Implementation of a GPS Based Software Tool to Conduct Road Inventory and Safety Audits

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ABSTRACT. Emerging methods for performing road inventory and safety audits at the network macroscopic level should be automated, reliable, and cost-effective. Current methodologies include specialized automated vehicles with high initial and maintenance costs or labor intensive during data collection and reduction process that are outside the budget of many agencies. This paper presents an overview and implementation of Road Condition and Safety Audit (RCSA), which is an open-source software that uses interpolation techniques to reference a road alignment video file with position information in a file collected with any GPS device. Having the capability of assigning a position to each video frame allows solving the problem caused by the lack of accurate position data that is typical when paper-based data collection techniques are used. The software can be used to document the location, characteristics and condition of road features using customizable menus thus allowing the use of the user-preffered grading methodology. Data obtained using the software can be exported to GIS systems and be used for identifying hazardous locations and in the decision making process of where to deploy the often limited improvement budget.

INTRODUCTION

Highway systems consist of a variety of physical elements and facilities that require of comprehensive and integrated management efforts to improve investment decisions through a

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given time period. The Federal Highway Administration (FHWA) promotes the development of asset management programs to incorporate the economic assessment of trade-offs between alternative investment options at the project or network levels (FHWA, 1999). The acquisition of accurate information about the system assets, such as pavements, bridges, signs, utilities, roadside safety related hardware and man-made or natural fixed objects, provides a transportation agency with a powerful instrument for making rational decisions and deploying resources in a more cost-effective manner. This information is also crucial for ensuring the safety of all highway users by detecting road geometric inconsistencies, inadequate elements or hazardous segments.

The identification and documentation of the condition of the pavement surface, the roadside safety hardware features, among other road elements, is crucial for establishing a successful surface asset management program. The use of emerging technology to develop time and cost-effective methodologies for performing road condition surveys and safety audits is a desirable aspect of any asset management system. The FHWA has identified the need to apply existing technology to develop software for roadway hardware management (Hensin and Rowshan, 2005). This road management area refers to an array of signs, signals, roadway lighting luminaries, support structures, guardrails, pavement markings, and deployed detecting devices.

This paper presents the implementation of an open-source software tool, called the Road Condition and Survey Analysis (RCSA) Video Survey, that integrates Global Positioning System (GPS) data and video clips from a road alignment into the process of performing RCSA surveys and road inventory surveys. The tool is focused towards the macroscopic aspects of RCSA and can be used to collect information regarding the location and condition of roadside hardware features. The process followed during the implementation of the tool and the type of data obtained is documented. Data collection for this paper took place at the city of Madison, Wisconsin. The road selected for the analysis is a segment of University Avenue which is a primary road of the city.

In addition, an analysis of the cost of implementing the tool during the data collection using different types of equipment is presented. The software was developed as an open-source solution that allows full access to the application source code, interoperability with existing systems and customization (Santiago, Colucci and Figueroa, 2007). The format used for exporting the data is compatible with existing commercial applications such as Geographical Information Systems (GIS) and databases, the data output can be customized to meet a specific user needs and making it compatible with existing databases. The compatibility and customization aspect of any new tool with existing applications is a critical issue for any data custodian.

LITERATURE REVIEW

Software tools developed with the purpose of collecting road data on the field must be designed with the principles of data inter-operability in mind. Four data-gathering principles, identified by the National Performance Review (2007), indicate that a data collection processes must be focused, flexible, meaningful and consistent. These principles can be applied to the design of any data collection system in order to make it successful.

Based on the aforementioned principles, data collection software tools must address the specific user/agency needs and allow for the customization of the parameters collected in order for it to be flexible and focused towards a specific task and to allow the collection of meaningful data. Another important aspect is that the tool must provide a consistent mechanism of collecting and exchanging the information. The latter suggests the use of an open and customizable file format for storing and exchanging the data. The format should allow stored data to be accessed by tools and environments others than those where it was collected. The format used should also be clearly documented. As stated in AASHTO's Strategic Highway Safety Plan, even the most accurately compiled set of data is meaningless if users are unable to work with it (AASHTO, 2005).

Many states, such as Michigan and Arizona, have implemented data integration programs. The Arizona Department of Transportation (ADOT) identified the need to create an asset management tool that could use available data from their Highway Performance Monitoring System (HPMS), Pavement Management System (PMS), and Bridge Management System (BMS), as well as data from other internal sources in the agency. The problem found during the implementation of their asset management tool was that the existing systems where developed independently, using a variety of software platforms and in the absence of agency-wide standards (FHWA, 2004).

