safety in Europe), PROMETHEUS (Program for European Traffic and Highest Efficiency and Unprecedented Safety), VITA II, SARTRE, HAVEit.

The expected levels of safety (in terms of probability of collision and severity) due to automated vehicle into operational conditions have been studied by Kanaris *et al.*, [9]; González *et al.* [10]; Michael *et al* [11]; Hamouda *et al*. [12]. This researches show that the safety of automated driving is derived primarily from constant headway and speed control; in addition, stresses the importance of inter-vehicles coordination and knowledge of vehicle's braking capability. Anyway, respect to the traditional highway, the AHS ensure the reduction of rear-end crashes in the hard braking emergency scenario.

Nowadays, many empirical researches are carried out around the world thanks to the reduction of construction costs of prototypes, given the relatively low costs of sensors and microcontroller boards (like Arduino, Raspberry, etc. [13]).

Despite the benefits described above are required numerous other studies before implementing AHS on existing highways in operation. Actual solutions for mitigating congestion on existing highway and motorway are based on appropriate traffic control strategies such as ramp metering, variable speed limits (VSLs), and hard-shoulder running (HSR) [14]. The use of shoulders during the traffic peak periods has been tested in the USA and is fairly common in Europe, above all in Great Britain, Germany, and the Netherlands. Highway with HSR systems have reported capacity increases in the order of 7÷22 %, depending on the configuration [15, 16]. Generally, the European installations combine use of HSR with Variable Speed Limit Systems (VSL). This because the speeds limits, in some traffic condition, can increase the capacity and reduce the probability of crashes.

The paper examine a case study of traffic control strategies on the motorway A22 in Italy, for reducing traffic congestion. Many traffic surveys were done with the aim to estimate capacity, speed levels and reliability and to evaluate the potential efficiency benefits correlated to the implementation of HSR, VSL and AHS.

2. THE A22 MOTORWAY

The A22 motorway is one of the principal axes of the Italian highway network linking the Po Valley and the A1 Freeway with Austria and Germany. The A22 is part of the TEN-T Network (Trans-European Road Network, corridor Helsinki - La Valletta) [17]. Overall length is 313 km approximately. The A22 is a typical divided four-lane motorway, with two hard shoulder (3, 45 m, each).

Figure-1. A22 motorway layout.

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The Annual average daily traffic (AADTS) is between 41.907 and 62.464 vehicles per day, as shown in Table-1.

These high values of traffic demand often produce low levels of service (LoS), delays and queues because the freeway has only two lanes in each direction.

To improve the capacity and hard-shoulder running is planned, in both directions, for a total length of 128 km, between the sections of Egna (km 102+00) and Verona Nord (km 230+00) [18].

Table-1. AADTs values.

N°	Km Init.	Km Fin.	Name	AADT [veh/day]
1	0+000	15+870	Brennero - Vipiteno	41.907
2	15+870	38+030	Vipiteno - Bressanone	44.159
3	38+030	47+600	Bressanone - Bressanone	48.388
4	47+600	53+070	Bressanone - Chiusa	46.896
5	53+070	77+470	Chiusa - Bolzano nord	50.362
6	77+470	85+330	Bolz. nord – Bolz. sud	48.778
7	85+330	101+800	Bolzano sud - Egna Ora	57.553
8	101+800	121+450	Egna - S.Michele	58.810
9	121+450	131+440	S. Michele - Trento nord	57.865
10	131+440	136+460	Trento nord - Trento centro	52.464
11	136+460	142+000	Trento centro - Trento sud	52.874
12	142+000	157+850	Trento sud - Rovereto nord	61.066
13	157+850	166+740	Rov.to nord – Rov.to sud	60.366
14	166+740	179+125	Rov.to sud - Ala Avio	62.075
15	179+125	206+670	Ala Avio - Affi	62.646
16	206+670	225+370	Affi - Verona nord	48.216
17	225+370	228+000	Verona nord - int. A4	60.431
18	228+000	243+670	int. A4 - Nogarole	62.675
19	243+670	256+180	Nogarole - Mantova nord	61.054
20	256+180	265+000	Mant. nord – Mant. sud	61.197
21	265+000	276+710	Mant. sud - Pegognaga	61.669
22	276+710	285+630	Pegognaga - Reggiolo Rolo	54.637
23	285+630	302+175	Reggiolo Rolo - Carpi	55.440
24	302+175	312+150	Carpi - Campogalliano	59.668
25	312+150	313+085	Campogalliano – int. A1	60.706

3. ANALYSIS OF TRAFFIC DATA ON A22 BRENNER FREEWAY

Sampling of traffic has been carried out at observation sections on the A22 Brenner Freeway for the years 2003, 2005, 2007 [19,20] and 2014.

