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Forensic Engineering Analysis of Traffic Signal Timing and Speeds Prior to Collision by Rule-Based Triage of Indirect Video

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Abstract

In most civil litigation cases pertaining to vehicle collisions, the courts attempt to assess and decide the proportion of shared liability of the drivers based on physical evidence as well as testimony of witnesses and perhaps experts. In North America's modern electronic-flooded society, an immense quantity of video coverage has become available from sources such as cell phones, security cameras, eyes-in-the sky traffic helicopters, dashboard cameras, and even personal drones. However, rarely is the camera focused directly on the area of interest. Security cameras may be pointed toward the back door of a property yet still have visual coverage of a nearby street. When faced with a case having multiple conflicting eyewitness accounts, it was pondered whether some of this indirect collateral imagery could be converted into useful knowledge — without access to expensive supercomputer-based image analysis. The author considered whether there were any rules of inclusion or exclusion that may be used in the triage of video footage to assist with determining a timeline of an event. This paper will attempt to provide some guidelines to the formation of an adaptable rule set, as a foundation for conducting the triage process, with reference to published and validated data. It will then go over a case where the methodology was applied.

Keywords

Tractor/trailer, vehicle, video, traffic signals, rule-based triage, stimulus, rural, second vehicle departure times, stopping probability

Part I — Method for Triage of Indirect Video Footage

Vehicle Actions and Site Geometry as Sources of Information

Within any typical video footage, a vehicle may be seen to start, speed up, drive by, turn, slow down, or come to a stop. That vehicle's behavior is a proxy for the driver's behavior. Although it provides useful physical information, it will never explicitly reveal the intentions of the driver — the reactions of the vehicle are a manifestation of the driver's inputs.

A video may show the first vehicle at a stop line facing a red signal. How long does it take for this vehicle to move when a new green ball lights? Certain technical studies[1] have been done on this starting activity. However, the actual position of the vehicle as first, second, or third in the queue at the stop line will change the departure interval parameter length. Some data is available from internal sensors (such as accelerometers), while other data has been developed from external factors, such as the moment a wheel of a vehicle completes a half revolution, after having been stopped. If movement can be seen, then it can both be described and compared to known landmarks in a frame. The primary and secondary categories and sources of information for the analysis are presented in **Figure 1**.

Category	Source
Primary	Security video footage encompassing the time of the incident.
	Known frame rate of the footage.
	Signal phase timing from the authority having jurisdiction (AHJ).
	Video codec needed to replay the video (sometimes proprietary).
	Local road geometry as measured by police and others.
Secondary	Time stamp in the video frame.
	Total Station survey or 3D laser scan of the site.
	Photographs of the site, the scene, and the vehicles.

Figure 1
Primary and secondary sources of information for the analysis.

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The physical characteristics of the roadway, such as the number and type of lanes, position of stop lines and crosswalks, local speed limits, and signal phases all come into play when considering the rules vehicles appear to follow. A Total Station survey or 3D laser scan from a commercial supplier can provide these coordinates to map the relative position in the frame to the absolute position on the ground.

Typical security footage is shot at 30 frames per second at low to medium resolution, and may be difficult to unlock for processing because of proprietary anti-tampering codecs. The presence of a time stamp on the videograph* is helpful. Check for metadata that may have timing information if it is not explicitly found on a screen time stamp. Without a time stamp for reference, the internal video metadata is the only timing information that would be available — and it may or may not be tied to the real world. Internal information can still be used to time activities if the frame capture rate is known. A known frame rate means that features in the viewable area can be the basis of calculated estimates of the velocities of vehicles. This is an independent source to be compared and contrasted with the physical evidence gathered post-collision.

Keep in mind that the distortion characteristics of the optical hardware must be considered, since the central field may have much less distortion than the edges of frame due to lens characteristics.

Steps to Follow for the Videograph Analysis

The key activity will be to patiently observe and document the video-recorded actions of the vehicles and determine if they are patterned in a way that would fit the signal phases of the lights that cannot be directly seen. It may be possible to track a vehicle that appears in one part of the frame, disappears momentarily, and then reappears in another portion of the view.

The larger the set of observations of these individual vehicle actions, the more confidence in the match between the overall action patterns and the phase sequence that will be obtained when an arbitrary degree of fit is apparent. The suggested steps are shown in **Figure 2**.

It can be cumbersome to quickly add, subtract, and calculate time intervals in the hour:minute:second (“h:mm:ss”) format — for ease of reference, a “tick” system was developed in which one unit is equivalent to one second on the videograph, where the original tick was at the beginning of the recording. To determine the number of seconds between two events, the smaller tick is subtracted from the larger. An arbitrary frame starting point can be chosen to simplify or shorten a period of interest into manageable size.

Each observation can be assessed with a validity criteria — that is whether it was reasonable or typical behavior, given the assumed signal phase for the direction the vehicle was traveling. A weighting rule will give more to observations in the direct foreground and in the camera field of view when compared to distant background vehicle actions. Certain angles may provide only enough information to check overall validity — in other words, a vehicle should not be in a place that would be contrary to typical rules of the road, except in special circumstances. An example would be a first-responder vehicle on its way to a fire. It is just as important to consider what a vehicle is not doing as it is to consider its actions. The investigator may ask whether there are patterns that fit the signal phases that cannot be directly seen.

The full set of observations is compiled into a spreadsheet set with the signal phases on the left-side columns and the sets of observations to the right. The rules and exclusions are applied to the observations. By iterating forward or backward, the phases are shifted until the best fit criteria are met to the satisfaction of the investigator. This

Step One	Create a spreadsheet with signal color by road, validity, time, observations by road with position in frame.
Step Two	Set one interval per row, matching seconds (or ticks).
Step Three	Observe the video, and note the number of vehicles, actions, and positions for each interval.
Step Four	Code the range of interest, then add the signal phase timing to the spreadsheet.
Step Five	Compare the activities and observations to the phase, and rank according to rules.
Step Six	Iterate the placement of phases until a validity acceptance criteria is met.
Step Seven	Verify the timing assumptions by validating the actions with an external source (SAE papers, data from third parties).
Step Eight	Set the signal phase sequence, and tie it to the observations.

Figure 2
Steps to follow for the videograph analysis of a collision.

* A videograph is the physical record made by a video device that describes movement captured in a scene over time. It is derived from Latin videre “to see” and Greek grapho “to describe.”

Advantages	Limitations
Provides an independent means of collecting data about the vehicle motion prior to, during, and after an event.	The assumptions about the vehicle actions can be scrutinized and disputed, if not carefully explained in the documentation.
It can allow development of a more precise timeline for the sequence of events.	The results are sensitive to the accuracy of the signal phase description obtained from the AHJ and to the quality of the ground survey.
It can be used to develop velocity information that can then be compared to the physical evidence and reconstruction calculations.	The clarity of the image may affect the frame analysis, since many security video cameras employ low resolution hardware or low frame rates.
It may reveal other helpful collateral data to create clearer context of the event.	The area of interest may be offset in a corner of the frame, or obscured by time stamp numbers.
It can be used along with video footage as a convincing display in testimony.	

