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Implementation of camera based speed management in India

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Abstract

Over the last decade, road infrastructure in India has improved significantly due to various initiatives taken up by the Government of India and various state governments. The upgraded roads have resulted in higher speed of vehicles in urban and rural areas, which invokes a need for speed management at some locations. In India, stand-alone speed limit signs are found ineffective due to several reasons such as bringing down the speed to a value below stipulated limit, restricting the speed during 24 hours a day whereas, in majority of locations, it is required only for a limited time, such as school zones. With this background, the paper deals with various aspects related to implementation of *speed management* using cameras, in lieu of physical measures, on Indian roads in order to overcome the disadvantages associated with physical measures for speed control and to ensure effective *enforcement*. The study specifically aims at identifying various parameters in installation of suitable speed camera in Indian context and then assessing the system using *AHP* (Analytical Hierarchy Process) on the identified factors of implementation, and *TOPSIS*S (Technique for Order Preference by Similarity to Ideal Solution) for evaluation of other parameters of implementation. It was found that, Fixed Speed Camera was the most suitable type of camera in Indian context and Long Tangents of Roads was the site, which inevitably required the installation of such system.

Keywords: speed management, enforcement, AHP, TOPSIS

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1. Introduction

The speed of vehicles on urban roads has become a matter of concern, as there are lot of accidents leading to fatalities. Around 1.25 million people die yearly, in road accidents world-wide and around 60% of the accidents are due to the over-speeding vehicles and India is second highest in terms of road accidents in a year after China (WHO, 2015). Also, several highways are passing through semi-urban areas and the pedestrian vehicular interaction is significant on these segments of roads. It is therefore, necessary to reduce the speed of motorized vehicles at several locations in order to reduce the road accidents in general and road fatalities in particular. Hence, speed managements should be a central element of any road safety strategy that takes into account the mobility, safety and environmental requirements. However, the available physical measures such as speed humps or rumble strips are found effective to bring down the speed to a much lower than the designated speed limit, due to inappropriate construction causing serious inconvenience to drivers and creating unwanted road bottlenecks and queues. Also, in majority of locations although the speed restriction is required only for a limited time (per se, only during school opening and closing hours, only during the period where roadside activities are present, etc.), physical measures unnecessarily restrict the speed during 24 hours in a day. With this background, the present work aims to investigate various aspects related to implementation of dynamic speed management using cameras (in lieu of physical measures) on Indian roads in order to overcome the disadvantages associated with physical measures for speed control and to ensure effective enforcement.

A speed camera system is not just an example of a technology; rather, according to Ropohl (1999), it is a complex socio-technical system in which human behavior, social organization, legislation, and technology interact with each other. According to several reviews, speed enforcement detection devices are promising interventions for reducing the number of road traffic injuries and deaths (Hoogerwerf, 1990; Elvik, 2004; Wilson, 2006).

According to the handbook of road safety measures (Elvik, 2004), speed cameras are found to effective in reducing the number of accidents by 17%. For the countries and jurisdictions, such as India, that have not yet implemented a speed camera program to a major extent, experience from other countries could be highly beneficial. Adaptation of an existing intervention that has already been tested would also appear to be an example of a scientific approach to road safety instead of implementing interventions which have not been evaluated (Mercy, 1993). There are several aspects which need to be understood before implementing such system such as, the type of speed camera to be implemented in context to Indian scenario and the selection of most important site for its implementation.

The paper presents some ideas underpinning the adoption of speed camera systems, such as the selection of suitable speed camera for Indian context and the most vulnerable location for its implementation in India. The paper deals with understanding the public perception towards most suitable speed management measure, analyzing various factors, by several statistical tools, affecting the selection of a speed camera and the location of its implementation using an online and paper-based survey.

The paper comprises of three major sections. The first section deals with giving a background of the statistical tools involved in the process of analyzing the factors involved and affecting the implementation of speed camera. The second section gives an idea of the survey design and the ways of collecting the data required for analysis. While the third section gives the results of analysis obtained by the statistical tools, followed by conclusion.

2. Theoretical Background of Statistical Tools Utilized

In the present work, AHP and TOPSIS are used for analyzing the idea behind implementation of speed camera in India. Although, these two tools are already explained and detailed in various literature, a brief outline of the two is documented below with relevance to the present work.