In the case of the Michigan DOT (MDOT), the agency wanted to increase their efforts towards increasing system maintenance activities instead of only infrastructure construction. MDOT designed an integrated Transportation Management System (TMS) application that had access to a single database containing all their asset information. MDOT merged their PMS, BMS, HPMS and other systems into a single integrated database providing continuous access to information. Lessons learned during the implementation process of the integrated system emphasized the importance of managing the data systematically to be converted into a corporate asset instead of being a source of conflict and misinformation. There is a need to establish standards and protocols for data timeliness, quality and collection that can be implemented among all the personnel working with the data collection process (FHWA, 2003).

Both cases previouly mentioned have one element in common, namely, existing data collection tools that needed to be integrated into a central database connected to data analysis tools and Geographical Information System (GIS) environments. Implementing the latter is not a technological challenge anymore, but an administrative one. The technology available allows the development of data collection that can be interoperated with equipments such as GPS devices. For example, a GPS device can be used during the data collection process in order to acquire information about the location of the road features. These devices can be integrated into the data collection process and the resulting file structure can be made compatible with existing databases and integrated, for example, into GIS tools for further analysis.

The emerging use of GPS devices for transportation engineering ranges from travel time studies to work zone safety evaluation studies (Quiroga and Bullock, 1998; Camilo et al, 2006; Wolshon and Hatipkarasulu, 2000; Monsere, 2006). GPS data has been used for the recording and analysis of car-following behavior in order to compare the results from car-following models. GPS data have also been used for evaluating the performance of loop detectors for the prediction of travel time on highways segments. The use of accurate GPS data is becoming more popular and thus represent an attractive solution in comparison to other methods such as the use of electronic equipment that has been traditionally used for measuring distance along a road alignment.

Commercial applications already implement GPS data into asset management applications. Those systems are proprietary and require the purchase of both hardware and software packages. Their capabilities include the semi-automatic detection of road features and defects. These solutions can be acquired and implemented by agencies into their existing management systems. As seen on the two examples presented, agencies already have existing pavement and sign management systems to perform their business processes. A review performed of the existing technologies show there are no tools available that are open and customizable by the user/agency to allow collecting information about roadside hardware conditions and performing road safety audits. In order to perform these tasks, the user/agency must develop their own systems or acquire existing proprietary tools. From the latter situation, is that the need of creating an open solution for this problem arises.

DATA COLLECTION AND ANALYSIS PROCESS

The process of using the RCSA Video Survey to perform road inventory, safety audits or condition surveys consists of three steps shown in the conceptual flowchart in Figure 1. The first step is collecting video and position data of the alignment while driving along it. Positioning the digital video camera during this process shall be consistent with the purpose of the study. For example, if the intention is to document features along a specific roadside, the camera should be directed towards that side (right-hand, left-hand or thru main lanes). Since position files are stored separately, it is possible to have as many digital video cameras required to survey the road, e.g., one camera pointing to the front while two other digital video cameras point towards each roadside.

During this step, the driver of the vehicle should select an operating speed suitable to the type of digital video camera used. It is the experience of the authors that a speed of around 50 km/hr (30 mph) while driving and using a digital video camera of 30 frames per seconds (fps) is adequate. An option to performing the data collection while driving is to have a handheld GPS device collecting position data while using a video camera to record video of features while walking along the alignment. This option solves the problem that happens many times while performing road safety audits of having an exact position from the field notes. This option allows using the capability of referencing video and position data into safety audits at a microscopic level and allows the engineer to actually focus on documenting everything in video and then accurately asign a position to each feature documented.