Figure 3
Summary of advantages and limitations of the method.

could be a threshold level, in which 95% of the observations are not in conflict with the setting of the phases, for example.

Figure 3 presents some advantages and limitations for the method under discussion. This method provides independent data about vehicle motion prior to, during, and after an event, and this may lead to a better resolution of the timeline. Velocity information derived from the comparison of features and positions can be compared and contrasted with that developed by regular collision reconstruction techniques. The method may reveal collateral data about the context and allow further insights into the collision event. Finally, indirect video footage may be a convincing tool for the litigation proceedings.

The limitations of the method include disputes about vehicle assumptions, if such assumptions are not properly set down. The results are sensitive to both the accuracy of the signal phase information from the AHJ and to the quality of the ground survey used to do position and motion analysis of vehicle actions. Resolution of video camera equipment is often low, and this may affect clarity and the frame analysis. Considerations should be made regarding the value of having the video enhanced by software techniques, and whether this would be appropriate. The area of interest may be at a frame edge (where the hardware may create distortion) or obscured by image features like a time stamp.

The reader may consider that for any given set of actions, certain conditions of the signal are impossible, which allows the triage to be performed while narrowing in on the actual possibility of signal color at a given instant.

Figure 4 provides some examples of descriptions for analysis of vehicle behavior in a situation where there are

Position in the Frame	Observed Vehicle Activity
Foreground Traffic	Going through to edge of frame, to a known position
	Stopping in the through lane
	Stopping in the left turn lane
	Accelerating from a stopped position in the through lane
	Accelerating from a stopped position in the left turn lane, then being seen in another frame portion
Approaching Background Traffic	Being seen approaching on the screen
	Going out of the videograph frame close to a stop line, with variable lane positions
	Being seen going through at pace; going through slowly; slowing to a stop; or stopped on the roadway
	Making a right turn into the foreground, then disappearing and then reappearing in another part of the frame
	Reacting to signals by slowing down, by going through, or by starting to accelerate

Figure 4
Example of description sets for two partial views of perpendicular roadways.

Figure 5
View looking north to the intersection of
Mayfield Road and Airport Road.

two partial views of perpendicular roadways.

Part II — Case Study Employing the Analysis of Indirect Video

A Southbound tractor and dump trailer combination collided with a West-turning car in daylight at a major rural intersection. The collision was observed either directly or indirectly by 16 nearby persons. These witnesses stated that the tractor/trailer was traveling at high speed at the moment it engaged the left-turning passenger vehicle, but offered conflicting accounts about the signal color facing the tractor/trailer driver. The collision resulted in fatal injuries to both the driver of the car and her passenger.

The Collision Site

Airport Road is a major arterial road with multiple asphalt-paved lanes, with an approximately north-south axis in the Peel Region. Mayfield Road is a designated regional road with dual lanes lying on an east-west axis. The posted speed for both was 60 km/h (37 mph).

Southbound Airport Road, just north of the intersection, consisted of a left turn bay, two through lanes (Lanes 1 & 2), and a right turn bay. South of the intersection, this became two through lanes (Lanes 1 & 2), adjacent to a filling station located on the southwest corner lot.

Northbound Airport Road was similarly configured, that is with a left turn bay, two through lanes, a right turn bay, and two through lanes north of the intersection. North- and south-bound portions of the highway were separated by a concrete median in the approaches to the intersection. This northward view is shown in **Figure 5**.

For eastbound traffic, Mayfield Road just west of the intersection comprised a left turn bay, a through lane (Lane 1), and a through/right turn option lane (Lane 2). East of the intersection, the eastbound lanes merged to form one through lane. Westbound traffic east of the intersection with Airport Road could employ a left turn bay, a through lane, and a through/right turn option lane. West of the intersection were two through lanes for westbound vehicles, separated from eastbound vehicles by a concrete median.

On the day of the collision, the northwest corner of the intersection was a construction site, which included a construction trailer and construction equipment. The northeast corner was vacant, with a barn building set some distance away from the roadway. Several tall electric concrete poles were set back from the east shoulder of northbound Airport Road, lying along a line parallel to the road's north-south axis.

Signal-Phase Information

The sequence of the two-phase signal phases at 2:30 p.m. on the date of the incident was gathered directly from the public works department:

a. For Mayfield Rd – Green Ball 35 seconds, amber 4 seconds, all-red 2.9 seconds;

b. For Airport Rd – Green Ball 35 seconds, amber 4 seconds, all-red 2.9 seconds.

The signals had been functioning correctly when checked during maintenance activities. The author observed that these phases were symmetrical — and that a full cycle comprised a total time of 83.8 seconds.

Collision Reconstruction Analysis

1) The Collision Scene

Photographs of the scene taken by police indicated that the tractor/trailer combination had come to rest in a jack-knifed position on the lawn area of the filling station. The passenger vehicle had been pushed in front of the tractor/trailer and came to rest in the driveway of the filling station (**Figure 6**). A short gouge in the asphalt was noted along the southward extension of the demarcation line of Lanes 1 and 2 traveled by southbound traffic at about 20 meters (66 feet) south of the southbound stop line. This gouge and the surrounding debris field indicated the probable area of impact (AOI), and their positions were specified by police data points. No tire marks were seen north of the gouge during the site inspection by