2.1 Analytic Hierarchy Process

AHP is a structured technique for organizing and analyzing complex decisions, based on mathematics and psychology. It was developed by Thomas L. Saaty in the 1970s and has been extensively studied and refined since then. Rather than prescribing a “correct” decision, the AHP helps decision makers find one that best suits their goal and their understanding of the problem (Saaty, 1990). It provides a comprehensive and rational framework for structuring a decision problem, for representing and quantifying its elements, for relating those elements to overall goals, and for evaluating alternative solutions. As discussed earlier, this is a three step process involving:

- Determination of pair-wise matrix

In this step, based on the response of all the respondents, an absolute comparative matrix is drawn by taking out aggregate of all the responses, termed as pair-wise matrix in AHP terminology.

- Determination of normalized value and principal vector

In this step, the normalized values of the ratings are obtained from the pair-wise matrix by dividing each column of the pair-wise matrix by the sum of the elements of the columns.

Following this, the principal vector is obtained by taking the average of all the elements in the row.

$$NVM(i,j) = \frac{PWM(i,j)}{\sum_{i=1}^{i=6} PWM(i,j)}, \quad (1)$$

$$PV(i) = \frac{\sum_{j=1}^{j=6} NVM(i,j)}{6}. \quad (2)$$

Where, NVM, PWM, and PV are normalized value matrix, pair-wise matrix, principal vector, i, j are the matrix indices.

- Consistency check

The final stage in AHP is to calculate a consistency ratio (CR) and consistency index (CI) to measure how consistent the judgments have been relative to large samples of purely random judgments. If the CR is greater than 0.1, the calculations are untrustworthy because they are too close for comfort to randomness and the exercise is valueless or must be repeated.

This is a two-step process as well, first process being calculation of maximum Eigen value which involves following equations.

$$\lambda_{max} = \max\left\{\frac{[PWM]\times[PV]}{[PV]}\right\}. \quad (3)$$

Where, λ_{max} is the maximum of the Eigen values.
The second step involves the calculation of actual CI and CR from the formulae stipulated below,

$$CR = \frac{CI}{RI}, \quad (4)$$

$$CI = \frac{\lambda_{max} - n}{n-1}. \quad (5)$$

Where RI is the Random Index, n is the number of factors, RI is 1.24 for n=6. If the CR value is found to be less than 0.1, it can be safely concluded that the analysis performed is consistent.

2.2 Technique for Order Preference by Similarity to Ideal Solution

The Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) is one of the suitable multi-attribute decision-making methods (Sadhukhan, 2016). Introduced by (Hwang, 1981) it is based on the concept that the chosen alternative should have the shortest geometric distance from the Positive Ideal Solution (PIS) and the longest geometric distance from the Negative Ideal Solution (NIS). It is a method of compensatory aggregation that compares a set of alternatives by identifying weights for each criterion, normalizing scores and calculating the geometric distance between each alternative and the ideal alternative, which is the best score in each criterion. Generally, the positive ideal solution is composed of all best values possible from the criteria, while the negative ideal solution consists of all worst values attainable from the criteria (Wang, 2016). The proximity to each of these performance poles is measured in the n-dimensional Euclidean sense. The method employed here follows the below steps:

- Formation of Decision Matrix (DM) and Normalized Matrix (NM)

The step basically deals with quantifying and categorizing the alternatives based on the importance selected by number of people. This step involves establishing the Decision Matrix (DM) obtained after collecting the responses by taking the mean of all the responses for a given alternative. In the next part, the elements of DM are normalized with respect to square root of sum of square of elements of DM as shown in following formula.

$$NM(i,j) = \frac{DM(i,j)}{\sqrt{\sum_{i=1}^{i=10} (NM(i,j))^2}}. \tag{9}$$

Where, *i, j* are matrix indices.

- Calculation of Positive Ideal Solution (PIS) and Negative Ideal Solution (NIS)

Determining the Positive Ideal Solution and the Negative Ideal Solution involves the Normalized Matrix as shown below.

$$A^*(i) = \begin{Bmatrix} \min(NM(1:10,j)) \\ \max(NM(1:10,j)) \end{Bmatrix} \begin{matrix} IL < 5 \\ IL \geq 5 \end{matrix}, \tag{10}$$

$$A^-(i) = \begin{Bmatrix} \max(NM(1:10,j)) \\ \min(NM(1:10,j)) \end{Bmatrix} \begin{matrix} IL < 5 \\ IL \geq 5 \end{matrix}. \tag{11}$$

Where, A*, A-, and IL are PIS, NIS and the importance level on the scale of 1-10 respectively.