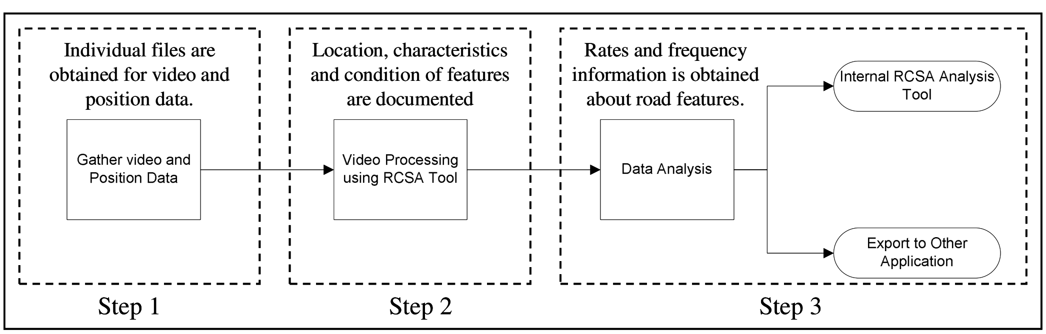

Figure 1. Three step process using RCSA Video Surveying

The second step is the virtual survey and identification of road features process. An analyst uses the tool to virtually drive along the alignment while documenting the location and condition of road features using the software menus. Once a change in road conditions or an appearance of a certain feature is observed in the video the analyst can select it's characteristics in the menu and the software assigns a position to that video frame. The type of features and characteristics documented in the tool depends upon the type of study being performed. For example, at first, the analyst might be interested in documenting the location and condition of guardrails only while latter it might be interested in documenting the location of utility poles. Because the survey is done virtually, a highway segment can be analyzed the times deemed necessary without requiring additional field visits. The ability of revisiting the site eliminates errors that occur as a result of the traditional data reduction process. Figure 2 shows the RCSA Video Survey window environment. Section B of the figure is where the alignment video is displayed. There are commands included in the software that allows playing the video faster or slower in addition to the traditional play, pause, forward and rewind commands. Sections A and C contains adaptable combo boxes whose content can be defined by the user to meet specific study needs. These combo boxes allow defining what characteristics does a specific frame of video contains. For example, it is possible that one of the boxes allows the user to specify the condition of an impacted utility pole or the condition of the pavement marking at that point. The content of each box is defined entirely by the user.

After the video survey and the documentation of the road features takes place, the third and last step of the process is the analysis of the data. There are two options for performing the data analysis. The first option is to use the data analysis module of the tool which allows the user to perform tasks such as the identification of the alignment segment with the higher number of feature occurrences per segment or produce a summary of the type of features on the segment and the occurrences of each feature. The second option is exporting the location and condition data into a format that can be read by a GIS, a spreadsheet program, a database, among others. If exported, the content of the output file will be a list of geograhic position associated with a road feature, and the parameters defined by the user to describe condition or charateristics of the feature.

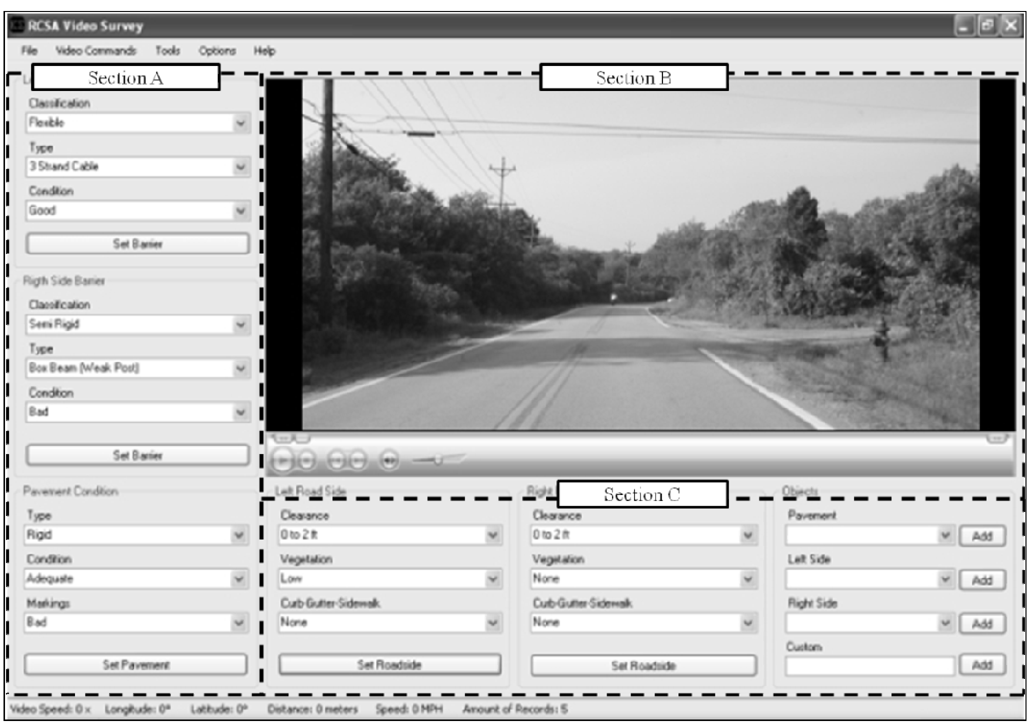

Figure 2. Screenshot of the RSCA Data Collection Module

FIELD OPERATIONAL COSTS

Even for tools with powerful capabilities, the implementation cost plays an important role. This section presents a cost evaluation of the RCSA Video Survey software. It analyzes the field operational cost of the tool and presents a conceptual function for the total cost. The field collection cost (F_{CC}) is defined as the cost of collecting the data (i.e. the cost corresponding to the first step of the process described on the tool description section). The F_{CC} has two components, a vehicle operating cost (V_{OC}) and a driver cost (D_C) as shown on Equation 1.