The main characteristics of the observation sections are given in Table-2.

The capacity analysis concerns the periods: 5÷11 May 2014 and 8÷14 December 2014. Furthermore, two additional sections (Rovereto - km 161+100 and Adige - 187+300) have been examined, by means surveys done in the year 2004 [20].

For each section and for intervals of 5 minutes and 15 minutes we calculated the macroscopic flow parameters: flow (q), speed (v) and density (k).

In accordance to the HCM 2010, the volumes estimated were adjusted by means equivalent factors relating to the composition of traffic (i.e. percentage of heavy vehicles), thereby obtaining an equivalent measure of passenger cars unit per hour (pcu/h) [2]. In all, has been carried out $N_{5'}$= 24.192 couples (v; k), (q; k), (v; q) (cfr. Table-3).

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Table-2. Observation sections.

Observation section	Location	Horizontal alignment	Vertical alignment; slolpe (%)
Kofler	063+500	Tangent	Curve: R = 10.000 m; slope =0,41 %
S. Michele	123+960	Tangent	Tangent , slope =0,03 %
Portale Affi	205+500	Curve: R = 1000 m	Curve: R = 10.000 m; slope = 0,23 %
Mantova	271+900	Tangent	Curve: R = 15.000 m; slope = 0,00 %

Table-3. Number of couples (v; k), (q; k), (v; q).

Sections	$N_{5'}$
San Michele 123+960 Nord	4.032
San Michele 123+960 Sud	4.032
Kofler 063+500 Nord	4.032
Kofler 063+500 Sud	4.032
Portale Affi 205+500 Nord	2.016
Portale Affi 205+500 Sud	2.016
Mantova 271+900 Nord	2.016
Mantova 271+900 Sud	2.016
Total	24.192

For each section, the flow diagrams are obtained by means of May model [20, 21, 22] in which the relationship between speed (v) and density (k) is given by the following equation:

$$v = v_f \cdot e^{-\frac{1}{2}\cdot\left(\frac{k}{k_{jam}}\right)^2} \qquad (1)$$

Where v_f is the free flow speed and k_{jam} the jam density. Transforming eq.(1) into a logarithmic form, we obtain:

$$\ln(v) = \ln(v_f) - \frac{k^2}{2\cdot k_{jam}^{\ 2}} \qquad (2)$$

$$v_1 = a + b\cdot D_1 \qquad (3)$$

In which: $v_1=\ln(v)$; $a = \ln(v_f)$; $b= 1/(2\cdot k_{jam}^2)$; $D_1=k^2$. Considering the fundamental relation between flow ($q = k\cdot v$), we obtain:

$$q = v \cdot \sqrt{\frac{\ln\frac{v_f}{v}}{\frac{0{,}5}{k_{jam}^{\ 2}}}} \qquad (4)$$

$$q = v_f \cdot k \cdot e^{-\frac{1}{2}\left(\frac{k}{k_{jam}}\right)^2} \qquad (5)$$

Eq. (4) and Eq. (5) allow the tracing of two further flow relations: $v = v(q)$ and $q = q(k)$.

Finally, the flow models were calibrated.

The parameters v_f and k_{jam} in eq. (1) can be estimated by means of the scatter points (k; ln(v)), applying the least-squares regression method.

For example, the Figure-2 shows the speed - density scatter points (k; ln(v)) for the right lane of the section "Kofler" (southbound roadway); we obtain:

- v_f=exp(a) = exp(4,3675)=78,85 km/h;
- $k_{jam} = \sqrt{\frac{1}{-2\cdot b}} = \sqrt{\frac{1}{-2\cdot(-0{,}0005)}}$ =31,62 veh/km/lane.

