VPL Project’09: an Integrated Station for Vehicles' Operating Conditions Survey

Cantisani Giuseppe⁎, Michele Di Vito⁎, Paolo Luteri⁎

⁎University of Roma La Sapienza, Department of Civil & Environmental Engineering - Eudossiana 18, 00184 Rome, Italy

Abstract

The study of relationships between characteristics of infrastructure and road user behavior cannot be accomplished exclusively by means of laboratory work, so real data acquisition becomes necessary. This research is finalized to realize a survey device, the VPL station, specifically designed to measure and store the operating parameters (speed, position and length) of transiting vehicles on sections of rural roads. The hiding techniques used for VPL station installation make it undetectable by users, so modifications in driving behavior are prevented. These solutions and the used technologies make the VPL station an useful tool available to the analysts for rapid surveys.

© 2012 The Authors. Published by Elsevier Ltd. Selection and/or peer-review under responsibility of SIIV2012 Scientific Committee

Keywords: Speed measurement; Vehicle’s monitoring station; Operating conditions survey.

1. Introduction

The increasing number of fatalities on road networks and the great sensitivity to related problems stimulate the study on this phenomenon and the identification of its major causes. Several research groups [1], [2], [3] studied the relationship between road safety and characteristics of infrastructure to find correlations or laws which allow a direct evaluation of safety. These researches outlined two different approaches having as input data different parameters and obtaining different final considerations: Road Safety Audit (or Review) procedures, [4], [5], and Design Consistency Theory [6]. Road Safety Audit/Review process evaluates the road safety related to the whole road characteristics, such as road equipment, road signs, geometric and structural characteristics of infrastructure. This method assigns a safety level to the analysed infrastructure as an output of an assessment process that includes also a direct investigation on the road.

The Design Consistency theory, instead, determines the road safety indirectly by means of a modelling and an analysis of road users’ behaviour. The evaluation of road geometry consistency considers speeds performed by

⁎ Corresponding author. Tel.: +39-06-44585-117; fax: +39-06-44585-121.
E-mail address: giuseppe.cantisani@uniroma1.it
road users depending on road characteristics. Lamm studies, since 1988, have focused the Operative Speed as the most important greatness to evaluate the road design consistency. This speed represents the road users’ behaviour in relation to road features. The scientific community associates the Operative Speed to the 85th percentile of speeds operated by each user. The 85th percentile speed is obtained by means of predictive models based on experimental speed measurements and it is related to the main characteristics of the road.

For both kinds of described analysis the experimental data about users’ behaviour are necessary, in order to obtain the statistical models able to represent the traffic flow operating conditions.

1.1. Modeling drivers’ behavior

Many international research groups have developed various predictive models of speed characterized by different level of accuracy and reliability. These models are determined in two distinct phases: in the first phase the users’ speed is measured directly on road tracks, while in second phase the acquired data are analysed by means of statistical methods. This statistical analysis provides a mathematical regression form of speed distribution as a result of an optimization process that calibrates the coefficients’ values. The obtained model is suited only to roads that have the same characteristics of the observed one. The literature models are mainly referred to extra-urban roads characterized by single carriageway, named Rural Roads, also because on these roads occurs the highest number of accidents.

The traditional predictive models are related to the characteristics of horizontal elements by means of geometric parameters like Curvature Change Rate (CCR), curvature Radius ($R$), or Degree of Curve ($DC$) [1], [2], [3]. However, several research groups are working on development and calibration of predictive models that consider, in addition, the characteristics of tangents, vertical elements and cross road section. Often, the development process of these models (data analysis, regression and calibration) allows their application only for limited intervals of input parameters.

Lamm Criteria evaluate the Road Design Consistency through kinematic data, comparing the speed variations due to horizontal characteristic of the road to a set of limit values.

1.2. Study purposes

As mentioned before, models and their parameters of calibration are closely related to the characteristics of road for which the model was made. Therefore, the calibration parameters have to be modified in order to analyse a road not similar to those represented by existing literature models. For very different conditions, the realization of a new model is required and an experimental phase concerning the measurement of drivers’ speeds is necessary. A monitoring system is required in order to observe automatically the characteristics of traffic flow and, for this reason, the reliability of these systems is very important for all research topics referred to drivers’ behavior. In this study a new integrated survey station is presented to perform speed measurement in specific planned condition. The survey station, named VPL Project ’09, is designed and realized specifically to observe the kinematic parameters of traffic flows. In particular, this system allows to measure speeds and to identify vehicle classes without any influence on road users’ behaviour. The absence of influence on drivers’ behaviour is obtained by means of particular solutions ideated and used to hide instrumentation to drivers’ sight. These solutions are detailed in the description on operational conditions explained in the following section.