$$F_{CC} = V_{OC} + D_C \qquad (1)$$

where:

F_{CC}: Field collection cost, dollars per km (dollars per mile)
V_{OC}: Vehicle operating cost, dollars per km (dollars per mile)
D_C: Driver cost, dollars per km (dollars per mile)

The V_{OC} itself has two components, namely an equipment acquisition cost (E_{AC}) and a vehicle variable cost (V_{VC}), as shown on Equation 2.

$$V_{OC} = E_{AC} + V_{VC} \qquad (2)$$

where:

V_{OC}: Vehicle operating cost, dollars per km (dollars per mile)
E_{AC}: Equipment acquisition cost, dollars per km (dollars per mile)
V_{VC}: Vehicle variable cost, dollars per km (dollars per mile)

The E_{AC} is the initial cost incurred by an agency or user in the acquisition of equipment such as GPS devices and video cameras. The E_{AC} is required if the previous components are not available before implementing the tool for field procedures. The E_{AC} can be expressed in terms of dollars per km (dollars per mile) if the equipment cost is divided by the total length of alignment surveyed over time. A significant amount of distance surveyed using the tool lowers the value of the E_{AC}. The V_{VC} can be obtained from sources such as the American Automobile Association (AAA) and it includes the cost of fuel and maintenance of the vehicle. The AAA estimates $0.11 per km as the V_{VC} for a minivan in their publication of driving costs for 2006. A minivan vehicle was selected as a similar vehicle to those used by transportation agencies or research laboratories during field data collection.

Figure 3 presents different V_{OC} curves expressed as a function of the total length of alignment surveyed and different E_{AC} values. Values of $2,000, $5,000, $8,000, $10,000 are used as different E_{AC} values in order to produce the V_{OC} curves. As expected, the V_{OC} is reduced when the total length of alignment surveyed is increased due to the reduction of the E_{AC} over time. The V_{OC} value is the first component of the F_{CC} as defined on Equation 1. The second component, the driver cost (D_C), can be estimated by assuming a driver salary rate of $12 per hour and an average vehicle speed of 50 km/hr during the survey. The assumption leads to a D_C of $0.24 per km. Figure 3 shows that the V_{OC} ranges from $0.14 to $0.28 per km for E_{AC} values of $2,000 and $10,000, respectively. With the values of V_{OC} and D_C, Equation 1 leads to a F_{CC} that ranges from $0.38 to $0.52 per km.