- Calculating the separation measures from ideal and non-ideal solution

The next part of the TOPSIS analysis is based on calculating the geometric distance of each alternative from ideal solution and non-ideal solution as shown in the following formulae.

$$d_j^+(i) = \sqrt{\sum_{j=1}^{j=10} (A^*(i) - NM(i,j))^2}\ , \tag{12}$$

$$d_j^-(i) = \sqrt{\sum_{j=1}^{j=10} (A^-(i) - NM(i,j))^2}\ . \tag{13}$$

- Determining the closeness of each alternative from the ideal solution

The next step is ranking the available alternatives on the basis of their closeness from the ideal solution using the following formulation of closeness index.

$$C_j^+ = \frac{d_j^+}{d_j^+ + d_j^-}\ . \tag{14}$$

3. Design of Survey instrument and database development

The survey was designed in such a way that the ideas behind the implementation of speed camera, such as, the most suitable speed camera for Indian context and the best suitable location of its implementation, was explored. To understand this, two different type of survey was designed and the results were analyzed with two different tools respectively. For the development of database, the questionnaires was prepared and its components and feasibility were tested by doing a pilot survey, involving a group of trained people carrying out the paper based survey in the field and taking the responses from the road user who were familiar with available speed control measures and who actually experienced the need for an effective enforcement of speed and adoption of effective measures. The details of how the survey was done and the data was collected has been elaborated in the below section.

3.1. Evaluation of available speed measures and speed cameras

To carry out the evaluation of the most suitable speed monitoring measures in Indian context, the road users were randomly selected and asked about their awareness about the speed control measures used in India. Only upon their agreement to the participation and having experienced the need of effective speed control measures, their responses were duly noted. They were asked to rank the available speed measures viz. speed humps, rumble strips, speed limit post, police enforcement and the speed cameras, from 1-5. The rank was based on their perspective on the available speed management measures and the proposed camera based speed management measures. Out of 216 users asked, 74 respondents actually participated in the survey.

3.2. Selection of suitable speed camera in Indian context

There are several factors which play a pivotal role in deciding the camera system to be employed with reference to particular working condition, such as location, flexibility, cost-involved, effectiveness, immediacy in punishment and infrastructure provisions. These factors were identified on the basis of detailed literature review as well as discussions and consultation with the stake holders comprising of transportation expertise, administrative authority (mainly traffic police), pedestrians, and commuters.

A detailed survey questionnaire was prepared regarding the importance of the identified factors and a paper based survey was done on a group of twelve experts. The experts were asked to compare each factors with the other factor, giving them a score from 1-9, 1 being least important and 9 being the extreme important than the other factor. They were briefed about the factors as given in Table 1 and the way to compare their importance.

Table 1 Description of the identified factors for the survey

Identified Factors	Description for Survey
Location	It refers to the selection of most crucial location where the speed camera is to be implemented. In this case it may be sites with high crash history, an intersection, a school zone or a busy highway.
Flexibility	Flexibility is in context to the time period for which the camera is active or functional.
Cost-involved	Cost involved in the process of adopting and implementing the whole speed camera system.
Effectiveness	It refers to the technical capability of a type of camera, its advantage over another type of camera. Such as halo effect, visibility, data storage capacity etc.
Immediacy in Punishment	It refers to the time taken by the whole system to complete its adjudication and punishes the violator
Infrastructure Provisions	It refers to the enhancement of existing infrastructure based on the type of camera system selected. Less is the enhancement or rebuilding of infrastructure required; with more ease the implementation would be done

3.3. Site selection

The next part of the study was to decide the location of the speed camera i.e. the most suitable location where the camera should be installed in order to satisfy all the needs, viz. effective monitoring and enforcement. The locations which were identified were grouped into 10 categories to be evaluated, i.e. long elevated corridors, sharp curve of roads, long tangent of roads, black spots, signalized intersections, un-signalized intersections, residential zones, school zones, market areas and at-grade pedestrians. To identify the most suitable site for installation, out of these 10 categories, once again a detailed questionnaire survey was designed, asking the respondents to rate the given sites on a scale of 1-10, 1 being least important for the installation of the camera and 10 being most important. The survey was conducted again on those road users, who willingly participated in the questionnaire survey with the fact that they were aware about the need of an effective speed control measures and were asked about the most important site for installation of speed camera in lieu of the fact that the site is the most prone site for accidents due to speeding. Their responses were duly noted to come up with the most crucial site for installation of speed camera by analyzing the responses by the mathematical tool of TOPSIS.

