USE OF RADAR DEVICES IN ROAD TRAFFIC SURVEYS

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ABSTRACT

The Department of Roads and Transportation of Polytechnic University of Bari owns CW radar devices for road traffic surveys. The radars can be used to measure traffic volumes and vehicle lengths and speeds.

Radar's manual suggests to refer to measures of length to install the devices. To verify the reliability of such measures , an experimental survey has been carried out.

The results of the survey have been used to study the errors of instruments when they are installed following the proposed (by the manufacturer) installation procedure as best as a meticulous operator without topographic helps could do *in situ*. Then the sensitivity of errors to changes in installation parameters have been analysed.

The paper concludes that is very difficult to avoid bias in length measures and that small deviations from the suggested angle of installation (30°) causes noteworthy increase in errors if the angle is slightly greater than the recommended one.

Keywords: traffic surveys, doppler radar detector, calibration

1. INTRODUCTION

The modern approach to road design and management claims the need of having at own disposal complete and reliable traffic databases. The correct knowledge of driver behaviour is of primary importance to understand which are the correct actions to be undertaken, whether infrastructural or managerial, to make the road service safe, reliable, comfortable and profitable. As for this issue, systems have been developed to detect the main traffic characteristics: volume, speed, vehicle types, weight.

Because of the intrinsic variability of road traffic, the accuracy of surveys is strongly influenced both by the kind of traffic data observed and by the environmental condition of the survey site. To face these problems, many different survey systems have been set up, even using very different technologies, which can collect traffic data accurate enough depending on the researcher needs. These systems go from the primordial manually actuated traffic counters to the more recent systems based on GPS/GSM technologies. Between these bounds, there are a lot of other automatic systems, usually installed on fixed stations, that use many different technologies: e.g., inductive loop, magnetic, piezoelectric, infrared, radar, ultrasonic, video image processing. Such a number of technologies, on one hand gives the idea of the attention and the importance of building these databases, on the other hand also highlights the difficulties that arose along the time to collect data really complete and reliable.

The use of these devices and the further data analysis is not simple so that already in 1988/90 the US Federal Highway Admnistration (FWHA) edited the Traffic Detector Handbook (Kell et al., 1990) to help the technicians in the use of the traffic surveying systems at that time more widespread (the inductive loops); this manual have been soon followed (in 1992) by the AASHTO Guidelines for Traffic Data Programs (AASHTO, 1992) and, more recently, by the Traffic Monitoring Guide edited in 2001 by the FHWA (2001). Beyond these basic publications, there are several other papers whose aim is to help the practitioners in the choice among the many systems in commerce. For this purpose the works in (Skszek, 2001; Martin et al., 2003; Middleton et al., 1999; FHWA et al., 2001; Elena Y Membela et al., 2003) give a valuable contribution.

The Roads and Transportation Department of Polytechnic University of Bari owns some traffic surveying devices based on the continuous wave radar technology. Before going on to use them for the research purpose they have been purchased for, the information about the accuracy and precision of the devices given by the manufacturer have been verified. For this purpose, the works in (Harvey et al., 1995; Busch, 2004; Gillmann, 2007) have been considered and further some in situ tests have been performed.

In the following pages the first step of the instruments calibration is reported and analyzed. In particular, the article describes a procedure for testing the radar systems accuracy, beyond the manufacturer indications, and gives some referential values for such an accuracy.

2. BRIEF DESCRIPTION OF SURVEYING DEVICES

There is not a unique device that can give output accurate enough for all applications in road traffic survey. The use of one technology rather than another should be carefully evaluated depending on the kind of traffic data to be collected, the desired accuracy, the characteristics of the traffic flow, the site of the survey, the time availability and (not the least) the available budget.

A first classification of the different surveying systems can be done according to the way of installing the detectors: 1) intrusive systems where the detectors are installed inside the roadway, 2) non-intrusive systems where the detectors are installed above or close to the roadway, and 3) off-road systems.