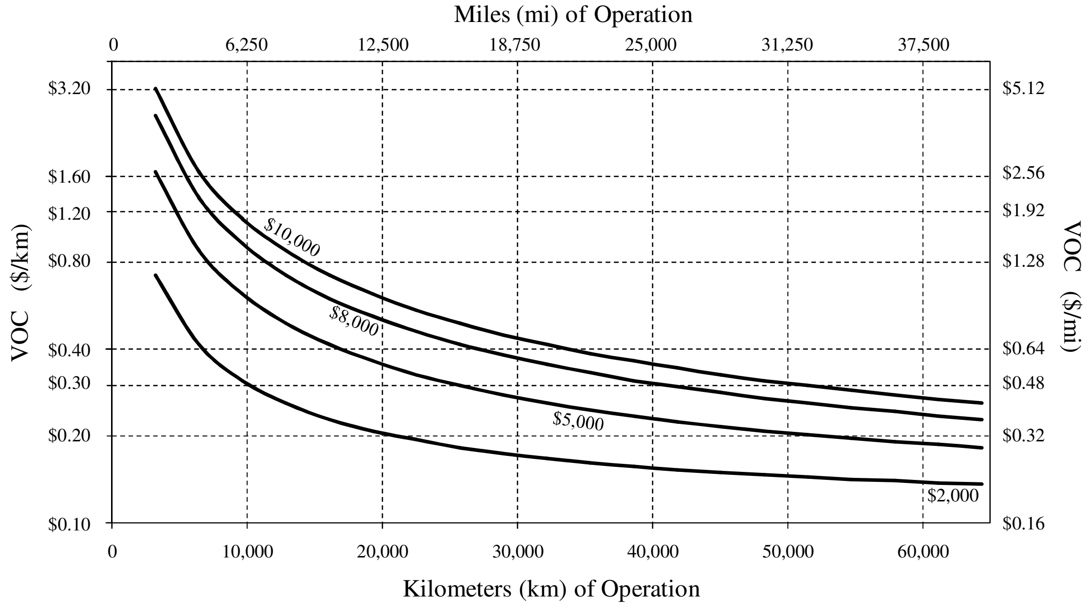

Figure 3. Vehicle operating costs (V_{OC}) per distance of road surveyed

Further discussion of the cost requires taking into consideration the cost of the personnel required for performing the data reduction process. This includes the personnel for analyzing the segment, summarizing data, preparing reports, among other costs. Salaries for this type of personnel varies significantly, therefore, these costs are not taken into consideration for the analysis previously presented. The total cost (T_C) associated with the data collection and analysis for a road segment is presented conceptually using the following definition:

$$T_C = \left(F_{CC} + f\left(p,i\right)\right) \times l \qquad (3)$$

where:

T_C: total cost
F_{CC}: field collection cost
l : length of the segment
p : performance of the data reduction personnel
i : layers of information desired
f : cost function associated with the data reduction process

The *f(p,i)* term of Equation 3 is a conceptual approach to estimate the cost of the data reduction process. It is defined as a function of the performance of the personnel doing the data reduction and the layers of information desired to be obtained from the segment. The performance of the analyst is expressed in terms of its productivity: how fast it can document specific road features, such as trees, guardrails, road signs, etc. The layers of information desired from a segment will depend upon the type of study being performed. Equation 3 assumes that *f(p,i)* is expressed in terms of dollars per km (dollars per mile). Lower values of *f(p,i)* can be achieved through training of personnel and with increased use of the tool. Since F_{CC} and *f(p,i)* are expressed in terms of dollars per km (dollars per mile), the sum of the two variables is multiplied by the length of the segment in order to obtain the T_C value.

SITE DESCRIPTION

University Avenue at the city of Madison in the state of Wisconsin is one of the primary roads in the city. The road segment evaluated is located at a mostly-residential area that is nearby the University of Wisconsin-Madison. The segment evaluated was subdivided into 9 sub-segments identified by the name of the street that intersects with University Avenue. Table 1 lists the intersection of streets with University Avenue that mark the beginning and end of each segment. Figure 4 shows a map of the study area with the corresponding segment ID and length.

Table 1. Starting and ending points of segments studied at University Avenue

Segment ID	**Starts At**	**Ends At**	**Segment Length (km)**
1	North Breese Terrace	Lathrop Street	0.10
2	Lathrop Street	North Prospect Avenue	0.11
3	North Prospect Avenue	Princeton Avenue	0.13
4	Princeton Avenue	Chamberlain Avenue	0.14
5	Chamberlain Avenue	Forest Street	0.16
6	Forest Street	North Allen Street	0.18
7	North Allen Street	Walnut Street	0.16
8	Walnut Street	Chestnut Street	0.13
9	Chestnut Street	Highland Avenue	0.12
		Total length:	1.23

Figure 4. Location of the road segments studied

The selected road segment for analysis has an AADT of 15,000 vehicles per day and a speed limit of 40 km/hr (25 mph). The segment has two lanes on each travel direction and includes three signalized intersections. Among the non-residential features that are located along the road are gas stations, car service centers, restaurants and small office buildings.

Road videologging starting at the beginning of segment 1 and ending at the end of segment 9, was recorded using a digital video camera. The travel direction of the survey is from North Breese Terrace towards Highland Avenue. Position data was collected simultaneously with the video collection using a consumer-end GPS. The two files obtained during the data collection process were analyzed using the RCSA Video Survey software. Using the software, the road was driven virtually and trees, utility poles, bus stops, signs and driveway entrances were documented for each side of University Avenue.

The features of the road documented from each side were located between the sidewalks and the centerline of the road. For example, trees located on the left side of the sidewalk were documented, while trees on the right side of the sidewalk were not in one run. The same rule was applied for signs, utility poles and bus stops. Driveway entrances were considered as a single point feature. The only continuous feature documented using the software in this example was the length of the segments were the data collection was taking place. The segment length allows the analyst to generate queries of certain group of features on a specific segment of the road.

The user also has the capability to apply either real time correction or post-collection corrections to the GPS position data in order to obtain a more accurate result of the length of continuous roadside features such as guardrails and sidewalks. Data from the analysis of the video were exported into a spreadsheet compatible format to obtain a visual summary of the results.