The purpose of the VPL Project ’09 realization is to build a device suitable to observe traffic flows with the following requirements: 1) small dimensions; 2) easy transport; 3) ease of installation in-situ; 4) no interferences with drivers’ behaviour or infrastructure operation; 5) low costs of production and maintenance; 6) long operating life; 7) high performance in of data process and storage; 8) easy post-processing of data; 9) self-designed firmware. In fact, the common monitoring stations are not totally useful or adequate for proposed aims, as described in the following section.
2. Monitoring systems

The technologies ordinarily used to acquire traffic flow characteristics are numerous and based on different approaches. The equipment of survey stations changes in relation to the purposes of monitoring that define requirements of instrumentation. All monitoring systems for vehicular traffic are constituted by the same structure of the information flow. The information starts from detection sensors and reaches the processing and storage unit through the transmission and the address of data. Some parameters like the duration of surveys and the number and type of variables to collect influence directly the choice of monitoring technology. The need to hide the surveying instrumentation to drivers’ sight has a special influence in the choice of sensors. In fact, stations recognizable by users do not alter the measured data and their reliability when the purpose of research is identification or quantification of vehicle flows. Instead, it is important to realize a survey station undetectable by drivers in order to observe the speed distribution of the traffic flow or other similar parameters concerning drivers’ behavior. The alteration of drivers’ behavior has different significance in relation to driving context, especially with regards to the Nation where the operating parameters are observed.

2.1. State of the art

The monitoring techniques are very different thanks to the large variety of technologies offered by industry. A first classification of existing techniques may be related to the automatism in acquiring data and consequently on the basis of the need of an operator during the monitoring phase. Generally, manual measurements are excluded because they require a continuous intervention of an operator; for this reason, manual measurements are only used for observations that have a short duration, because of the costs, the fatigue of human observer and the consequent risk of mistakes.

The automatic systems are constituted always by four main components: a detector, an interpreter, a recorder and a data processor. The detector should be sensitive to measured parameters (vehicular flow, vehicle speed, etc.) and it should generate a signal for each measure. The interpreter (CPU) receives and decodes signals and the obtained information are transmitted to recorder for data storage. The data can be processed in real time or in a post-processing phase.

Below are listed the most used technologies, categorized on two different types of sensor installation. The main common features for each technique are represented by different icons for a better summarization and a faster comparison. The meaning of each icon is described in Table 1. Systems based on Intrusive Technology are listed in Table 2 and systems based on Non-Intrusive Technology are listed in Table 3 and Table 4. Both technologies allow to achieve automatically kinematic data of traffic flows, with greater or lesser precision depending on sensor type. However, each technology is provided with a short note that explains the specific additional features.

Table 1. Legend of symbols.

| Icon | Description |
|------|-------------|
| 🔴 | Speed measurement; |
| 🔴 | High precision measurement; |
| 🔴 | Complex installation; |
| 🔴 | Multilane road not analysed; |
| 🔴 | Simple installation; |
| 🔴 | Malfunctions create dangerous situations; |
| 🔴 | Measure of time interval between vehicles; |
| 🔴 | Measure of vehicle’s transversal position; |
| 🔴 | Infrastructure interventions on installation; |
| 🔴 | Low efficiency with high volume traffic; |
| 🔴 | Installation requires traffic interruption; |
| 🔴 | Vehicle class determination; |
| 🔴 | Vehicle wheelbase measurement; |
| 🔴 | Intrinsic fragility of the system; |
| 🔴 | Multi-axial vehicle not analysed; |
| 🔴 | Low efficiency with bad weather condition; |
| 🔴 | Low/Medium/High autonomy and electrical power supply; |
| 🔴 | Low/Medium/High installation costs; |
| 🔴 | Low/Medium/High operating costs. |
The principle of this detection system is to ensure that a receiver perceives the energy from a source and evaluate information resulting from obstruction of ray. These sensors are quite cheap and provide reliable results only if carefully designed in relation to operating conditions.

Table 4. AIR + Laser - Active Infrared sensor and Laser.