In the first kind of systems, the detectors ore mostly installed into the pavement and many different technologies are used: inductive loops, magnetic sensors, pneumatic road tubes, piezoelectric detectors and other weigh-in motion detectors. Nowadays these systems are still largely diffused as they have been widely used up to the recent past; however they present many problems mainly due to poor flexibility, to the maintaining problems and to the high failure rates under certain environmental and traffic conditions.

Non-intrusive systems include active and passive infrared, microwave radar, ultrasonic, passive acoustic, and video image processing. Active infrared, radar, and ultrasonic are active detectors that mainly use the Doppler effect to detect the traffic characteristics. Passive infrared, passive acoustic, and video image processing are passive detectors that measure the difference of the energy emissions of the vehicles or the image of the detection zone. With the introduction of these systems many of the problems above mentioned have been overcome.

The off-road system are systems that use advanced technologies to detect traffic such as probe vehicle and remote sensing. Technologies in probe vehicles include Global Positioning System (GPS), cellular phones, Automatic Vehicle Identification (AVI) and Automatic Vehicle Location (AVL), which require in-vehicle devices. Remote sensing technology uses arterial or satellite images to analyze and extract traffic information. In figure 1 a diagram of all the possible technologies sorted by these 3 categories is presented.

DETECTOR TECHNOLOGIES	*Intrusive*	*Inductive Loop*	Preformed
			Saw-cut
			Trenched-in
		Magnetic	Induction Magnetometer
			Dual-axis Fluxgate Magnetometer
		Pneumatic Road Tube	
		Piezoelectric	Polymer Molecular Chains
			Crystals
			Ceramics
		Weigh-in-Motions	Bending Plate
			Piezoelectric
			Load Cell
			Capacitance Mat
			Fiber Optic
	Non-intrusive	*Active Infrared*	
		Passive Infrared	
		Microwave Radar	True Presence Microwave Radar
			Doppler Microwave Radar
		Ultrasonic	
		Passive Acoustic	
		Video Image Processing	Tripline
			Closed-loop Tracking
			Data Association Tracking
		Combined Detector technologies	
	Off-road	*Probe vehicle*	GPS
			Cellular Phone
			AVL
			AVI
		Remote Sensing	
	Manual Counting		

Fig. 1 – Diagram of the different traffic detectors technologies (Source Martin et al., 2003)

The possible use of each technology, its accuracy and the ease of managing are reported in tables 1 and 2.

Detector technologies		**Count**	**Presence**	**Speed**	**Occupancy**	**Vehicle Classification**	**Multiple lane detection**
Inductive loop		x	x	x	x	x	
Magnetometer		x	x	x	x	x	
Pneumatic road tube		x		x		x	N/A
Infrared	*Active*	x	x	x	x	x	x
	Passive	x	x	x	x	x	
Ultrasonic		x	x		x		
Passive acoustic		x	x	x	x	x	x
Video image processing		x	x	x	x	x	x
Radar - Doppler		x	x	x	x	x	x

Tab. 1 – Detection capabilities for several technologies (based on data reported in Martin et al., 2003 and Elena y Mimbela & Klein, 2003)

Detector technologies		**Count accuracy**		**Speed accuracy**	**Classification accuracy**	**Ease of installation**	**Ease of calibration**	**Cost**
		Low vol.	**High vol.**					
Inductive loop		<5%	<5%	<10%	<10%	low	high	low
Magnetometer		<5%x	<5%	<5%x	N/A	fair	fair	moderate
Pneumatic road tube		<10%	>10%	>10%	N/A	high	high	low/mod
Infrared	*Active*	<5%	<5%	<10%	<5%	high	high	mod/high
	Passive	<10%	>10%	>10%	>10%	high	high	low/mod
Ultrasonic		<5%	<5%	>10%	>10%	high	high	low/mod
Passive acoustic		<10%	<10%	<5%	>10%	high	high	moderate
Video image processing		>10%	<5%	<10%x	>10%	low	low	high
Radar - doppler		<5%	<10%	<5%	>10%	low	low	low/mod

Tab. 2 – Detection accuracy and ease of installation/calibration for several technologies (based on data reported in Martin et al., 2003 and Elena y Mimbela & Klein, 2003)