RESULTS AND ANALYSIS

Once the data collection and documentation process were completed, data were summarized into a spreadsheet compatible format in order to generate a table and graphical output for the data. This representation allows clearly identifying the segment with the highest occurrence of a specific feature such as trees or utility poles. Table 2 presents a summary of occurrences by roadside for five layers of information namely trees, utility poles, bus stops, signs and driveway entrances on both roadsides. Using the data on this table allows the analyst to perform further analyses in an efficient way, to preserve the data by inclusion into a database or generating reports. The travel direction of the survey is from North Breese Terrace towards Highland Avenue.

Table 2. Roadside feature occurrences by segment ID – University Avenue

Roadside Feature	**University Avenue Segment ID**								
Right Side	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
1. Trees	0	0	0	7	11	3	0	8	6
2. Utility Poles	0	2	0	1	0	0	1	0	0
3. Bus Stops	0	0	1	1	0	2	0	1	0
4. Signs	2	3	2	4	2	2	1	2	4
5. Driveway Entrances	1	0	1	3	4	5	5	1	2
Left Side	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
1. Trees	5	0	7	8	8	7	5	8	4
2. Utility Poles	3	4	3	5	5	5	5	5	4
3. Bus Stops	0	0	1	0	1	2	0	1	1
4. Signs	2	2	2	2	2	3	2	2	1
5. Driveway Entrances	0	0	1	4	4	3	3	1	3

Table 2 data can be pooled into three layers of information for further analysis, as shown on Table 3. The first layer contains an aggregate of the amount of trees and utility poles for a specific segment of the road. The second layer contains an aggregate of the bus stops and the signs, whereas, the third layer contains information about the driveway entrances on the roadside. The grouping process was done according to similarities between the features. For example, the differences between a vehicle impacting a tree or a utility pole are not significant.

Table 3. Pooling of similar roadside features by segment ID – University Avenue

Roadside Feature	**University Avenue Segment ID**								
Right Side	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
1. Trees and Utility Poles	0	2	0	8	11	3	1	8	6
2. Bus Stops and Signs	2	3	3	5	2	4	1	3	4
3. Driveway Entrances	1	0	1	3	4	5	5	1	2
Left Side	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
1. Trees and Utility Poles	8	4	10	13	13	12	10	13	8
2. Bus Stops and Signs	2	2	3	2	3	5	2	3	2
3. Driveway Entrances	0	0	1	4	4	3	3	1	3

Figure 5 and Figure 6 contain a visual representation of the three layers of information shown on Table 3. The aggregate of feature occurrences on each layer is plotted in order to simplify the process of identifying the road segment with higher occurrences. Although the results are plotted on a chart, a map containing the location of each feature could have been used. On the right roadside, corresponding to Figure 5, segment 5 contains the highest amount of trees and utility poles, while segment 4 has the highest number of bus stops and signs. On the other hand, segments 6 and 7 contain an equal amount of driveway entrances. Figure 6 corresponds to the left roadside. Segments 4, 5 and 8 have an equal amount of trees and utility poles, while segment number 6 has the highest occurrences of bus stops and signs. Finally, segments 4 and 5 have equal occurrences of driveway entrances.