Finally, we obtain: $q = 78{,}85\cdot k\cdot e^{-\frac{1}{2}\left(\frac{k}{31{,}62}\right)^2}$

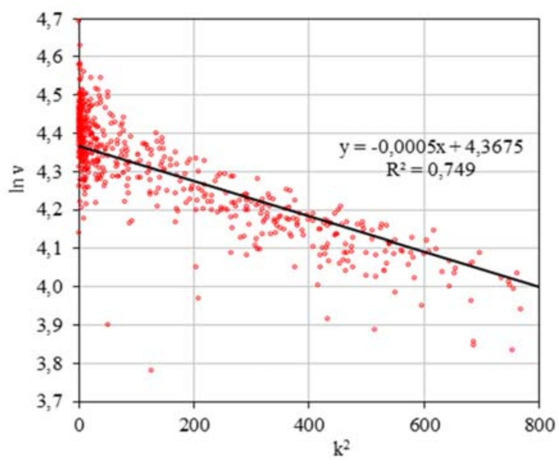

Figure-2. Speed density scatter points (k; ln(v)) and regression line (section Kofler, southbound roadway, right lane).

Figure-3 shows the fundamental diagram for the right lane of the section Kofler (southbound roadway).

In Figure-4 are plotted the relations $q = q(v)$ for the two lanes and for the carriageway of the section San Michele (southbound roadway).

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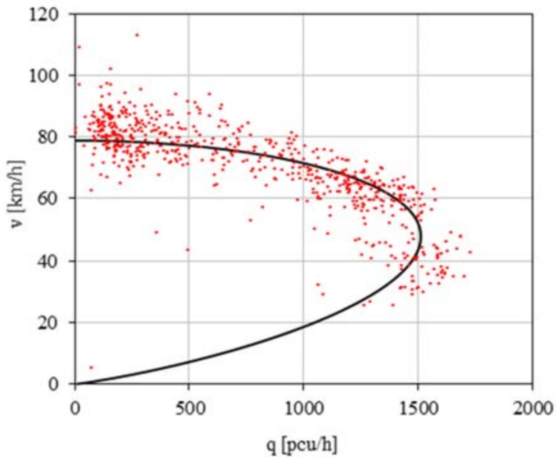

Figure-3. Speed - flow scatter plot for the right lane.

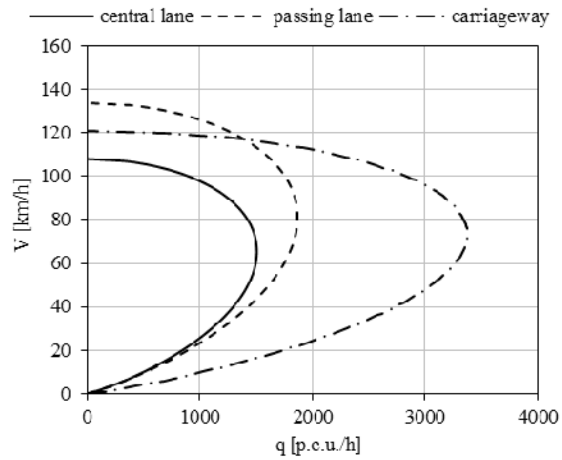

Figure-4. Speed - Flow diagrams for the right lane, passing lane and carriageway (section san Michele, southbound roadway).

The Tables 4-10 provide the traffic flow parameters (capacity "C", free-flow speed "v_f", jam density "k_{jam}") obtained for some of the sections analysed.

Table-4. Traffic flow parameters (section San Michele).

Lane - carriageway	**San Michele (km 123+960) - northbound roadway**			
	v_f (km/h)	k_{jam} (pcu/lane/km)	**C** (pcu /h)	v_{jam}(km/h)
right lane	108	23	1484	66
passing lane	134	23	1901	81
carriageway	121	46	3361	73

Table-5. Traffic flow parameters (section San Michele).