3. THE CW RADAR SYSTEM

A continuous wave radar system is a particular kind of radar transmitting and receiving continuous waves, typically sinusoidal signals. Usually, the transmitted signal can be a frequency modulated or an amplitude modulated continuous wave. In the first case, the radar is named a FM-CW radar. In this kind of radar, the transmitted frequency is varied in a known way along the time. CW radars differ form pulsed radar because they emit the signal in a continuous way, while in this second type the signal is emitted in short bursts. One of the advantages of CW radar is the simplicity of the required hardware. Peak power for CW radars is much lower than the one needed for pulsed devices. This aspect makes CW radar more attractive for low cost and simple systems such as road traffic monitoring systems. With respect to a pulsed radar, a CW radar presents the disadvantage that it cannot detect distance of the target, because it cannot estimate the flight time of the emitted radiation. The ranging feature can be obtained with the use of FM-CW radars, even if such systems reveal much prone to Doppler ambiguity and range ambiguity errors.

A fixed frequency CW radar is able to estimate, without ambiguity, the radial relative approaching (v_{rad}) speed of a moving target. This measure is obtained by direct estimation of the Doppler frequency of the received signal. Then the actual estimated speed (v) is derived by trigonometric considerations:

$$v = \frac{v_{rad}}{\cos(\varphi)} \qquad \text{(Eq. 1)}$$

where φ represents the visual angle, i.e. the angle between the sensor pointing angle and the lane direction (see fig. 3).

A simple way to implement a speed meter based on a CW radar can be the use of a counter and a threshold based system: for the baseband Doppler signal received, the threshold is used to produce pulses with a period proportional to the Doppler frequency in the acquisition time lag in which the moving target crosses the illumination beam of the radar. All the positive pulses above the given threshold are simply counted and corrected to give a precise estimate of the approaching target.

Also the vehicle length can be estimated. One hypothesis of a possible hardware cheap implementation is to set two different threshold levels to be used to write two different equations taking care of vehicle path distance from the instrument and vehicle length (this two equation set is prone to errors in vehicle speed estimation). By simple geometric considerations, the distance of the vehicle path from the lane border can be easily estimated basing on the beam aperture and the knowledge of the threshold level.

3.1 Analyzed instruments

The detectors at disposal of Polytechnic University of Bari are 6 CW radar devices (fig. 2) with emission frequency f = 24,125 GHz, wave length λ = 12,5 mm and antenna opening angle θ = 12°. On a single carriageway road they can count vehicles and they detect their speeds, lengths and gaps in both the driving directions. As for this matter, data given by the manufacturer are:

- range of measured speeds: 8 ÷ 254 km/h
- accuracy of measures: ±3% (speed) and ±20% (length)
- minimum time gap between vehicles: ± 0.2 seconds
- operating temperature: –20C°/60C°

According to the manual, the device must be installed on poles at a distance (d) from the carriageway edge between 0.50 m and 2.00 m, with an angle φ = 30° toward the nearest vehicular direction (see fig. 2 and 3), at a height of 1,00 m over the road surface (anyhow not less than 1,00 m and no more than 2,20 m).

The soundness of the installation must be checked on site time by time, by connecting the radar device to a laptop and verifying that the measured vehicle lengths corresponds to the real one (that is given by the vehicle manufacturer). In a case of errors going over the accuracy limits of ±20%, the radar must be rotated (1° steps): the installation with an angle less than 30° gives an overestimate of both length and speeds; an angle greater than 30° gives measures underestimate.

Fig. 2 – Views of the used radar devices

4. CALIBRATION

4.1 The problem

The experimental survey has been organized referring to the installation procedure suggested by radar's manufacturer to assess

- the actual accuracy of length measures when the device is installed in "ideal" conditions, i.e. when the parameters comply the guide rules;
- the changes in length measure error caused by the variations in the angle (small and large variations) and the distance (with $0.50 < d < 2.00$ m).