Source and detector are mounted on opposite sides from expected detection point. In this case, detection occurs when the object stops energy flow between source and detector. This operation mode requires extreme precision in arrangement of transmitting and receiving units, with a potential inherent difficulty of the survey. Failure reflection of the ray is wrongly interpreted as presence of a vehicle.
Retro-reflective photocell
The source and receiver functions are coupled and reside on the same side in comparison to expected detection point, saving space for installation and wiring. A reflector with mirroring prismatic surface reflects the emitted energy. The installation requires extreme precision in arrangement of reflector unit, vibrations or dirty surface can avoid the correct operation of sensor. Failure reflection of the ray is wrongly interpreted as presence of a vehicle.

Reflex photocell
The operating mechanism is similar to reflection photocell, but the directly reflection of light beam by object making unnecessary the use of a reflector. Detection occurs when a sufficient proportion of energy is reflected from object reaching the receiver. The installation is very easy and reliable. A missed reflection of beam is not interpreted as a transition vehicle, but the vehicle data is simply lost. A non-reflection of the rays is possible if the vehicle surface is dirty, dark or particularly tilted in comparison to bright ray.

Defined reflex photocell
The basic structure and detection mechanism is the same of reflex model, but, in this case, the beam source and detector field of view are focused on a common point. Therefore, the object must be in a specific position to reflect enough light to receiver. This method, without the use of reflective, guarantees the highest precision and the widest range. This type of photocell keeps all the advantages of reflex photocell.

3. The VPL Project '09

3.1. General description

Starting from the review of existing monitoring equipment, the authors considered that technologies and devices actually available are not completely compliant for the general purposes of their research aims regarding operating conditions. Therefore, they decided to develop and realize a new monitoring station. This new device was expressly designed for the research purposes with a specific focus on the main advantages of various existing technologies and combining the disjointed strengths. So, the VPL Project '09 is designed to monitor traffic flow on Rural Roads in order to define a predictive model of operating speed. As said, this purpose needs a study of the correlation between characteristics of road and related speed of drivers. This correlation must be referred to a specific operating status, named free flow speed condition, according to the HCM definition. In particular some specific conditions are required: isolated passenger vehicles (spaced of at least 5 seconds), marked and paved roadways, no intersections near the monitored road section, longitudinal grades ≤5%. The recognition of road geometry must be guaranteed; therefore the measuring station is designed to operate in daylight conditions with optimal visibility. In order to limit the cost of hardware and to simplify the elaboration of acquired data, the design of VPL Project '09 is finalized to monitor just one lane of a rural road.

The VPL Project '09, described in Table 5, employs a couple of infrared beams placed perpendicularly to traffic flow. These beams can detect the typology of transiting vehicles without any intervention of operator. The reflection of infrared beams by the vehicles’ lateral surface is perceived by system and it allows to calculate the vehicular flow attributes. The chosen sensors are two reflex photocells, which have an operative range about of 2.6 meters; in this way their installation is allowed on the right roadside and their beams are reflected by vehicles’ side, so preventing errors due to optical overlapping of vehicles in the opposite lane [7] [16].

Table 5 - VPL Project '09

A couple of infrared beams allows to measure speed and length of each vehicle transiting on the monitored lane, while a third sensor measures their distance from the VPL station. The recorded data give information about time interval between following vehicles.
For each vehicle the system measures speed, length and delay time from previous transiting vehicle in order to determine the vehicular flow condition, free or not. Moreover, the device is equipped with another infrared distance sensor which determines the vehicle’s transversal position in the lane; unfortunately, at present, the infrared sensor showed to be not so reliable for this particular function and some further adjustments will be adopted, probably by replacing the sensor with an ultrasonic one. During the monitoring process, all traffic data are recorded and stored by the appliance on a Secure Digital (SD) card. Therefore, using a common PC, it is possible to acquire further information such as the density of the vehicular flow and to establish a relationship between observed speed and other parameters (vehicle length, road characteristics). The main original characteristics of the survey station and its possible advantages are detailed below.

3.1.1. A non-intrusive technology-based system

The VPL Project’09 contains both sensors and elaboration unit. Many of commercial monitoring systems are based on invasive technologies (pneumatic tubing, inductive loops) or they alter road users’ behaviour, mainly because their appearance is similar to enforcing equipment used by police. Systems based on photoelectric sensors have good performances with a limited interference with road users and the infrastructure; therefore, the VPL Project’09 includes two infrared sensors, cheaper than laser sensors but accurate enough for purposes of this research. The operating arrangement is similar to other commercial devices, but it does not interfere with road users and infrastructure thanks to original hiding solutions that make it undetectable.