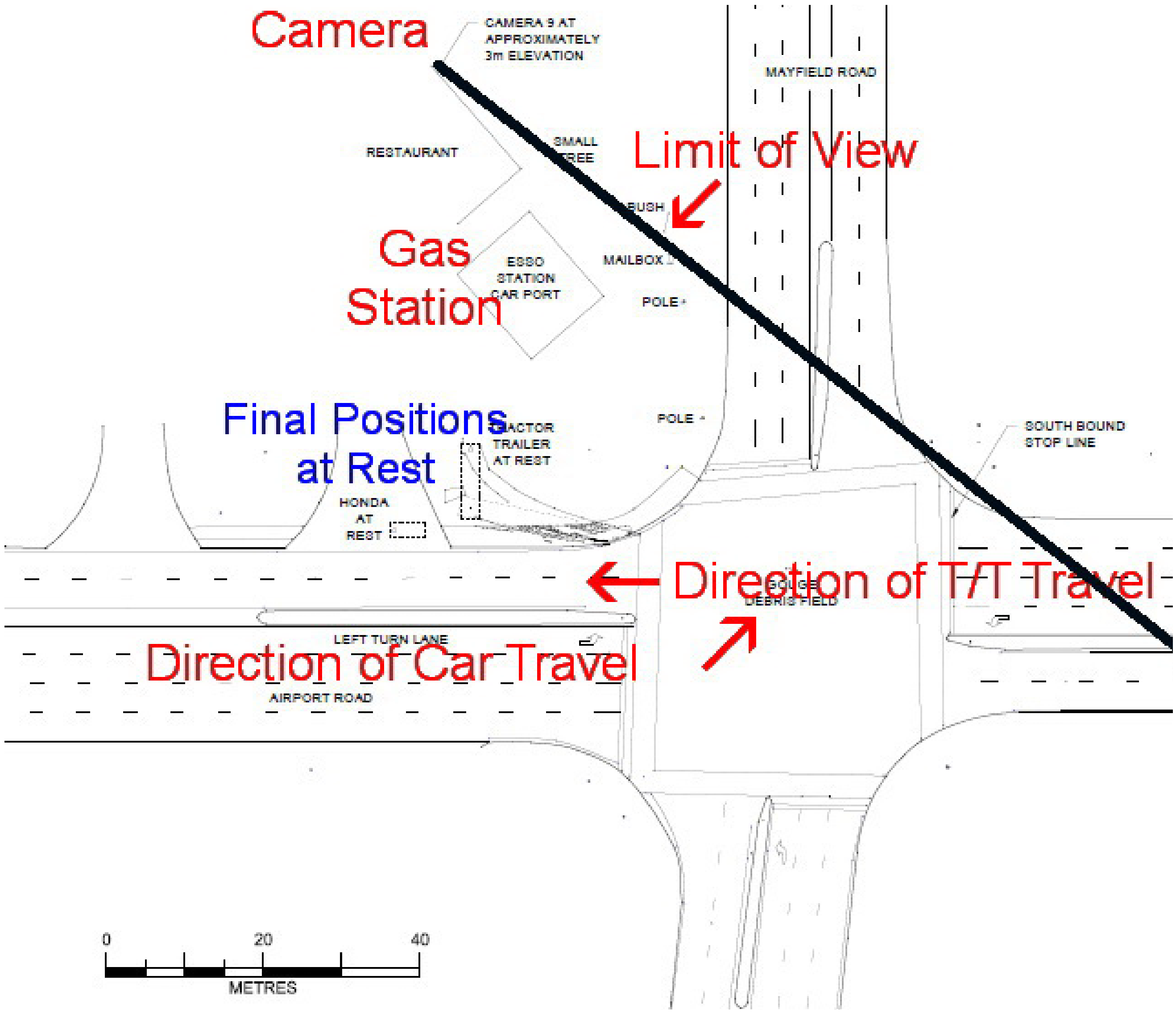


Figure 6
The scale diagram incorporates Arcon's Total Station measurements and information from of the Ontario Provincial Police (O.P.P.) collision reconstruction team's site drawings. It provides an excerpt that zooms in on the area of interest, showing the directions of vehicle travel, the final positions at rest, and the camera with the limit of view.

police officers. Tire marks extended from 6 meters (20 feet) beyond the gouge to the positions at rest. Tire impressions were seen in the soft ground on the lawn of the station, as shown in **Figure 7**.

2) The Passenger Vehicle (Honda)

This vehicle was a silver-colored early '90s model year, four-door Honda Civic. There was a major crush laterally from the trailing edge of the right rear door forward to the front bumper, inboard past the centerline, from 85 cm (33.5 in.) to a maximum of 130 cm (51.2 in.) at a fold in the roof panel. The vehicle had characteristics of being rolled as if overridden in the engagement. There were tire marks on the central portion of the right rear door, and

Figure 7
View to the northeast along the path of post-impact vehicle movement.

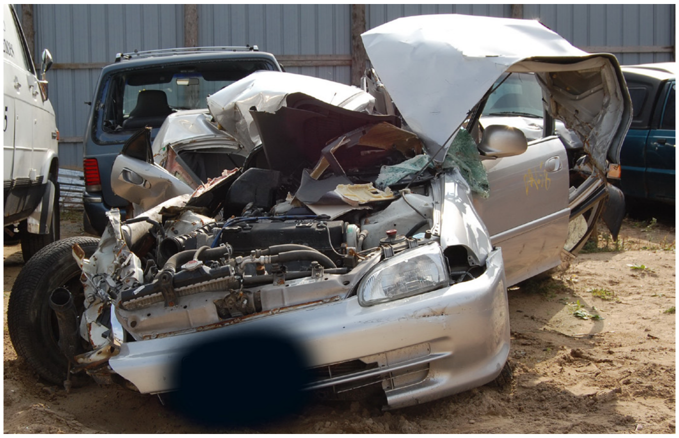


Figure 8
Front view of the Honda, showing depth of lateral crush.

similar marks on the bumper fascia just forward of the right front wheel, as seen in **Figure 8** and **Figure 9**.

3) The Tractor/Trailer Combination

The Western Star tractor was a blue mid-'90s conventional. The trailer was a Cobra dump body fully loaded with gravel. The calculated length of the combination was 20.1 to 20.3 meters (65.9 to 66.6 feet). The right front tractor bumper had been deformed upward and aft (**Figure 10**), with the lower portion pushed back. Bumper deformation extended across to the left side, which was folded back and under the driver's side headlight assembly (**Figure 11**). The right front wheel suspension components had deformed to splay the wheel outboard at the front with respect to its typical position. Contact was noted on the suspension components. There was silver paint transfer on the forward portion of the bumper.

4) The Impact Engagement

The Honda was engaged from the right side rear passenger door to the right front bumper by the left, center,

Figure 9
Right side view of the Honda.

Figure 10
Front view of the tractor
with post-impact bumper deformation.

Figure 11
Driver's side oblique view of the tractor.

and right sides of the tractor bumper, over the bumper's full width of 2.4 meters (7.9 feet). The depth of the crush at 100 cm (39.4 in.) height was greater than 85 cm (33.5 in.), which indicated that the passenger compartment was deformed to a depth of more than halfway, while other characteristics of the crush pattern demonstrated override of the tractor bumper over the Honda had occurred.

5) Eyewitness Commentary and Distribution

The eyewitnesses were distributed all around the AOI from 20 to 150 meters (66 to 492 feet) away. Their comments are summarized in **Figures 12a** and **12b**, with a cluster of reported speeds ranging from 90 to 100 km/h (56 to 62 mph). The author compiled the geographic distribution information of the eyewitnesses, as shown in **Figure 13**.