The first aim was to verify the correctness of the accuracy stated by the manufacturer for the "ideal" conditions of installation; in fact, the actual accuracy is needed to evaluate the outcomes of a survey. Anyway, since the beginning of the experimental test, it was clear that while installing the radar at the recommended height is quite easy, problems arise with the distance from the carriageway and the angle between the axis of the radar and the direction of the traffic flow. Poles for installing the device along roads are hardly ever at the same distance from the edge of the carriageway and, at the same time, it is really demanding setting the angle precisely at 30°. Therefore, in the second stage of testing, errors have been assessed induced by the variability of φ and d on the length measures, which, according to the manufacturer, can be used to verify the correctness of the installation *in situ*.

The accuracy of the device in measuring vehicle lengths has been evaluated assuming the length stated by car manufactures (usually known with a detail sufficient for comparison with radar measures, given in units of 10^{-1} m) as the true value.

The accuracy of counting has been verified for the lane closest to the radar (the one to which also the length measures refer), but it has not been reported for sake of brevity. The accuracy of speed measures is complicated by the difficulties in evaluating the actual speed of vehicles and it is currently under analysis.

4.2 Accuracy of radars under "ideal" conditions

To evaluate the reliability of the devices, values given by the radar have been compared with those obtained by a video recorded from an overpass. The position of instruments is shown in fig. 3; measures have been made with

- $\varphi = 30°$ (evaluated with the best possible accuracy granted by trigonometric alignments and verified through the check of length measures *in situ*, i.e. the suggested installation procedure has been implemented as best as a meticulous operator without topographic helps could do *in situ*)
- $d = 1.30$ m (measured *in situ* with a measuring tape)
- bm (base of measure) = 44.85 m (with the same measuring tape)

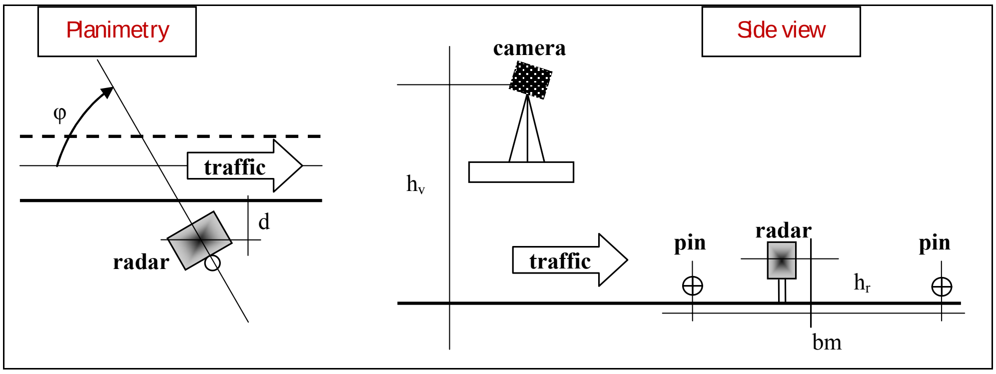

Fig. 3 – Side and plane view of the test configuration

Let

$$e_l = \text{length error} = (\text{radar length}) - (\text{actual length}) \qquad \text{(Eq. 2)}$$

$$e_l\% = \text{relative length error} = \frac{e_l}{\text{radar length}} \cdot 100 \qquad \text{(Eq. 3)}$$

To get to an exhaustive conclusion on the correctness of the radar measures, it has been deemed necessary:

- first of all, to exclude faulty or abnormal functioning of the device
- then to calculate the distribution parameters of e_l and $e_l\%$, in particular means, which represent the bias and can be different from 0 also for well-functioning devices because of an imprecise installation
- eventually to verify the reliability of the device, a crucial feature to evaluate if the device is suitable for a given kind of survey.

The validity of the conclusions on the parameters of measure populations inferred from the sample depends on the number and representativeness (i.e., in case of continuous measure such as the speed measures given by the radar, the coincidence between the interval of measures of the sample and that of the population) of the sample itself. So before the statistical analysis it is necessary a study of the range of validity of the outcomes. Tab. 3 summarizes the features of the available data; all the measures concerns the class of cars (see [1]), for which are valid the outcomes described in the following.