4. Hardware components

The core of system is a Programmable Interface Controller (PIC) which handles and elaborates the signals coming from the infrared sensors. This type of microprocessor guarantees low cost, wide availability, large user base, extensive collection of application notes, availability of low cost or free development tools and serial programming capability. After the elaboration of signals, all data processed by the PIC are stored in a SD card for a subsequent post processing phase on a PC. This solution guarantees an intrinsic stability of system because each operating condition is managed by the unit, therefore, it can be defined a “self-governing” system.

The development process of monitoring system has been various steps; in the final configuration the system is composed by two principal units: a brain unit and an eye unit.

The brain unit, Fig.1 (a), is a small PVC box containing the following elements: PIC microcontroller prototyping board with USB connector and a SD/MMC card slot, 1.2Ah-12V battery, 16x2 LCD display, electrical board for charging the battery from a 230V power input, connectors for external sensors and other electrical components to manage the power of the internal circuits, see Fig.1 (b).

![Fig. 1. (a) Brain unit; (b) Components of the monitoring station.](image-url)
The PIC board installed into the unit handles and elaborates signals coming from sensors and, at the end, it puts the elaborated data in the SD card. The LCD display shows the information about the state of process. This brain unit has dimension 19×11×6 cm and a weight of 800g. The assembly steps of brain unit are represented in Fig.2 (a). The eye unit, Fig. 2 (b), is a one meter long aluminum bar with two photocells and distance sensor installed at the ends. The eye unit is realized with high precision process. The sensors are fixed with various screws at the opposite ends of the aluminum bar. This operation is made with care because an imprecision on beams parallelism produces a direct effect on measured value and on reliability of the system. The eye unit must be installed on the roadside, as described below.

4.1. Firmware

The design environment used to create the firmware is MPLAB IDE Microchip. In fact, the programming software must be compatible with the processor on microcontroller board, the Microchip PIC18f4550. This software is freeware and it includes an integrated toolset for the development of embedded applications. MPLAB C Compiler is the language used to program the PIC18 MCUs. This software, also known as MPLAB C18, is a full-featured C compiler for the PIC18 family and it is ANSI compliant. The MPLAB C18 is used as integration of MPLAB IDE because of it allows a source-level debugging and its project management is easy to use.

To program a PIC microcontroller usually is used an external development board; instead, the PIC18f4550 used in VPL project’09 is integrated on a dedicated board and it comes pre-loaded with a USB bootloader. In other words, the PIC has a small section of programmable memory where the firmware for the bootload is allocated. Thanks to this boot block the PIC18F4550 can be re-programmed without an external programmer.

4.1.1. Firmware planning.

The firmware is designed through different development phases. The first step is the graphical schematization of all the logical procedures concerning acquisition and elaboration of the data. The drawn flow chart is useful to translate the logical procedures in the programming code. The work activities of VPL system is summarized in five main groups of operations: 1) get information from sensors; 2) check received information; 3) calculate characteristics of vehicular flow; 4) save data in flash memory buffer; 5) store the data in the SD card once the buffer is full and clear it. The most important group of operations is the check of information obtained from sensors. In fact, the sensitivity of the photocells depends on characteristics of reflecting surfaces or rather the bodyworks of vehicles. In particular, some small parts of vehicles' bodywork cannot reflect back the light to the receiver sensor because of the presence of plastic parts, rough elements, dark colour targets or dirty surfaces. So the perception of a vehicle could be not continuous and consequently it is difficult to obtain its real length; this problem occurs also using some commercial systems based on the same technology.

The discontinuous perception of vehicle’s side could be interpreted by the PIC as the passage of another near vehicles. In fact, the first sensor generates a rising edge in the info voltage when it perceives a vehicle and it
generates a falling edge in voltage when the reflection ends. It is important that the PIC does not associate a new vehicle to every rising edge event, but it is impossible to distinguish if the falling edge is caused by the end of vehicle or by an interruption of reflection. To solve this problem some hypotheses were introduced about the minimum time delay between two consecutive vehicles. This minimum time value is compared with the time interval between two consecutive rising edge to deduce if the last one is caused by some unreflecting parts of the first vehicle or by another vehicle. The minimum time delay between two consecutive vehicles has been related to speed calculated by the firsts rising events and to a typical length of a passenger car, 4.5 meters. The speed is calculated by means of the time interval between the first rising edges of the two photocells and the physical distance between their beams axis. In this way the system calibrates itself and the processor does not calculate the vehicle speed for every rising edge coming from the second sensor.