Few eyewitnesses recalled directly observing the signal status during the moments leading up to the collision,

No.	Position with Respect to Area of Impact	Comment on Tractor/ Trailer Speed	Comment on Signal Color for Tractor/Trailer
1	60 m west/northwest on the construction site, standing	Well over 90 km/h	Color unknown
2	70 m south/southwest, parked by coffee shop	90 to 100 km/h	Amber at truck entry
3	Accompanied #2 but did not recall the event.		
4	25 m south/southeast, stopped at northbound Lane 1 stop line	Not going 80 km/h	Amber northbound
5	150 m north/northeast in northbound Lane 1, driving	60 to 70 km/h	Amber northbound
6	60 m west/northwest on the construction site, standing	Well over 80 km/h	Red for southbound
7	45 m east in Lane 1 of Mayfield Westbound, stopped	Going really fast	Red for north/south
8	30 m northwest, at the construction site behind the fence	80 km/h, Maybe over 100 km/h	
9	30 m east, stopped in a westbound car on Mayfield	At least 100 km/h	Green for Mayfield
10	30 m east, stopped in a westbound car on Mayfield	100 km/h	Green for Mayfield
11	60 m west/northwest on the construction site, standing		
12	80 m south in the northbound left turn lane, to coffee shop	Over the limit of 60 km/h	
13	150 to 200 m north/northwest of the intersection, standing	Looked overspeeding	
14	15 m west, stopped in the eastbound left turn lane		Green for Mayfield after impact
15	40 m northwest, on an excavator at the corner	80 to 100 km/h	
16	50 m southwest pumping gas at the Esso, standing	90 to 110 km/h	

Figure 12a
Synopsis of eyewitness geographic distribution at the scene (in metric units).

No.	Position with Respect to Area of Impact	Comment on Tractor/Trailer Speed	Comment on Signal Color for Tractor/Trailer
1	197 feet west/northwest on the construction site, standing	Well over 56 mph	Color unknown
2	230 feet south/southwest, parked by coffee shop	56 to 62 mph	Amber at truck entry
3	Accompanied #2 but did not recall the event.		
4	82 feet south/southeast, stopped at northbound Lane 1 stop line	Not going 50 mph	Amber northbound
5	492 feet north/northeast in northbound Lane 1, driving	37 to 44 mph	Amber northbound
6	197 feet west/northwest on the construction site, standing	Well over 50 mph	Red for southbound
7	148 feet east in Lane 1 of Mayfield westbound, stopped	Going really fast	Red for north/south
8	98 feet northwest, at the construction site behind the fence	50 mph, Maybe over 62 mph	
9	98 feet east, stopped in a westbound car on Mayfield	At least 62 mph	Green for Mayfield
10	98 feet east, stopped in a westbound car on Mayfield	62 mph	Green for Mayfield
11	197 feet west/northwest on the construction site, standing		
12	262 feet south in the northbound left turn lane, to coffee shop	Over the limit of 37 mph	
13	492 to 656 feet north/northwest of the intersection, standing	Looked overspeeding	
14	49 feet west, stopped in the eastbound left turn lane		Green for Mayfield after impact
15	131 feet northwest, on an excavator at the corner	50 to 62 mph	
16	164 feet southwest pumping gas at the Esso, standing	56 to 62 mph	

Figure 12b
Synopsis of eyewitness geographic distribution at the scene (in U.S. customary units).

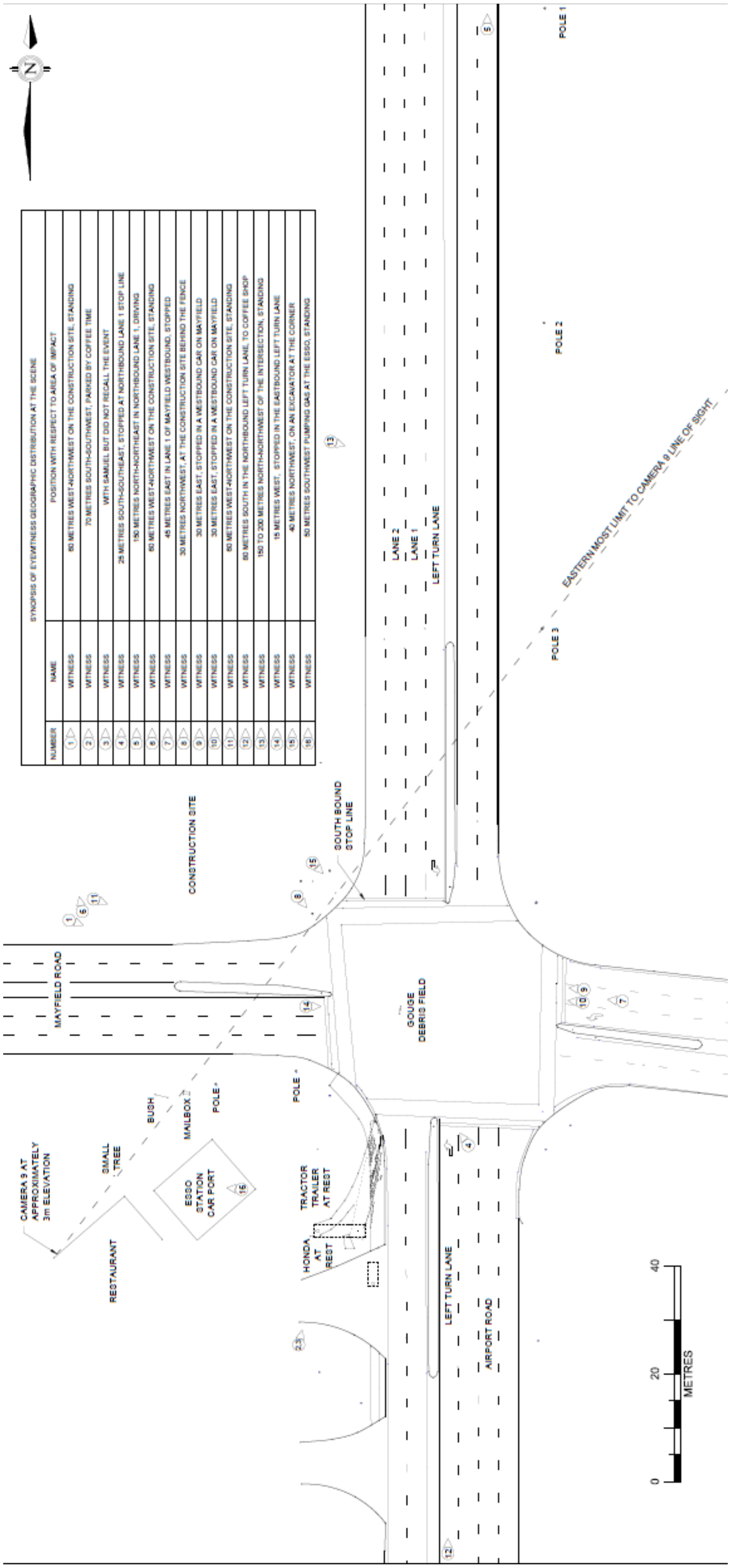


Figure 13
Scale drawing of witness positions at the scene.

Figure 14
Camera 9 was mounted at the southwest corner of the restaurant.

but many recalled that the sound of multiple truck horn blasts had immediately preceded the loud collision noises.