Lane - carriageway	**San Michele (km 123+960) - southbound roadway**			
	v_f (km/h)	k_{jam} (pcu/lane/km)	**C** (pcu /h)	v_{jam}(km/h)
right lane	109	21	1420	68
passing lane	129	22	1747	78
carriageway	110	50	3340	68

Table-6. Traffic flow parameters (section Mantova).

Lane - carriageway	**Mantova (km 271+900) - northbound roadway**			
	v_f (km/h)	k_{jam} (pcu/lane/km)	**C** (pcu /h)	v_{jam}(km/h)
right lane	103	32	1973	62
passing lane	129	48	-	-
carriageway	-	-	-	-

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Table-7. Traffic flow parameters (section Mantova).

Lane - carriageway	**Mantova (km 271+900) - southbound roadway**			
	$\mathbf{v_f}$ (km/h)	$\mathbf{k_{jam}}$ (pcu/lane/km)	**C** (pcu /h)	$\mathbf{v_{jam}}$(km/h)
right lane	103	32	1968	62
passing lane	126	29	2209	76
carriageway	-	-	-	-

Table-8. Traffic flow parameters (section Rovereto).

Lane - carriageway	**Rovereto (km 161+100) - southbound roadway**			
	$\mathbf{v_f}$ (km/h)	$\mathbf{k_{jam}}$ (pcu/lane/km)	**C** (pcu /h)	$\mathbf{v_{jam}}$(km/h)
right lane	105	23	1493	64
passing lane	127	26	2012	77
carriageway	114	50	3468	69

Table-9. Traffic flow parameters (section Adige).

Lane - carriageway	**Adige (187+300) - northbound roadway**			
	$\mathbf{v_f}$ (km/h)	$\mathbf{k_{jam}}$ (pcu/lane/km)	**C** (pcu /h)	$\mathbf{v_{jam}}$(km/h)
right lane	103	21	1341	63
passing lane	120	22	1581	73
carriageway	113	40	2703	68

Table-10. Traffic flow parameters (Section Adige).

Lane - carriageway	**Adige (187+300) - southbound roadway**			
	$\mathbf{v_f}$ (km/h)	$\mathbf{k_{jam}}$ (pcu/lane/km)	**C** (pcu /h)	$\mathbf{v_{jam}}$(km/h)
right lane	109	24	1607	66
passing lane	129	26	2043	78
carriageway	116	51	3621	71

A typical relationship between flow rate of lane (i.e., right lane Q_{right} and passing lane Q_{pass}) and total flow rate Q_t of roadway is given in Figure-5.

Figure-6 shows the same type of relationship but in terms of percentage.

4. EVALUATION OF MOTORWAY CAPACITY WITH HARD-SHOULDER RUNNING

This layout presents three lanes for each carriageway (hard-shoulder running/right lane, central lane and passing lane).

In accordance to empirical observations on Italian motorways (A1 and A14) [20], for this layout, the values of free flow speed and the jam density for the right lane - hard-shoulder running (HSR) - ($(v_f)_{right}$ and $(k_{jam})_{right}$) can be deduced by requiring that the central lane presents intermediate characteristics between those of the right lane and the passing lane; namely:

$$\frac{(v_f)_{pass} + (v_f)_{right}}{2} = (v_f)_{central} \tag{6}$$

$$\frac{(k_{jam})_{pass} + (k_{jam})_{right}}{2} = (k_{jam})_{central} \tag{7}$$

Having obtained $(v_f)_{right}$ and $(k_{jam})_{right}$ - by eq.(6) and eq.(7) - $(v_{jam})_{right}$ can be calculated with the eq.(1), by imposing that $k=(k_{jam})_{right}$:

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$$(v_{jam})_{right} = (v_f)_{right} \cdot e^{-\frac{1}{2}\left(\frac{(k_{jam})_{right}}{(k_{jam})_{right}}\right)^2} \quad (8)$$

The capacity can be calculated with the equation $C = (v_{jam})_{right} \cdot (k_{jam})_{right}$.

The carriageway capacity can be estimated as sum of the lanes capacities.