4. Data analysis and results

4.1. Selection of suitable speed camera in Indian context

After obtaining the survey response, the data obtained was structured and analyzed as stated earlier with the help of AHP. The principal vector obtained by AHP gives the weightage of all the factors to be considered for evaluation of a particular camera system. After the weightage were obtained for respective factors, as shown in Table 2, the existing systems of cameras viz. Fixed Speed Camera, Mobile Speed Camera, Red Light Speed Camera, and Average Section Speed Camera were evaluated for all the earlier identified factors separately. In this process, a Comparison Matrix (CM) is obtained by giving each type of camera, a rating on a scale of 1-10 based on the above identified factors, 1 having the least importance and 10 having most importance.

Table 2 Weightages of each factor obtained after AHP

Location	0.32
Flexibility	0.14
Cost-involved	0.12
Effectiveness	0.33
Immediacy in Punishment	0.06
Infrastructure Provisions	0.03

The Comparison Matrix (CM) obtained, thereafter with the Principal Vector (PV) gives the final rating of the different speed camera system and it proves to be a benchmark in comparing the systems based on each factors and finally compiled data provides relative comparison between the systems.
The final rating of the camera was obtained using following equation.

$$FR(i) = \sum_{j=1}^{j=6} CM(i,j) \times PV^{T}(j) \,. \tag{15}$$

Where, FR is the final rating matrix of cameras, PV is the principal vector and CM is the Comparison Matrix.

Table 3 Final rating matrix obtained

Types of Camera	FR(i)
Fixed speed camera	9.57
Mobile speed camera	6.88
Average section control camera	6.92
Red light speed camera	6.97

4.2. Evaluation of available speed measures compared to speed cameras

Based on the rankings (1-5) given by a group of 74 people to the available speed control measures as compared to camera based system, the responses were analyzed using TOPSIS for all the given 5 measures used as alternatives and the Closeness Index was obtained as shown in Table 4.

Table 4 Ranking of different speed control measures based on closeness index Cij

Type of Camera	**Cij**	**Rank**
Speed Humps	0.92	2
Rumble strips	0.01	5
Speed limit posts	0.02	4
Police enforcement	0.78	3
Camera based enforcement	0.99	1

4.3. Site selection

In this analysis, ten sites that were identified as most important for installation of cameras were treated as alternatives and fit across in the TOPSIS model while different importance levels (i.e., 1, 2, 3, 4, …10), 1 being the least important and 10 being the most important site for implementation, were assumed to be selection criteria of preference to a particular alternative among the sites. The respondents' rating of different categories of sites being most crucial for speed camera implementation has been summarized in Figure 1. All ten levels, 1-10, were weighted equally to represent equal probability of choosing. After the responses were duly noted, it was analyzed using TOPSIS, with the objective of maximizing the importance levels 5-10, considering them as positive, whereas minimizing the importance levels 1-4 by making them negative in a positive ideal solution. The negative ideal solution included minimization of importance levels 5-10, considering them as negative, and maximization of importance levels 1-4 by making them positive.