Observations from the Videograph from Camera 9

Camera 9 was located by the air pump at the rear of the restaurant building, as shown in **Figure 14**. The videograph from Camera 9 became available during litigation proceedings, which provided an opportunity to do a motion and time analysis of the positions of the vehicles. The footage was studied with a video player program (DVR.exe, version 1.4.1.23).

The camera viewing angle did not include the intersection or the signal status. The scaled site diagram (**Figure 6**) depicts the eastern limits of the line of sight of the video camera, which was mounted at a height of 3 meters (10 feet) above the sidewalk, 1 meter (3.3 feet) from the southwest corner of the building comprising the coffee shop. The footage of the bright sunny summer day was in color, with a detailed time-stamp number set visible in the upper right of the frame. There was no soundtrack in the copy of the video provided for analysis. **Figure 15** depicts the view from the south side of Mayfield Road by the bushes toward Camera 9.

Application of the Methodology for Assessing Vehicle Behavior

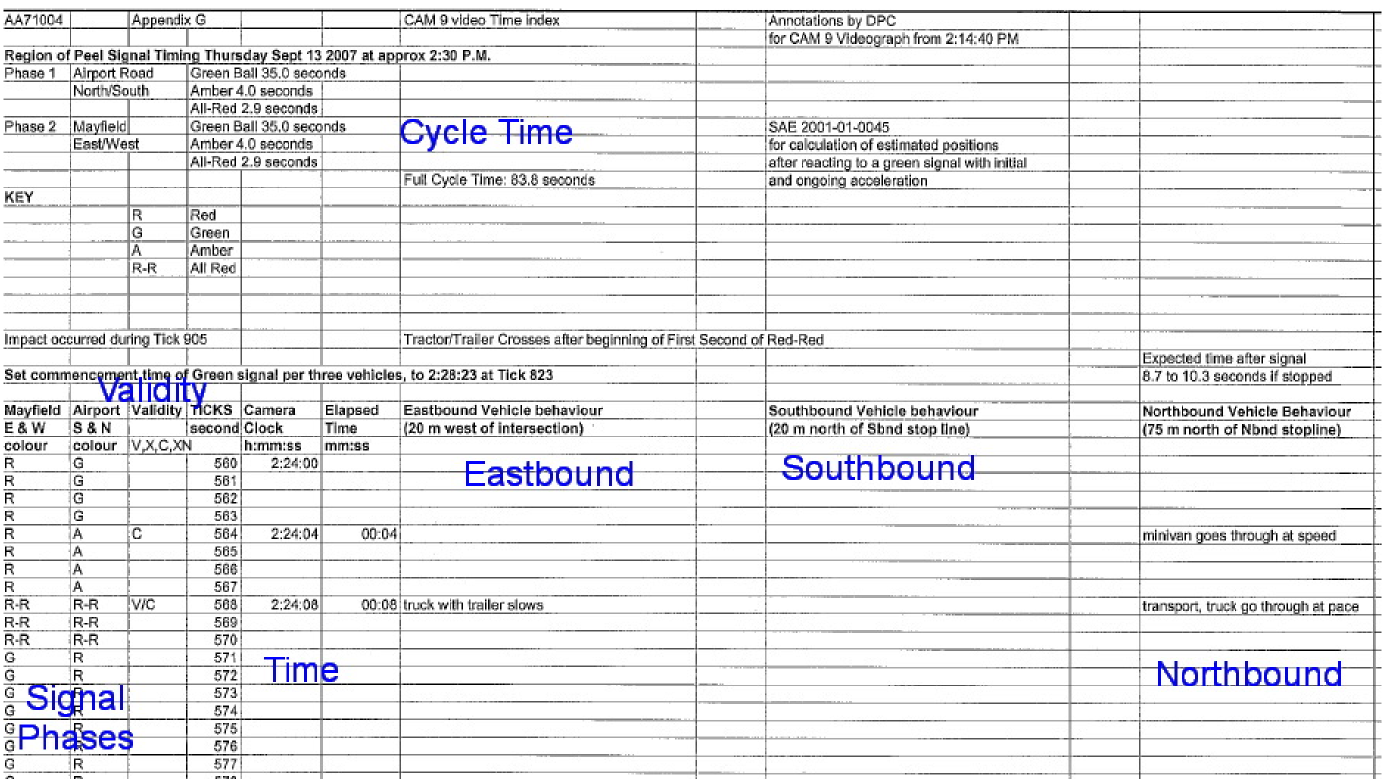
The steps outlined in **Figure 2** were implemented after gathering the information listed in **Figure 1**. A spreadsheet for analysis of the videograph was set up, covering the period from 2:24:00 p.m ("hours:minutes:seconds" format), approximately 6 minutes prior to the event, to 2:36:00, which was about 6 minutes after the collision. A tick system was created in which one unit is equivalent to one second on the videograph, where the first tick was at the beginning of the recording and for which 2:24:00 was equivalent to tick 560. Recall that to determine the number of seconds between two events, subtract the smaller tick from the larger.

The actions of the vehicles were described in a brief summary line (for example, *"white van coming to a stop in lane 1 eastbound"*) as recorded at a particular tick on the videograph. The behavior of vehicles for eastbound, southbound, and northbound traffic were scrutinized — from known positions on the scale diagram of 20 meters (66 feet) west, 20 meters (66 feet) north and 75 meters (246 feet) north of the respective stop lines. This procedure gave a population of 83 sets of observations of vehicle behavior, each of which could be characterized independently.

Figure 15
View toward Camera 9 from the south edge of Mayfield Road.

A two-column set was added on the left side of the spreadsheet with the signal colors for eastbound/westbound and northbound/southbound, using the symbols G, A, R and R-R for green ball, amber, red, and all red conditions, respectively. An excerpt of the first page of the spreadsheet is shown in **Figure 16**, with categories highlighted in blue. The next step was to determine a phase cycle starting point based on the description of behaviors.

Each event was ranked with validity criteria — that is whether it was reasonable behavior, given the signal phase for the direction the vehicle was traveling. More weight was given to observations in the foreground of the



AA71004 Appendix G CAM 9 video Time index Annotations by DPC for CAM 9 Videograph from 2:14:40 PM

Region of Peel Signal Timing Thursday Sept 13 2007 at approx 2:30 P.M.