Likewise, the jam density of the carriageway can be estimated as sum of jam density of each lane.
Instead, v_f e v_{jam} are obtained with expressions $v_f = C/[k_{jam} \cdot \exp(-0,5)]$ and $v_{jam} = C/ k_{jam}$.

By way of example, Table 11 shows the traffic flow parameters for the section San Michele (southbound roadway) with HSR. For this section in Fig. 7 is given the relation v = v(q) and in Fig. 8 the relation v = v(k).

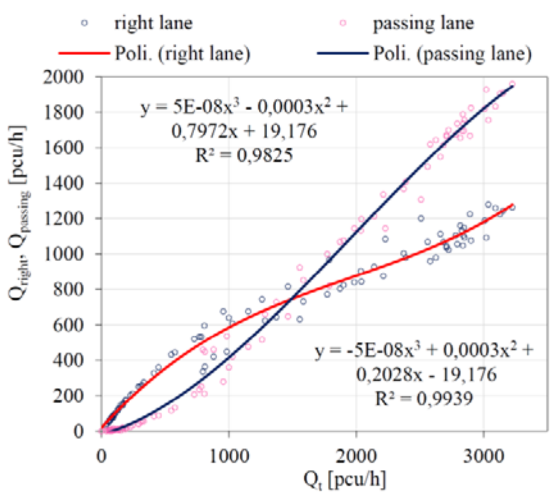

Figure-5. Relationship between flow rate of lane and total flow rate Q_t (San Michele, southbound roadway).

For the section San Michele, northbound roadway, the capacity is C = 3.361 veh/h without HSR and C = 4.535 veh/h with HSR (increase of 35%).

Instead, for southbound roadway the capacity is C = di 3.340 veh/h without HSR and C = 4.247 veh/h with HSR (increase of 27%, cfr. Tables 4, 5, 11, 12).

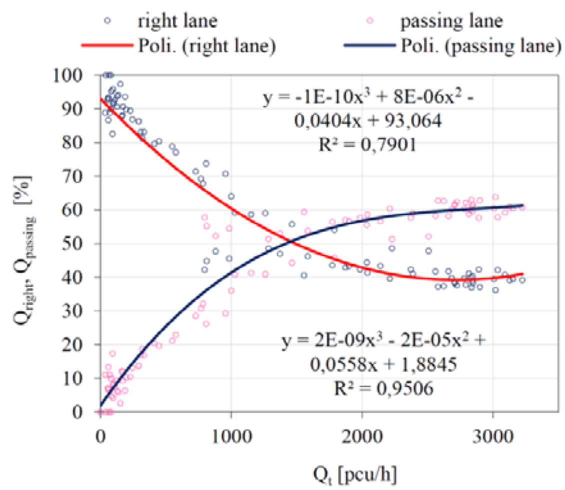

Figure-6. Relationship between flow rate of lane and total flow rate Q_t (San Michele, southbound roadway).

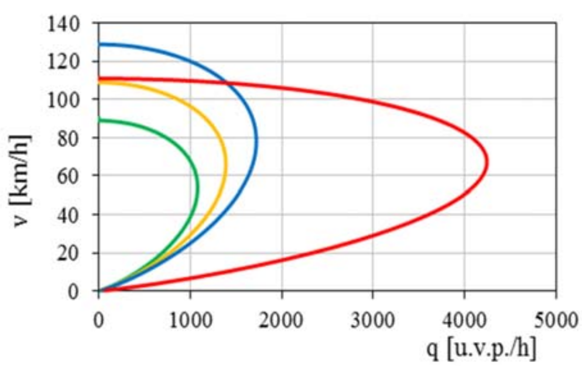

Figure-7. Speed - Flow diagrams for the right lane (HSR, green), median lane (yellow), passing lane (blue) and carriageway (red). Section San Michele, southbound roadway.