Source	Observations (no.)	Minimum (dm)	Maximum (dm)
Radar	50	33	52
Camera	50	33.40	49.10

Tab. 3 – Characteristics of the sample used for analysis of length measures in "ideal" conditions

When measures are made through devices which function in a correct way, errors are stochastic and, as a consequence, tend to distribute in a normal way. The Kolmogorov-Smirnov test (Garson, n.a.) does not show significant differences between the distribution of e_l and the normal distribution. This outcome allows ruling out an abnormal functioning of the radar within the calibration speed range.

An important characteristic required to measure instruments is linearity, that is a (positive and) linear relationship between measures and true values (Figliola & Beasley, 2006). The regression of radar lengths against actual lengths (whose results are given in tab. 4) highlights a weak association between length measures and true values (Pearson's correlation R = 0.398), as it could be expected given the high value of $e_l\%$ declared by the manufacturer; this means that the device is not reliable in detecting actual length but it can be used only for vehicle classification. Moreover, it can be noted that the model includes a significant positive constant, circumstance which suggest a possible zero error and so a bias of measures.

Dependent: radar length				
$R^2 = 0.158$ (R = 0.398)		Significance of R^2 difference = 0.004		
	Coefficient	Std error	t	Sig.
Constant	26.609 dm	5.725 dm	4.648	.000
Actual length	0.412	0.137	3.005	.004

Tab. 4 – Regression analysis of radar length vs. actual length

From tab. 5, it derives that

$$e_l\% = [(4.52 \pm 2.87) \pm 20.27]\% \quad (\mathrm{p} = 95\%)$$

The confidence interval at 95% for mean of $e_l\%$ do not include 0 and so it shows the presence of a bias, conclusion confirmed by M-estimators (see [2]), not shown for the sake of brevity.

		e_l		$e_l\%$	
		Statistics	Std error	Statistics	Std error
Mean		2.1940	0.62688	4.52	1.433
95% CI for mean	Max	0.9342		1.64	
	Min	3.4538		7.40	
Std deviation		4.43274		10.135	
Min		-9.00		-27	
Max		13.70		29	

Tab. 5 – Parameters of populations of length errors

Finally, to assess the reliability of measures, the trustworthiness of the manufacturer declaration on precision has been evaluated. To this aim, the proportions of errors greater and smaller than 20% (absolute value) in the sample have been compared with binomial distributions (see [3]) with different percentages of values "within 20%" and "beyond 20%". The partition of the sample between "measures with $e_l\% \leq 20\%$" and "measures with $e_l\% > 20\%$" is consistent at 95% of confidence with a binomial distribution in which the first kind of measures are 99%. As a consequence, it can be taken for granted an accuracy equal to that given in the radar manual.

4.3 Changes in measure errors

The radar producer dictates the ranges within the angle between the radar and the lane axis and for the distance between the device and the road edge must be included to have the accuracies reported in the manual, in particular affirming that an increase of the angle bring about a systematic decrease of the length and speed measure. As the evaluation of the length errors is suggested to check that the radar is correctly installed, it has been thought useful to assess the influence of deviations from the recommended values on the length measures.

To this aim, a different survey has been utilized, whose characteristics are summarized in tab. 6. The range of length analyzed is that of cars, the number of observations in each non empty cell is sufficient to draw significant conclusions.

			Angle (°) between radar and lane axes					Total
			15	27	30	33	45	
Distance (m) between radar and carriageway edge	0.7	Number of observations	29	49	93	42	29	242
		Min actual length observed	36.0	25.0	33.4	33.4	25.0	25.0
		Max actual length observed	48.4	47.7	49.2	49.2	47.7	49.2
	2.0	Number of observations	31		33		29	93
		Min actual length observed	25.0		33.4		25.0	25.0
		Max actual length observed	48.4		47.7		49.2	49.2
Total		Number of observations	60	49	126	42	58	335
		Min actual length observed	25.0	25.0	33.4	33.4	25.0	25.0
		Max actual length observed	48.4	47.7	49.2	49.2	49.2	49.2

Tab. 6 – Characteristics of the sample used for analysis of changes in errors

Tab. 7 shows a General Linear Model of the length relative error, built through sums of squares of the IV type, implemented in SPSS v. 14 for samples with empty cells. The sum of the η^2’s shows that the model explains 91.7% of the total variance of the sample, and so it reproduces the dependent quite well. All the three independents – distance, angle ad distance-angle interaction – are significant. η_p^2’s prove that the error variability is due predominantly to the angle. Outcomes are the same if, through the ω^2’s, the population instead of the sample is taken into consideration.