4.1.2. Microcontroller program - operating frequency.

As explained in the previous paragraph the VPL computation depends on the voltage of sensors that represents the state of infrared beams. The firmware uses the peripheral interrupt sources of the PIC18f4550 to perceive the signals of sensors, while various software interrupts are implemented as instructions in the instruction set. The processor saves its state and it begins the execution of an interrupt handler when it occurs. PIC18 devices have two interrupt vectors with different priority. The high priority vector sources can interrupt low priority ones, whereas low priority interrupts are not processed while high priority one is in progress.

High priority interrupt is connected to overflow of internal counter of processor. The CPU has a maximum operating speed of 48MHz and it makes one operation every 4 clock hits. Setting the main internal timer of the PIC to 8 bit frequency and using a prescaler of 128 with an initial value of 209, the PIC controls the state of photocells about every half of millisecond (0.000501s), as calculated in (1).

\[
\frac{128_{\text{prescaler}} \cdot 4 \cdot (256_{\text{timer\ overflow}} - 209_{\text{timer\ initial\ value}})}{48MHz_{\text{operating\ speed}}} = 501.3 \ \mu s
\] (1)

The state of photocells is defined with an error of 0.001sec, in fact, the sensors have a switching frequency of 1000Hz and the microprocessor verifies their state every half of millisecond.

5. Operational conditions

5.1. Installation features

The major innovative feature of the VPL Project ‘09 is the easy installation. The eye unit is studied to obtain an easy installation on every roadsides configuration in Italian context. There are two possible schemes of installation, depending on the presence of a safety barrier on the roadside. If a W-beam guardrail is present, it is sufficient to lean the eye unit into the wave of the barrier. In fact, some magnets are present on the rear side of the bar and they fasten it onto the metallic surface of guardrail. The brain unit can be hidden easily behind the barrier post where the operator can control the work in progress. If there is no barrier on the roadside the eye unit can be fixed into a common mobile barrier, a new jersey of polyethylene (PE). This element was modified to mount the bar and to allow the monitoring by sensors, see Fig. 3.

The brain unit is put into the barrier through an opening in the rear side. The PE new-jersey has small dimension (100×70×40 cm) and a weight of about 8kg, so it can be easily carried in a car.

The LCD display shows the state of the monitoring activity at detection of each vehicle and it provides various information such as total number of vehicles; in particular, a count of vehicles in free flow conditions is displayed. The retro-illumination of display allows to read monitoring information in low light condition. The retro-illumination is controlled by a switch, so it is possible to power on the led just in case of necessity, without wasting energy.
Roadside requirements: The VPL can be adapted to various roadside configurations but the parallelism between road surface and the infrared beams of the sensors must be guaranteed. This requirement is necessary to allow a correct interception of vehicles by the sensors, see Fig. 4. To obtain the parallelism in PE new-jersey configuration, the roadside surface should be parallel to the carriage surface, on the contrary some adjustment has to be applied under the barrier.

The monitoring station can be positioned both on the right and on the left roadside just inverting the connection order of sensors with the brain unit. As explained before, the VPL Project’09 is designed to monitor the traffic flow on rural roads on one lane at a time. It is possible also to use it for the traffic counts in the intersection, so obtaining useful informations for theoretical and functional models [16] [17] [18].

5.2. Operational features

The installation of VPL station is very easy thanks to the little dimensions of device. In PE new-jersey configuration only two minutes are required, while the installation on guardrail is even faster. After installation the operator has to power on the brain unit and to insert the SD card in the slot, in this way the monitoring process starts. During the survey the VPL device absorbs about 200mAh, so, with the installed rechargeable battery of 12V-1200mAh, an operating time of 6 hours is guaranteed. Anyway, the battery is rechargeable and the charger board installed in the device allows to charge it. Using a specific connector on the brain unit case it is possible to charge the battery with the 230V AC domestic power supply. Furthermore, the diffusion of 12V power supply allows to use the device with different power sources.