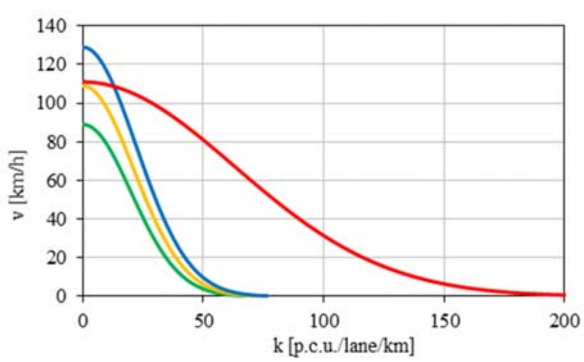

Figure-8. Speed - density diagrams for the right lane (HSR, green), median lane (yellow), passing lane (blue) and carriageway (red). Section San Michele, southbound roadway.

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Table-11. Traffic flow parameters A22 with HSR.

Lane - carriageway	San Michele (km 123+960) -northbound roadway			
	v_f (km/h)	k_{jam}(pcu/lane/km)	C (pcu /h)	v_{jam}(km/h)
right lane (HSR)	82	23	1150	50
Central lane	108	23	1484	66
passing lane	134	23	1901	81
carriageway	108	69	4535	66

Table-12. Traffic flow parameters A22 with HSR.

Lane - carriageway	San Michele (km 123+960) - southbound roadway			
	v_f (km/h)	k_{jam}(pcu/lane/km)	C (pcu /h)	v_{jam}(km/h)
right lane (HSR)	89	20	1080	54
central lane	109	21	1420	68
passing lane	129	22	1747	78
carriageway	111	63	4247	67

5. EVALUATION OF MOTORWAY CAPACITY WITH AHS

In an automated highway, the capacity of one lane can be computed considering, preliminarily, the minimum safety spaces "s" between platooned automated vehicles [23].

The Figure-9 shows the positions of the leading and following vehicles, traveling in platoons, at moment in which the leading vehicle begins to decelerate; at the end of the stopping maneuver of the following vehicle is required a safety margin (s_0) [24].

Using the following notations can be found the relationship between speed v, deceleration and spacing s [24]:

- v initial speed of the two vehicles;
- a_1 deceleration rate of the leading vehicle;
- a_2 deceleration rate of the following vehicle;
- δ perception-reaction time of the following vehicle;
- $s_0$safety margin at the end of deceleration phase (s_0 = 0,5 m) ;
- $\bar{s}_2(t)$ is the space of the following vehicle during the perception and reaction time δ ($\bar{s}_2(t) = v \cdot \delta$);
- $s_1(t)$ is the distance covered during the deceleration of the leading vehicle;
- $s_2(t)$ is the distance covered during the deceleration of the following vehicle;
- L is the length of vehicles (L = 5, 25 m).

$$s = \bar{s}_2(t) + s_2(t) - s_1(t) + s_0 + L \tag{9}$$

In which:

$$s_1(t) = \frac{v^2}{2 \cdot a_1} \tag{10}$$

$$s_2(t) = \frac{v^2}{2 \cdot a_2} \tag{11}$$

Introducing eq.(10) and eq. (11) in the eq. (9), we obtain:

$$s = v \cdot \delta + \frac{v^2}{2 \cdot a_1} - \frac{v^2}{2 \cdot a_2} + s_0 + L \tag{12}$$

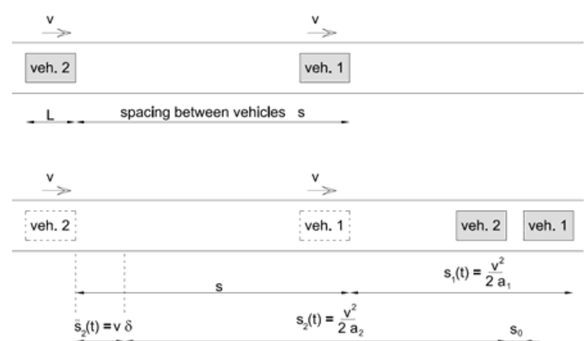

Figure-9. Safety spacing between platooned vehicles.