Phase 1 Airport Road North/South: Green Ball 35.0 seconds; Amber 4.0 seconds; All-Red 2.9 seconds

Phase 2 Mayfield East/West: Green Ball 35.0 seconds; Amber 4.0 seconds; All-Red 2.9 seconds

Full Cycle Time: 83.8 seconds

SAE 2001-01-0045 for calculation of estimated positions after reacting to a green signal with initial and ongoing acceleration

KEY: R Red; G Green; A Amber; R-R All Red

Impact occurred during Tick 905

Tractor/Trailer Crosses after beginning of First Second of Red-Red

Set commencement time of Green signal per three vehicles, to 2:28:23 at Tick 823

Expected time after signal 8.7 to 10.3 seconds if stopped

Mayfield E & W colour	Airport S & N colour	Validity V,X,C,XN	TICKS second	Camera Clock h:mm:ss	Elapsed Time mm:ss	Eastbound Vehicle behaviour (20 m west of intersection)	Southbound Vehicle behaviour (20 m north of Sbnd stop line)	Northbound Vehicle Behaviour (75 m north of Nbnd stopline)
R	G		560	2:24:00				
R	G		561					
R	G		562					
R	G		563					
R	A	C	564	2:24:04	00:04			minivan goes through at speed
R	A		565					
R	A		566					
R	A		567					
R-R	R-R	V/C	568	2:24:08	00:08	truck with trailer slows		transport, truck go through at pace
R-R	R-R		569					
R-R	R-R		570					
G	R		571					
G	R		572					
G	R		573					
G	R		574					
G	R		575					
G	R		576					
G	R		577					

Figure 16
Excerpt of the first page of the spreadsheet for videograph analysis.

camera field of view, which is the eastbound lanes of Mayfield, than for observations of traffic on southbound Airport Road. The northbound traffic observations served as a checking tool only. **Figure 17** lists the range of vehicle activity for the positions in the frame. Each point was verified to affirm whether it matched a corresponding column that set the signal phase, using the known sequence described by the traffic authority in its correspondence. The analysis showed that, at certain times, the vehicles had behaved as if the lights were at specific phases of the cycles.

The sets of observations were further compiled for ease of reference and discussion as shown abridged in **Figure 18**. Observations that matched the choice of phases are described in that manner, while conflicts are highlighted in red. Critical times are highlighted in green.

Signal Phase Sequence Analysis for the Full Cycle Immediately Prior to the Collision

Further consideration of the observations found an eastbound silver-colored pickup traveling through and slowing down at Tick 784 (**Figure 19**), followed by an eastbound black sedan that slowed down near the right frame edge after Tick 796 (**Figure 20)** and stopped at Tick 822 **(Figure 21).**

The positions of the black car and the silver pick-up are shown in plan view at Tick 822 in **Figure 22**.

At Tick 825, the black car was observed (see **Figure 23**) beginning to move in response to a green signal (at 2:28:25.4). Using the criteria in SAE 2001-01-0045[1] (see **Appendix A**), which gave 1.4 to 1.5 seconds as an unanticipated response to a signal for the first vehicle and actual observations of second vehicle behavior in line, the black car was estimated to have moved ahead from 2.2 to 3.0 seconds after the green ball appeared for eastbound traffic. There were no clearing vehicles proceeding to finish their turns westbound from northbound at this time.

Position in the Frame	Observed Vehicle Activity
For Eastbound Mayfield Traffic	Going through to edge of frame, about 20 m (66 feet) from the eastbound stop line.
	Stopping in the through lane (Lane 1), as the driver reacts to an amber or red ball signal.
	Stopping in the left turn lane, as the driver reacts to an amber or red ball signal.
	Accelerating from a stopped position in the through lane, after the driver reacts to a green ball signal.
	Accelerating from a stopped position in the left turn lane, after the driver reacts to a green ball signal, then being seen northbound.
For Southbound Airport Traffic	Can be seen approaching on the screen, behind the time stamp digits.
	Go out of the videograph frame (easternmost limit) at 20 m (66 feet) north of the southbound stop line, near pole three, if in Lane 1, and later if in Lane 2.
	Can be seen going through at pace; going through slowly; slowing to a stop; stopped on the roadway.
	May make a right turn onto westbound, so they disappear and then reappear in the foreground.
	They react to signals by slowing down, by going through, or by starting to accelerate.
For Westbound Mayfield Traffic	Can only be seen after clearing the site line, about 53 m (174 feet) from the westbound stop line.
	Would take 7.3 to 8.0 seconds minimum to arrive at the sight line, if starting from a stop, applying the SAE 2001-01-0045 criteria of 1.4 seconds after a green signal for movement to start.
	May be northbound traffic clearing after a left turn.
	May be southbound traffic coming around the corner at pace, or after being stopped.
For Northbound Airport Traffic	Through traffic moving through at pace may have passed through the intersection at least 73 m (239 feet) south when we see them at the sight line in the video; at 60 to 80 km/h (37 to 50 mph), or 16.6 to 22.2 m/s (54.5 to 72.8 feet/sec), the time could be 3.3 to 4.4 seconds.
	It takes 8.7 to 10.3 seconds to reach the point of view, if the vehicle was stopped at the northbound stop line and has a 1.4 second delay after the green signal.
	Left turns by eastbound vehicles can be seen at the start of the turn in Cam 9 footage, and then again 9 to 10 seconds later as they proceed northbound.
	Right turns eastbound from Lane 2, which is for straight with right turns optional; cannot discriminate these.

Figure 17
Case study decision rules for analysis of vehicle behavior.

	Abridged Summary of Observations				
			Key for codes / Number of Matches	**Percentage**	**Correct Match Percentage**
			Remained Invalid - X 0	0.0%	
	Iteration 10 - using time green signal at 2:28:23 and 2:29:05		Newly Invalid - XN 3	3.6%	
	Impact at 2:29:45.5, Tick 905		Correct with changes - C 69	83.1%	**96.4%**
	Tractor trailer entered the intersection at tick 904 after the southbound red signal		Still Valid -V 11	13.3%	
		Z	TIME OF IMPACT - Z 4		Total points = 83 + 4 = 87
	Commentary or Observations				
Tick			**Eastbound**	**Southbound**	**Northbound**
560	start of analyzed period	C			
688	match	C		silver vehicle comes to a stop	
699	pickup truck appears to go through on a	XN/C	traffic moving througn on red	school bus stops for a green 50 m away	
770	match	C		large truck comes to a slow stop after car	
778	dump truck through at speed, enters on a red signal	C	dump truck through at speed		
783	match	C/V	silver pick up truck coming to a stop	large truck crawling along	
784	match	V	lt brown bob tractor comes to stop left turn lane		
787	match				
789	match	C		large truck keeps moving	
793	match	C/C		large truck goes by edge of frame	transport goes through
800	match	C/C	black car comes to a full stop by	southbound dumptruck goes through at	
815	match	C		white cube van goes through	
823	likely green light time per vehicle analysis, Tick 825, 831				
825	***black car begins to move ahead, followed by others***	C	black car begins to move ahead, followed by others		
831	*westbound car passes edge of frame*				
846	match	C			bobbed tractor seen going north
848	***transport goes through, perhaps after***	XN			transport through
850	match	C	line of traffic, last white pickup drive		
855	match	C	dark vehicles follow through		
860	match	C			
865	start of green signal to match Tick 873				
870	***match***	C		rt turning bus passes; other bus has gone through	
873	white vehicles (2) go through	C			white vehicles (2) go through
876	match	C			vehicle driving through
883	match	C	no eastbound traffic	no southbound traffic	dumptruck passes through at pace
887	match	C			red dumptruck passes at pace
894	white car slowing to stop	C	whjte car slowing to stop		
898	white car stopping, left turn lane	C	white car stopping, left turn lane	A/R	
900	**dark car passes edge at pace at 2:29:40.5**	Z	**no vehicles seen**	**dark car passes edge of frame at pace**	**no vehicles seen**
901		Z	**no vehicles seen**	**involved transport comes into view**	**no vehicles seen**
903	**FR TRUCK AT EDGE OF SCREEN at 2:29:43.8**	Z	**no vehicles seen**	**rear of transport passes a pole in view**	**no vehicles seen**
904	**inv transport exits the camera view 2:29:44.6**	**Z**	**no vehicles seen**	**involved transport exits the camera view**	**no vehicles seen**
905	**LIKELY IMPACT, 20 M SOUTH OF STOP LINE, 2:29:45.5**				
912	**REACTION TO CRASH BY RF PASS RED CAR - points with her arm**				
916	match	V	pickup truck comes to a stop, left turn lane		
926	match	C		school bus approaches intersections, slowing	A/R
938	match	C		dark vehicle coming to a stop behind bus	