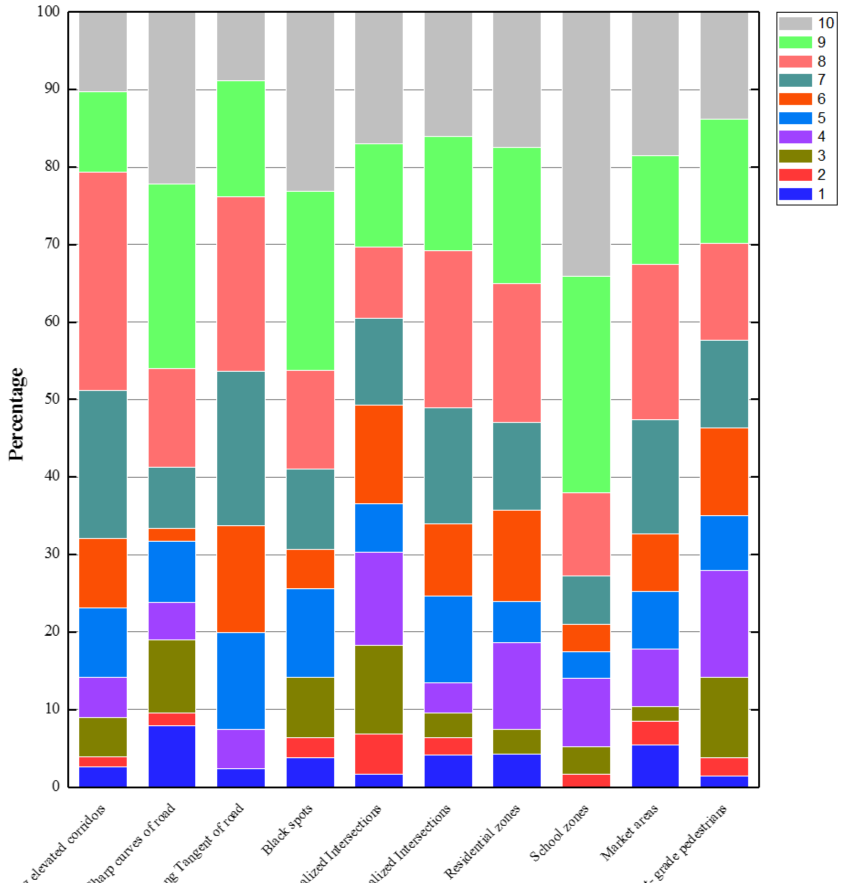

Figure 1Summary of respondents rating of different identified sites

Finally, the ranking of each alternative, i.e. different category of sites, on the basis of their closeness from the ideal solution, called the closeness index, was found. Based on this index the sites are prioritized with respect to highest and lowest closeness index. Table 5 shows the closeness index.

Table 5 Prioritization of sites based on closeness index

Sites	C_j^+	Rank

Long elevated corridors	0.59	2
Sharp curves of road	0.40	9
Long tangent of roads	0.69	1
Black spots	0.53	6
Signalized Intersection	0.36	10
Un-signalized intersection	0.57	3
Residential zones	0.55	5
School zones	0.56	4
Market areas	0.47	7
At-grade pedestrians	0.43	8

As it can be seen from Table 5, on the basis of mass opinion and analysis, Long Tangent of Roads is the most suitable site for installation of speed camera and accordingly the other sites based on the rank.

5. Conclusions

The present work describes various interesting results and ideas behind the implementation of speed camera system in India. The findings clearly shows how a most crucial site which is most prone to accidents, has come out to be the best suitable location for the implementation of speed camera. It is very interesting to understand that TOPSIS proved to be the most effective tool in deciding the most crucial criteria in the given different dimensions and alternatives. Also, with the help of survey and analysis using TOPSIS, it was found that people in India were much in favor of camera based speed management over the other physical measures being used now. Also, based on detailed literature review, several factors for implementation of speed camera in Indian context, proved pivotal for understanding the gap in the effective management of a speed control measure. The study delivered a detailed implementation scenario of speed camera system for enforcement and management in India, which can further be worked upon to understand and address the issues related with its implementation. The work can be further explored by doing a pre-implementation and a post implementation assessment of the scenarios. This could help in getting a quantitative understanding of the benefits and effectiveness of camera based speed management technique.

References

1. Cameron, M. and Delaney, A., 2006. Development of strategies for best practice in speed enforcement in Western Australia.
2. Hoogerwerf, A., 1990. Reconstructing policy theory. Evaluation and program planning, 13(3), pp.285-291.
3. Hwang, C. L. and Yoon, K., 1981. Multiple attribute decision making: methods and applications Springer. New York, (1981).
4. Mercy, J. A., Rosenberg, M. L., Powell, K. E., Broome, C. V. and Roper, W. L., 1993. Public health policy for preventing violence. Health Affairs, 12(4), pp.7-29.
5. Ropohl, G., 1999. Philosophy of socio-technical systems. Techno: Research in Philosophy and Technology, 4(3), pp.186-194.
6. Saaty, T.L., 1990. How to make a decision: the analytic hierarchy process. European journal of operational research, 48(1), pp.9-26.
7. Sadhukhan, S., Banerjee, U. K. and Maitra, B., 2016. Commuters' willingness-to-pay for improvement of transfer facilities in and around metro stations–A case study in Kolkata. Transportation Research Part A: Policy and Practice, 92, pp.43-58.
8. Shyur, H. J., 2006. COTS evaluation using modified TOPSIS and ANP. Applied Mathematical Computations, 251-259.
9. Wang, Y. M., 2016. Fuzzy TOPSIS method based on alpha level sets with an application to bridge risk assessment. Exp. System, 309-319.
10. Wilson, C. W., 2006. Speed enforcement detection devices for preventing road traffic injuries. Cochrane Database of Systematic.
11. World Health Organization, 2015, Global status report on Road safety, Geneva, Switzerland: NVI.