Dependent: length relative error						
Source	Type IV SoS	F	Sig.	η^{2a}	η_p^{2a}	ω^{2a}
Correct model^b	2053491.143	461.377	0.000			
Intercept	403243.449	0.164	0.686			
Distance	46679.624	15.771	0.000	0.004	0.046	0.004
Angle	1850415.901	803.512	0.000	0.904	0.908	0.902
Distance * Angle	97766.819	16.111	0.000	0.009	0.090	0.008
Error	160664.219					
Total	2449820.721					
Corrected total	2214155.362					

[a] See [4]

[b] R^2= 0,908, corrected R^2 = 0,906

Tab.7– General Linear Model of length relative error

The analysis of the expected marginal means (see fig. 4) shows that there are not significant differences between measures got with the instrument at 0.7m from the carriageway edge and those got at 2.0m, confirming that the predominant factor is the angle. As expected, the relative error decreases when the angle increases as a consequence of the measures given by the radar, being the same the average values of actual lengths.

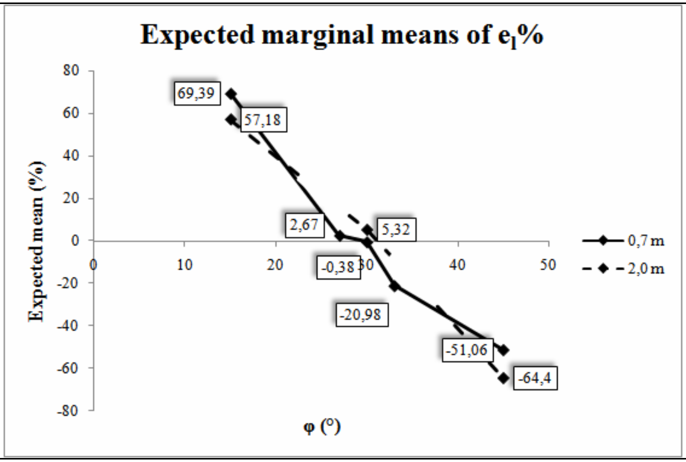

Fig. 4 – Expected relative length errors

In particular, one can see that small negative gaps from the recommended value of 30° do not result in significant difference in the errors; on the contrary, when the device is placed in position with angles slightly greater than 30°, differences between error means becomes significant and noteworthy. This can be partly explained by the functioning mechanism of radars, as it is shown with reference to speed measures for which formulas are simpler. Let

$$e_s\% = \text{relative speed error} = \frac{\text{radar speed - actual speed}}{\text{radar speed}} \cdot 100 \qquad \text{(Eq. 4)}$$

$$B[e_s\%]_{\Delta\varphi} = \text{bias component of } e_s\% \text{ due to the pointing error} \qquad \text{(Eq. 5)}$$

The vehicle speed is estimated with the hypothesis of a sensor pointing angle of 30°; if a pointing error Δφ is made; it turns out to be

$$B[e_s\%]_{\Delta\varphi} = \frac{\dfrac{V_{rad}}{\cos 30°} - \dfrac{V_{rad}}{\cos(30° + \Delta\varphi)}}{\dfrac{V_{rad}}{\cos 30°}} \cdot 100 = \left[1 - \frac{\cos 30°}{\cos(30° + \Delta\varphi)}\right] \cdot 100 \qquad \text{(Eq. 6)}$$

where Δφ is the error in pointing angle.