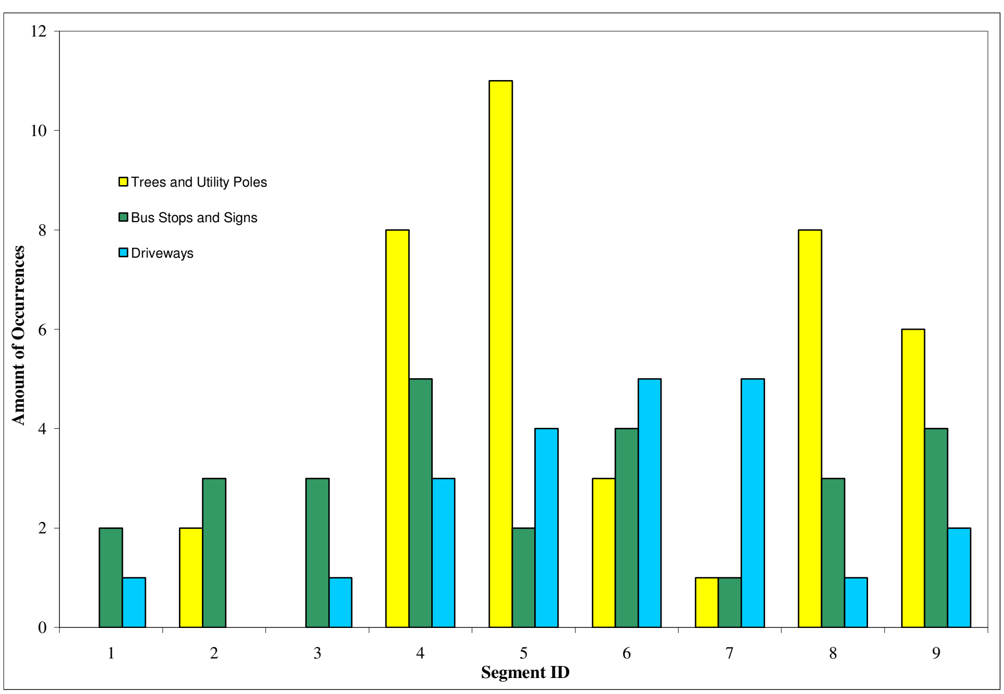

Figure 5. Right-hand side roadside occurrences by segment ID

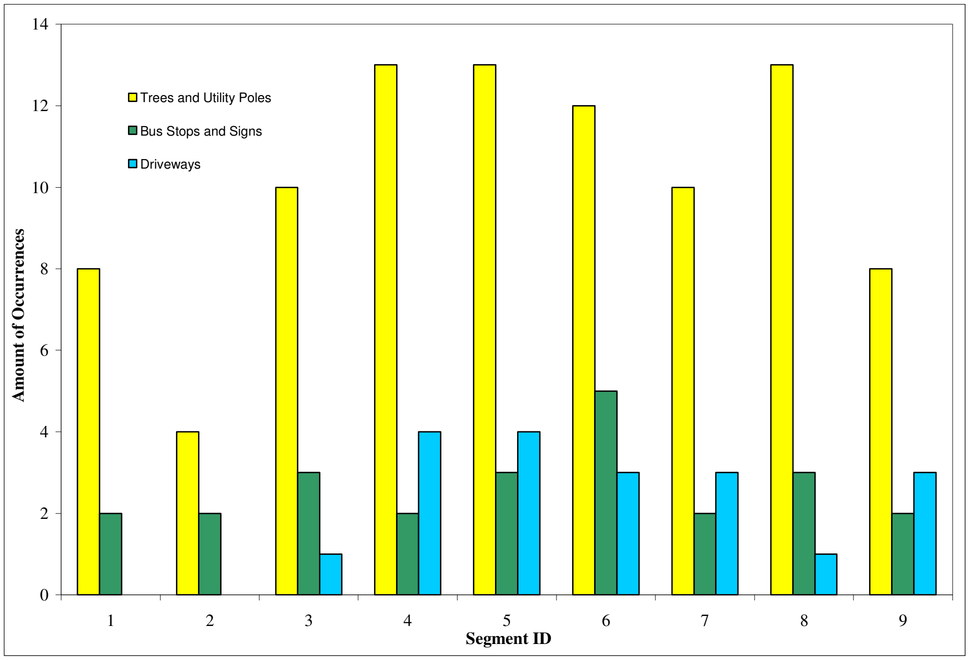

Figure 6. Left-hand side roadside occurrences by segment ID

The data analysis shown herein contains information regarding the occurrences of features. The data from Table 3 can be converted into a ratio of features per length of alignment. This can be done by dividing the amount of occurrences on each segment by the length of the segment and is done automatically by the software as one of its outputs. This type of information, when combined with traffic volume data allows the data analyst to use the output of a process as the input for accident prediction models. Table 4 shows the density of features per segment, in terms of occurences per kilometer, using the same pooling convention as Table 3.

Table 4. Density of occurrences by segment (occurrences per kilometer) for each roadside

Characteristic	**Segment ID**								
Right Side	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
1. Trees and Utility Poles	0	18	0	56	67	17	9	51	49
2. Bus Stops and Signs	24	27	23	35	12	23	9	19	33
3. Driveway Entrances	12	0	8	21	24	28	44	6	16
Left Side	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
1. Trees and Utility Poles	96	48	120	157	157	145	120	157	96
2. Bus Stops and Signs	24	24	36	24	36	60	24	36	24
3. Driveway Entrances	0	0	12	48	48	36	36	12	36

Based on these results, it can be seen that segments 4 and 5 on the left side of the road have the highest density of trees and utility poles per kilometer, 157, while segments 1 and 2 on the right side have no presence of trees and poles. It can also be seen that segment 6, also on the left side, have the highest density of bus stops and signs per kilometer, having 60 per kilometer. Finally, segments 4 and 5 on the right side have the highest density, 48, of driveway entrances per kilometer.