Figure 18
Abridged compilation of observations.

Figure 19
Silver pickup slowing at Tick 784.

Figure 20
Black car slowing at Tick 796.

Figure 21
Black car stopped at frame edge at Tick 822.

At Tick 831, the first of three westbound vehicles can be seen (**Figure 24**) at the edge of the frame at 2:28:31.4. It was assumed that this vehicle was first in line, at a position that was 53 meters (174 feet) east of where it can be

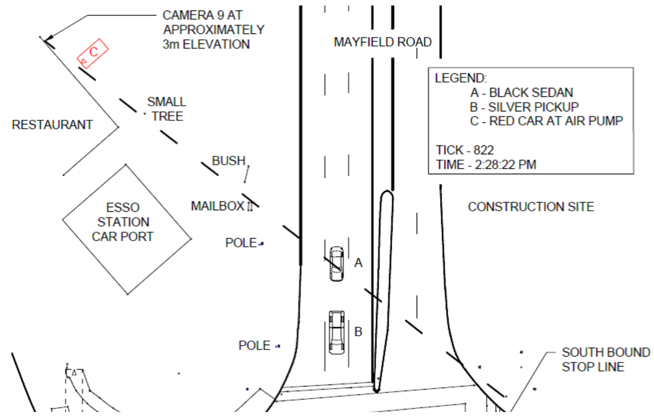


Figure 22
Positions of black sedan and silver pick-up truck at Tick 822.

Figure 23
Black car begins motion eastbound during Tick 825.

Figure 24
First westbound vehicle emerges from the right side of frame at Tick 831.

first seen in the videograph. Using the single-frame analysis technique, the speed of this vehicle was calculated to be from 45 to 50 km/h (28 to 31 mph), which was consistent for acceleration from a stop, using the SAE 2001-01-0045 guidelines. It was then estimated that the earliest this vehicle could appear on screen was from 7.1 to 8.0 seconds after the green signal for westbound Mayfield traffic.

The proposed start time of the eastbound/westbound Mayfield green signal was set to 2:28:23, Tick 823, to coincide with both observations because the analysis showed that it could not reasonably be later than this.

At Tick 873, (or 2:29:13), there were three northbound vehicles in the videograph that had traveled about 73 meters (240 feet) north of the northbound stop line. One is seen in **Figure 25**.

Figure 25
First northbound vehicle seen at tick 873.

Time Stamp (h:mm:ss)	Signal Phase	Tick
2:28:23	Start of green for eastbound Mayfield Road	823
2:29:05	Start of green for southbound Airport Road	865
2:29:40	Start of amber for southbound Airport Road	900
2:29:41	Start of 2nd second of amber for southbound Airport Road	901
2:29:42	Start of 3rd second of amber for southbound Airport Road	902
2:29:43	Start of 4th second of amber for southbound Airport Road	903
2:29:44	Start of 1st second of all-red	904
2:29:45	Start of 2nd second of all-red	905
2:29:46	Start of third portion of all-red, only 0.9 seconds duration	906
2:29:47	Start of green for eastbound Mayfield Road	907

Figure 26
Correspondence between time stamps, signal phases, and tick designations.

If they had been stopped at that position, each would take between 8.7 to 10.3 seconds to traverse the intersection and be seen on the videograph, assuming once again that the criteria in SAE 2001-01-0045[1] can be applied. Had the vehicles not started from a stop, then they could have arrived between 7.2 and 8.3 seconds (earlier, that is) after the appearance of a northbound green signal. The group of vehicles appeared to be clustered together.

These findings led to the setting of the proposed green signal start for northbound and southbound Airport Road at 8 seconds prior — that is at 2:29:05, Tick 865.

Green Ball Start Time for the Cycle Immediately Prior to the Collision

The latest possible moment for the start of the green signals for Mayfield Road was at Tick 823, while for Airport Road it was Tick 865, for the Phased Signal Cycle immediately before the collision event. The limited possibility that it could have been one or two seconds earlier was considered (if the motion of the analyzed vehicles was more aggressive), but was discounted because these two start times fit exactly within the known timing regime published for the incident date.

The hypothesis that these green signal commencement times were correct was accepted. Subsequent analysis of the collision was accordingly based on these times. The 83 sets of observations were compared with typically expected traffic behavior with the hypothesized signal status at any given tick. **Figure 26** lists the designated ticks and corresponding Camera 9 time stamps that arose after the signal phase analysis.

The concordance between observations and signal phases was 80 of 83 sets (96.4%), with one major and two minor exceptions:

1) An eastbound pickup truck apparently runs a red light at Tick 699 (major);

2) A transport moving through northbound at Tick 848 (minor); and

3) Another transport moving through northbound at Tick 1186 (minor).

Given that direct observation of the northbound lanes was impossible from the videograph of the scene, the latter two observations were discounted without undermining the validity of the group. The second and third

Figure 27
Dark vehicle traveling southbound at the end of Tick 899.

Figure 28
The dark vehicle leaving the frame at midpoint of Tick 900.

exceptions could have been by vehicles that turned right on the red signal.

The strong concordance formed the basis for a high degree of confidence with respect to the correctness of the hypothesis of the green signal commencement times for the phase cycle at Tick 823 (eastbound/westbound) and Tick 865 (northbound/southbound) immediately prior to the collision event.