Fig. 5 plots eq. 6: it can be noted that

- the sign of $B[e_s]_{\Delta\varphi}$ changes with the sign of $\Delta\varphi$ as stated in the manual ($\Delta\varphi > 0$ implies $B[e_s]_{\Delta\varphi} < 0$];
- the rate of change of $B[e_s]_{\Delta\varphi}$ increases with $\Delta\varphi$. This implies that, given $|\Delta\varphi|$, $|B[e_s]_{\Delta\varphi}|$ for 30° + $|\Delta\varphi|$ is greater than for 30° - $|\Delta\varphi|$;
- as the trends of errors in speeds (analytically determined) and lengths (fig. 5) are similar, the suggestion of calibrating the device looking at length measures appears to be right, even though this conclusion needs to be checked with a thorough study of speed measures.

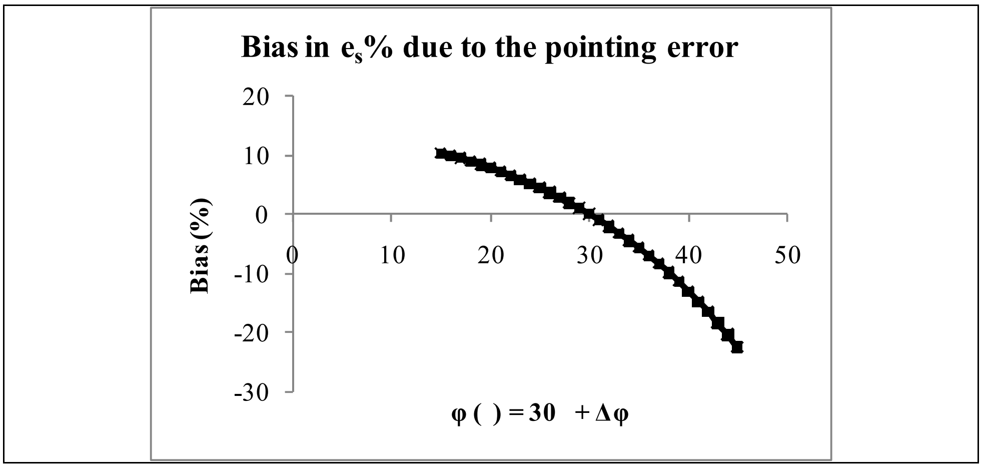

Fig. 5 – Percent error with respect to the sensor pointing angle

To sum up, it can be concluded that, installing the device, it is crucial avoiding gross errors in evaluating the angle and it is better making mistakes by shortcoming than by excess.

5. CONCLUSIONS

Radar detectors are among the most economic and handy devices used for traffic survey. But data provided by manufacturers on installation procedures, technical features and measure accuracy are often poor and not very precise, in any case not suitable for research purposes. To face this problem, an experimental survey has been carried out at Polytechnic University of Bari to know the actual accuracy of measures given by such detectors.

Initially, the accuracy of length measures in "ideal" installation conditions has been evaluated, by comparing the radar measures with those declared by cars' manufacturers. As a first result, a procedure has been set up that must be followed for analyzing data. It consists of three steps:

- excluding faulty or abnormal functioning of the device, studying the linearity between actual and reported values and the normality of error distributions;

- calculating the parameters of the distributions of total and relative errors, to assess bias and precision;
- verifying the reliability of the measure device.

It turned out that, even following very closely the installation procedure suggested by manuals, it is very difficult to avoid bias in length measures and that the precision of the length measure can be assumed equal to ±20% (the value reported in the manual) with a confidence of 95%.

Then it has been studied the influence on the measures (of length) of the parameters which can vary during installation: distance of the detector from the carriageway edge and the angle with the traffic flow direction. The latter has a significant and noteworthy impact on the quality of measures, while distance is less important. Moreover, it has been found that also small deviations from the suggested angle (30°) give rise to significant increase in errors if the angle is slightly greater than the recommended one; on the contrary the influence of small negative deviations is quite negligible.

The manufacturer suggests to verify the installation through an evaluation of the length measure errors. Errors in speeds (analytically determined) and lengths (from survey) show similar trends; this would seem to point out that the proposed procedure is right. Anyway the issue will be further investigated when data on speeds will be available.