In the VPL prototype the storage device is a 32MB SD memory card that has an available memory space of 30,866,928 bytes. For each vehicle the VPL stores in the card 20 bytes of data; the stored data are speed, length, transversal position in the lane, delay time from the previous vehicle and information about the flow condition. Therefore, with a continuous power supply, the VPL can store the data of 1,543,346 vehicles that is a high storing capacity. The data are stored in a csv file with an appending process, so, each new data is appended into a starting file previously put in the card. After the monitoring, the csv file can be opened with a PC and data can be processed by any commercial software like Microsoft Excel, MatLAB or any text editor.
5.2.1. Weather condition requirements

The system is designed to operate in good weather conditions, as explained. For this reason, the VPL has not been tested in presence of fog, rain or snow, also because the features of sensors advise against to work in these conditions. However, VPL can operate in every light condition because the response of sensors depends only on target colour.

VPL station is designed to measure free flow speed for temporary use under dry weather conditions. The limited time of survey due to the mobility of the station allows to maintain photocells clean, thanks to simple routine maintenance.

6. Test Campaign

6.1. Environmental conditions

VPL Project’09 has been tested in the area around the city of Rome. Various road sections on two-lane rural roads were selected. Each section has good pavement with marked lines, little longitudinal grade and no intersections are present nearly the section. The selected roads have low traffic volume and drivers are familiar with the road. Furthermore, there are no obstructions to traffic flow (uninterrupted-flow facilities) and each road section has been monitored in good weather conditions. Therefore, free flow speed condition has been guaranteed during the tests and drivers’ behaviour depends only on geometric and environmental characteristics of the road.

6.2. Data acquisition

The test has been performed on 21 different sections of Two-Lane Rural roads. The VPL station has worked for a total time of about 24 hours and it has detected about 3200 vehicles. The large number of acquired data and the short time needed for surveys confirm that VPL Project’09 is a suitable tool for the analysts.

6.3. Diagrams of results

The acquired data have been analysed by means of statistical methods; cumulative distribution function and probability density function of observed speeds have been calculated and they are showed in Fig. 5 and Fig. 6.

For each section the operative speeds have been determined. Graphical representations show the results of this analyses for one section of road and it is possible to appreciate the major concentration of data near the average speed value. In Fig. 7, instead, speed data are related to monitored vehicles’ lengths. This representation shows the greatest number of passenger cars and the highest speed values associated with this kind of vehicle.

---

**Fig. 5. Cumulative distribution function of observed speeds.**
7. Conclusions

The presented research starts from the study of safety theories related to road infrastructures that consider the speeds of drivers and the corresponding correlation with road characteristics. For these studies, generally a preliminary experimental phase is needed to acquire the drivers’ speeds in real context and to determine the predictive models by means of a statistical regression of them. For these purposes, a new survey station, the VPL Project’09, was designed to acquire the drivers’ speeds in specific road contexts. In fact, the VPL station was designed after a comparison about characteristics of common monitoring technologies and their suitability to achieve the conventional parameters used for safety evaluations.

The VPL Project’09 has many of the advantages of non-intrusive technologies and it has low construction and operating costs. The operating autonomy, the high storage capacity, the easy installation and the hiding solutions allow to obtain realistic values of monitored parameters, without any influence on drivers’ behaviour. The high accuracy of measures and the possibility to store directly the measuring data after a first elaboration make the VPL Project’09 a useful survey tool also for end-users not involved in realization of survey station.

The presented phase of research was mainly focused to obtain information about operating stability of new station. In fact it is most important to establish if different components can work fine together. The result of this test is that the sensor of distance didn’t work as expected and it will be replaced with an ultrasonic sensor. The quantitative comparison of data will be performed in the next step, comparing the information obtained by
surveys with the ones measured by existing fixed stations; also a specific study of accuracy and benchmarking of instrumentation will be made after the upgrading phase.

After the updating and the validation of VPL station, the final step will be to relate road characteristics to drivers’ behaviour.

References

[1] Gibreel, G. M., Easa, S. M., Hassan, Y., El-Dimeery, I. A. (1999). “State of the art of highway geometric design consistency”. Journal of transportation engineering.

[2] Lamm, R., Psarianos, B., Mailaender, T. (1999). “Highway design and traffic safety engineering handbook”. McGaw-Hill, New York, USA.