Whereas that k = 1/s and q = k·v = 1/s·v, the flow–speed relationship is

$$q = \frac{v}{v \cdot \delta + \frac{v^2}{2 \cdot a_1} - \frac{v^2}{2 \cdot a_2} + s_0 + L} \tag{13}$$

This equation is plotted in Figure-10 for three cases:

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- automated highway systems, type 1 (automated vehicles with a_1 = 0,45 g, a_2=0,5 g and δ = 0,1 s);
- automated highway systems, type 2 (automated vehicles with a_1 = 0,45 g, a_2= 0,5 g and δ = 0,3 s);
- normal lane (vehicle with manual control, a_1 = 0,45 g, a_2= 0,5 g and δ = (2,8-0,01·v), in which v is expressed in km/h).

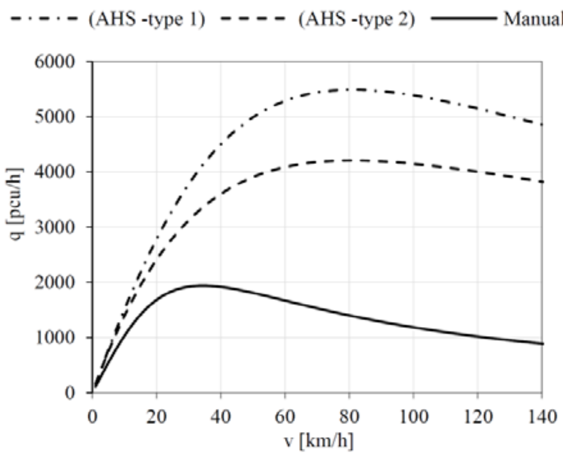

Figure-10. Capacity of one lane with an AHS.

As shown in Figure-10, under the intermediate assumptions previously mentioned, the theoretical maximum capacity of one lane for an AHS is around 5.500 veh/h for a reaction delay δ = 0,1 s (AHS - type 1) and 4.200 veh/h for a reaction delay δ = 0,3 s (AHS - type 2).

Instead, the capacity of one lane in which there are only manual vehicles is below about 2.000 veh/h (if δ = 2, 8-0, 01·v, cfr. Italian guidelines for the Design of Road Infrastructures [25]).

The expected maximum capacity for the motorway under study is the sum of the capacity of the normal lanes (cfr. Tables 4-10) - in which there are only manual vehicles -and the capacity of the lanes implemented with an AHS- used by automated vehicles - (cfr. Figure-9).

Further analysis is required to assess the environmental benefits of the AHS [26, 27, 28].

Unlike the HSR, the Automated Highway systems are still under study and experimentation. Therefore, the results obtained in this section, are just theoretical.

Only in a near future, this technology could be implemented on existing motorway, as the A22.

6. CONCLUSIONS

This research shows the benefits, in terms of capacity, achievable with the implementation of specific traffic control strategies as the hard-shoulder running (HSR) and the automated highway systems (AHS).

A case study concerning the Italian A22 motorway ("Autostrada del Brenneo"), belonging to Trans-European Road Network, corridor Helsinki - La Valletta, was examined.

Actually, the A22 is a divided four-lane with two hard shoulder (one for each direction).

The estimation of capacity was carried out for the following sections:

- Kofler - km 063+500;
- S. Michele - km123+960;
- Portale Affi - km205+500
- Rovereto - km 161+100;
- Adige - km187+300;
- Mantova - km271+900.

Based on the traffic of the year 2014, were calculated 24.192 couples speed-density (v; k), flow-density (q; k), speed-flow (v; q), in all.

By means of this couples, for each lane of all the above mentioned sections, were obtained the flow diagrams, the traffic flow parameters (capacity C, free flow speed v_f, jam density k_{jam}) and the relationship between flow rate of lane (right lane Q_{right} and passing lane Q_{pass}) and total flow rate Q_t.

The current carriageway capacities are in the range 2.703 veh/h ÷ 3.621 veh/h.

To increase the operational performances of the A22 a hard-shoulder running (HSR) is planned, in both directions, for a total length of 128 km, between the sections of Egna (km 102+00) and Verona Nord (km 230+00).

The results of the study show that the implementation of the hard-shoulder running can increase the capacity of the sections up to 35%.

With regard to the AHS, currently in the process of study and research, the benefits could be even more meaningful. In fact, according to the safety conditions of the platooned automated vehicles assumed in this research, a dedicated single lane with an AHS gives rise to a capacity of about 5.500 veh/h.

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