This tool has the capability to add severity and condition levels to each object observed during the survey and its associated inspection dates. Subjective ratings can also be included to each roadside feature in a very simple manner. For example, a 20-m long standard section metal semi-flexible guardrail on the right-hand side of the road can be rated as fully functional with a rating of 8 to 10 at the inspection date of December 10, 2007. In a follow-up survey conducted December 10, 2009 on the same road, the same 20-m long semi-flexible guardrail has been impacted several times and has sustained its maximum deflection exceeding 1.1 meters. At this inspection data, the semi-flexible guardrail can be rated between 0 and 3 and will require replacement. The same approach can be applied to signs, utility poles, pavement defects, traffic signal masts, road hardware and other potential hazardous features. The RCSA Analysis Module can be used to develop time-dependent performance curves showing the rating history of the road features. Prediction models can be developed using a database containing several years of data to estimate the time for repair and budget allocation. The density of impacts per kilometer to barriers, trees and signs on a given road segment or corridor can be compared to the base scenario in a particular year as shown in Figure 7.

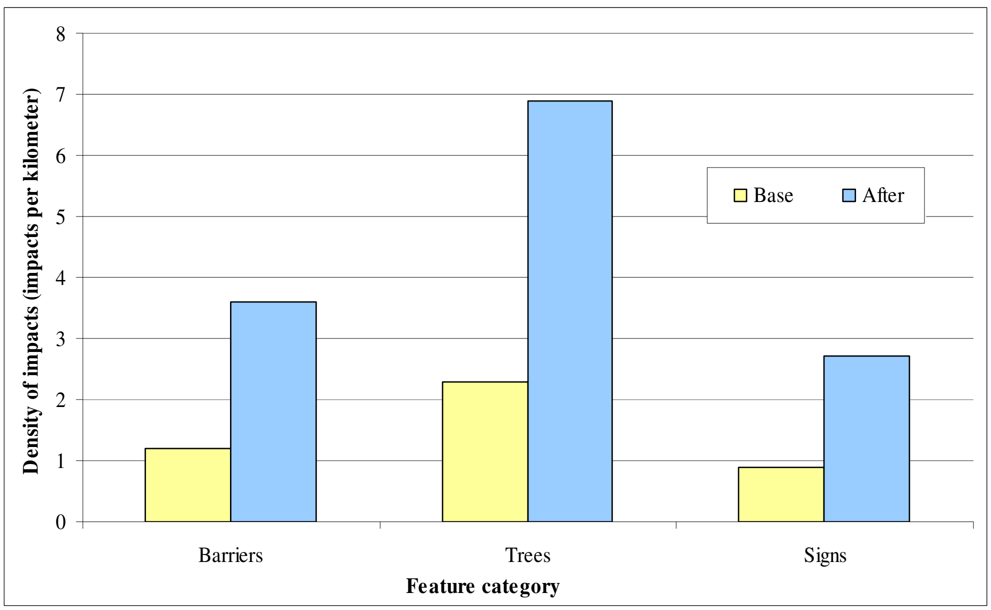

Figure 7. Density of impacts per kilometer for the base year and future scenario for barriers, trees and signs

In Figure 7, it is assumed that a survey was performed during a base year. The survey was used to obtain the density of impacts per kilometer of several roadside features, e.g. barriers, trees and signs. A similar survey can be performed a year later to obtain the same values. When data about density of impacts is obtained, prediction models of a segment performance can be obtained. These prediction models can be used for purposes of planning improvements on the road network in addition to identify areas that are prone to safety problems.

CONCLUSIONS

This work introduced the RCSA Video Survey software tool capable of integrating video and position data from a road alignment in order to perform road condition, road inventories and safety audit surveys at a macroscopic level by using an interpolation process between the video and position file that assigns a geographic coordinate to each frame on the video. This allows a user to virtually drive along the road while documenting the location and condition of roadside features. Position information is crucial on any of the mentioned types of surveys and it has been one of the hardest challenges to overcome in the past. The virtual environment used reduces the time required on the field by data collection personel while also reducing discrepancies between how field data is interpreted during the collection and then during the data reduction process. Because of its customizable interface and output, data obtained with the software can be integrated into existing databases, analyzed using spreadsheet programs and/or plotted using GIS tools.

The presented tool is not intended to compete with existing proprietary data collection solutions. It is intended to act as a cost-efficient tool for agencies that does not have any type of data collection tools or do not have the budget required to acquire proprietary solutions. As it can be seen on the data presented, the tool can be used by these agencies to generate inventories of roadside features and use the data for identifying hazardous road segments or for crash prediction models. Since this tool is fully customizable, its uses are limited only by the user, state highway agency or ministry of transport that implements it.

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