[3] Hassan, Y. (2004). “Highway Design Consistency: Refining the State of Knowledge and Practice.” Transportation Research Record: Journal of the Transportation Research Board, no 1881.

[4] Transit New Zealand (1993).

[5] Montella, A. (2005). “Safety Reviews of Existing Roads: Quantitative Safety Assessment Methodology”. Transportation research record n. 1922, pp. 62-72.

[6] Lamm, R., Choueiri, E. M., Hayward, J. C., Paluri, A. (1988). “Possible design procedures to promote design consistency in highway geometric design on two lane rural roads.” Transportation Research Record 1195, Washington D.C., pp. 111-122.

[7] Lee J. and Park B. B. (2012). “Determining Lane Use Distributions Using Basic Freeway Segment Density Measures”. Journal of Transportation Engineering, Vol. 137, No. 2, pp. 210-217.

[8] Coifman B. and SeoungBum K. (2009). “Speed estimation and length based vehicle classification from freeway single-loop detectors”. Transportation Research Part C: Emerging Technologies. vol. 17, issue 4, pp. 349-364.

[9] Soriguera F. and Robusté F. (2011). “Estimation of traffic stream space mean speed from time aggregations of double loop detector data”. Transportation Research Part C: Emerging Technologies. vol. 19, issue 1, pp. 115-129.

[10] Cinsdikici, M. G. and Memiş, K. (2010) “Traffic flow condition classification for short sections using single microwave sensor” EURASIP Journal on Advances in Signal Processing.

[11] “Highway Capacity Manual.” (2000). Transportation Research Board, Washington, D.C.

[12] Kai-Tai S., (2007) “Image-Based Traffic monitoring with shadow suppression”. Proceedings of the IEEE. vol. 95, issue 2, pp. 413 - 426.

[13] Laparmonpinyo, P., (2010). “A video-based traffic monitoring system based on the novel gradient-edge and detection window techniques”. Computer and Automation Engineering (ICCAE), The 2nd International Conference on.

[14] Dailey D. J., Cathey F. W., and Pumrin S., (2000). “An algorithm to estimate mean traffic speed using uncalibrated cameras” IEEE transactions on intelligent transportation systems, vol. 1, no. 2.

[15] Arbabi, H., (2011) “Monitoring free flow traffic using vehicular networks.” Consumer communications and networking conference (CCNC), 2011 IEEE.

[16] Cantisani, G., Loprencipe, G., & Primieri, F. (2012). The integrated design of urban road intersections: A case study. Paper presented at the ICSDC 2011: Integrating Sustainability Practices in the Construction Industry - Proceedings of the International Conference on Sustainable Design and Construction 2011, 722-728. Retrieved from www.scopus.com.

[17] Mauro, R., & Branco, F. (2010). Comparative analysis of compact multilane roundabouts and turbo-roundabouts. Journal of Transportation Engineering, 136(4), 316-322. Retrieved from www.scopus.com

[18] Mauro, R., & Cattani, M. (2004). Model to evaluate potential accident rate at roundabouts. Journal of Transportation Engineering, 130(5), 602-609. Retrieved from www.scopus.com

[19] Xinyong Zhao and Shi An, “Study on the Application of Interval Speed Monitoring Technology and Vehicle Track Pattern Confirming Technology in Road Network”. ASCE Highway Transportation, vol. I, pp. 91-96. Proc. doi:http://dx.doi.org/10.1061/41177(415)12.

[20] Sensors Image - PT - http://www.bikecommuters.com/2009/11/10/make-it-count/

[21] Sensors Image - IL - http://www.josephdecarlo.com/author/jdecarlo/page/3/

[22] Sensors Image - TC - http://www.uniroma2.it/didattica/TTC/

[23] Sensors Image - VM1 -http://www.enterpriseflasher.com/prod-weather-nc-100.php

[24] Sensors Image - MR -http://www.fardata.eu/static/show/Wavetronix/id=41

[25] Sensors Image - PIR - http://www.mountain-plains.org/pubs/html/mpc-03-154/p2.php

[26] Sensors Image - AIR - http://www.pyramidtiming.com/PSTphotocells.htm

[27] Sensors Image - AIR - http://www.ifm-electronic.com/ifmit/web/dsfs/O4H501.html

[28] Sensors Image - AVIP - http://www.treehugger.com/traffic-monitorint-computer.jpg