ENDNOTES

[1] The software provided with device classifies vehicles in four classes, according to their length: 0-30 dm motorcycles, 31-55 dm cars, 56-95 dm heavy vehicles, 96-255 dm long heavy vehicles.

[2] M-estimators (HUBER, 1964) are a generalization of the maximum likelihood estimators and provide robust estimates of the mean value of the population, i.e. estimates valid also when the model hypothesized for the population (for errors, the normal distribution) is only approximately corresponding to actual one.

[3] Given a population made up of elements E and non-E, in percentages equal respectively to p% and (1-p)%, the probability to get m times the value E in n independent experiments id given by the binomial or Bernoulli distribution.

[4] η^2 is percentage of total variance in the dependent explained by the variance between the categories of the independent; it has the meaning of R^2 in linear regressions; η^2 depends on the number of independent variables and on their magnitudes. η_p^2 is a coefficient with a meaning analogous to η^2, but is defined in such a way that is not depending on the other independent variable; it has the fault of not being additive. ω^2 is an estimate of the variance explained by the independent variable in the population (Kirk, 1982; Tabachnick, 1989).

REFERENCES

AASHTO (1992) – *Guidelines for Traffic Data Programs* – America Association of State Highway and State Officials, Washington, DC, USA.

BUSCH, F. (2004) - *Detector Test Combination Detector ASIM TT 295 - Final Report* – Technischen Universität München, Munich, Germany.

ELENA Y MIMBELA, L., KLEIN, L. A. (2003) – *A Summary of Vehicle Detection and Surveillance Technologies used in Intelligent Transportation Systems* – New

FHWA (2001) – *Traffic Monitoring Guide* - Federal Highway Administration, Washington, DC, USA.

FHWA, US DOT, MINNESOTA DOT (2001) – *Evaluation of non-intrusive technologies for traffic detection.*

FIGLIOLA, R. S., BEASLEY D. E. (2006) – *Theory and Design for Mechanical Measurements, 4th edition* – Wiley.

GARSON, G. D. (n.d.) – *Topics in Multivariate Analysis*. Retrieved 01/02/2007 from http://www2.chass.ncsu.edu/garson/pa765/statnote.htm.

GILLMANN, R. (2007) – "Accuracy Assessment of Traffic Monitoring Devices Vehicle by Vehicle" – *Transportation Research Record,* 1945.

HARVEY, B.A., CHAMPION, G. H., RITCHIE, S. M., RUBY, C.D. (1995) – *Accuracy of Traffic Monitoring Equipment* – Georgia Institute of Technology, Atlanta, USA. Available at www.fhwa.dot.gov/ohim/atme/atme.htm.

HUBER, P. J. (1964) – "Robust estimation of a location parameter" – *Annals of Mathematical Statistics*, 35, pp. 73-101.

KELL, J. H., FULLERTON, I.J., MILLS M. K. (1990) – *Traffic Detector Handbook* – US Federal Highway Administration, Washington, DC, USA.

KIRK, R. E. (1982) – *Procedures for the behavioural sciences, 2nd edition* – brooks/Cole, Belmont, CA, USA.

MARTIN, P. T., XIAODONG WANG, Y. F. (2003) - *Detector Technology Evaluation* – Mountain Plains Consortium, University of Utah, Utah, USA. Available at www.mountain-plains.org/pubs/pdf/MPC03-154.pdf.

MIDDLETON, D., JASEK, D., PARKER, R (1999) – *Evaluation of Some Existing Technologies for Vehicle Detection, Project Summary Report 1715-S* – Texas Transportation Institute, TX, USA.

SKSZEK, S. L. (2001) - *"State of the Art" Report on Non-Traditional Traffic Counting Methods* – Federal Highway Administration, Washington, DC, USA.

TABACHNICK, B. G., FIDELL, L. S. (1989) – *Using multivariate statistics, 2nd* – Harper & Row, New York, USA.

TAYLOR, J. R. (2000) – *Introduzione all'analisi degli errori : lo studio delle incertezze nelle misure fisiche* – Zanichelli, Bologna, Italy.