Calculation of Vehicle Speeds by Videograph Frame-by-Frame Feature and Position Comparison

At a playback speed of one frame per 1/30th of a second, the videograph revealed that a dark vehicle, likely a car, passed the edge of the videograph frame. When analyzed in single-frame mode, the time stamp indicates this occurred at 2:29:40.5 in the Tick 900 interval. The author

Figure 29
The front of the tractor/tractor becomes visible behind the time stamp edge at Tick 903.

had to assume that it was in Lane 1. This dark vehicle traveling several seconds ahead of the tractor/trailer had a calculated speed of 18.7 to 20.6 meters per second (61.3 to 67.6 feet/sec), or 68 to 74 kilometers per hour (42 to 46 mph). It is shown in the upper right corner of the frame in **Figures 27** and **28**. This calculation was done at 2:29:39.66 (20th frame of 30) to 2:29:39.93 (28th frame of 30).

In a similar way, the speed of the tractor/trailer was calculated as 19.6 meters per second (64.3 feet/sec), which is equivalent to 71 kilometers per hour (44 mph). It was determined through the author's forensic engineering analysis of the physical evidence that the tractor-trailer was traveling in Lane 1. This determination was consistent with witness statements. This calculation was done at 2:29:42.97 (29th frame of 30) to 2:29:44.0 (30th frame of 30) seconds on the videograph. These positions are shown in **Figures 29** through **31**, which are screen captures. The nominal accuracy was 3%, putting the tractor/trailer speed at 69 to 73 km/h (43 to 45.3 mph). This was well below the estimates by all witnesses.

The tractor had not passed the edge of the frame at the start of the all-red, as shown in **Figure 31**, and the corresponding ground position is shown in the plan view of **Figure 32**. The tail end of the trailer had moved past the edge of the frame by the 14th of 30 frames of Tick 904, as shown in **Figure 33**, confirming that it had not entered the intersection before the all-red phase had begun.

Speed and Position of the Dark Vehicle

On the videograph, the tractor/trailer can be observed at the edge of the time stamp at Tick 843 — about four

Figure 30
The front of the tractor/trailer emerges by the time stamp at the mid-point of Tick 903.

Figure 31
The front of the tractor trailer at the start of all-red, Tick 904.

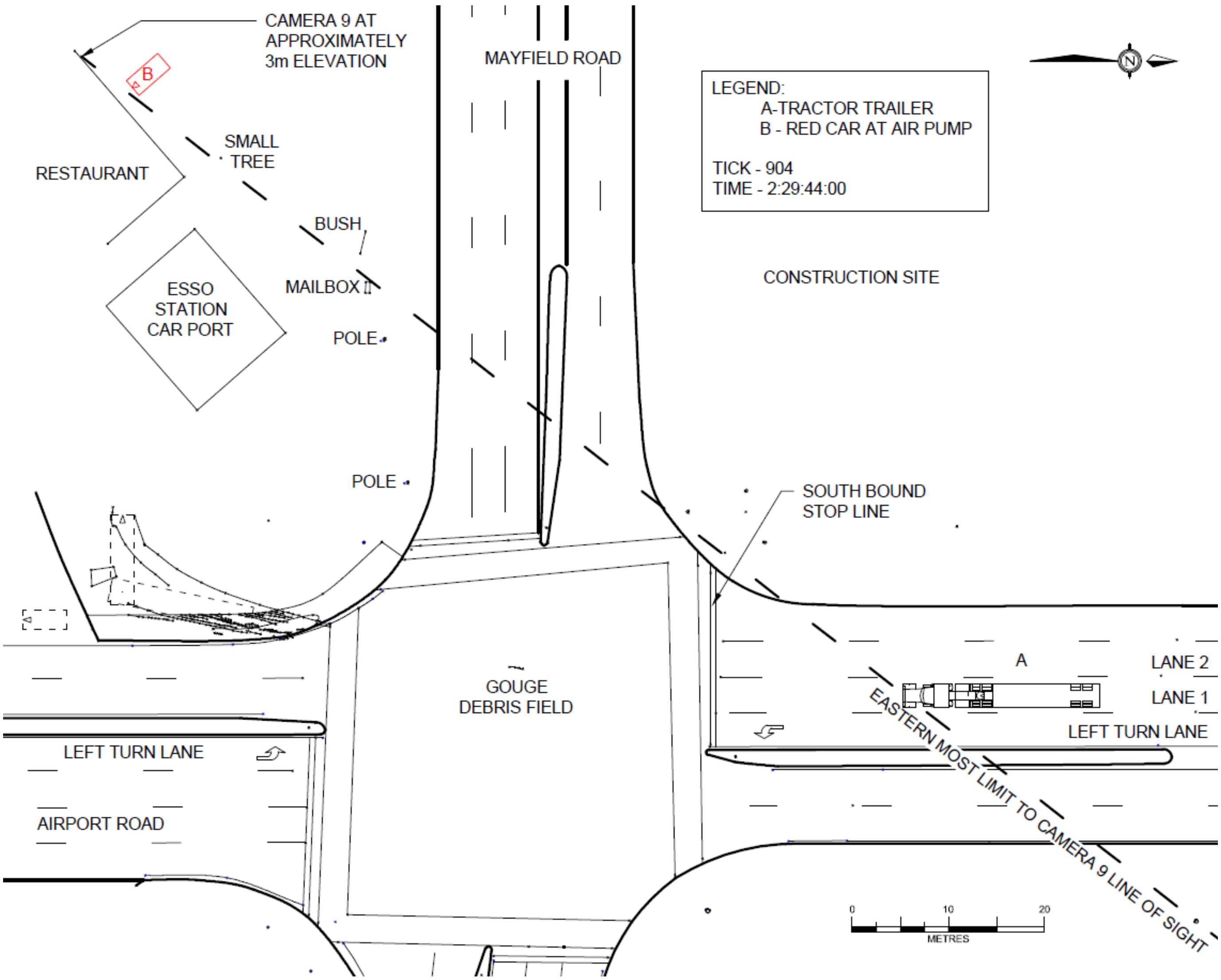


Figure 32
Position of the tractor/trailer at the beginning of all-red, Tick 904.

Figure 33
At the midpoint of Tick 904, the first second of all-red, the end of the tractor/trailer is at the edge of the screen.

full seconds behind the dark vehicle, which has passed the same position at Tick 839. This geometric configuration implied that both vehicles at similar speeds cannot enter on an amber.

The positions of the vehicles are depicted in **Figure 34** (with the key in **Figure 35)** at the intervals from the PC Crash analysis, with the key indicating that the bar corresponds to the signal color at any position for the 4-second-long amber signal and 2.9-second all-red signal for southbound traffic. The dark vehicle crossed the stop line and entered the intersection at 2:29:41.4, during Tick 901, the 2nd second of southbound amber. Since the Honda and the dark vehicle did not collide, this vehicle passed by the Honda as the Honda began its turn left to proceed westbound (**Figure 36**). The position of the dark vehicle restricted the motion of the Honda's turn to after

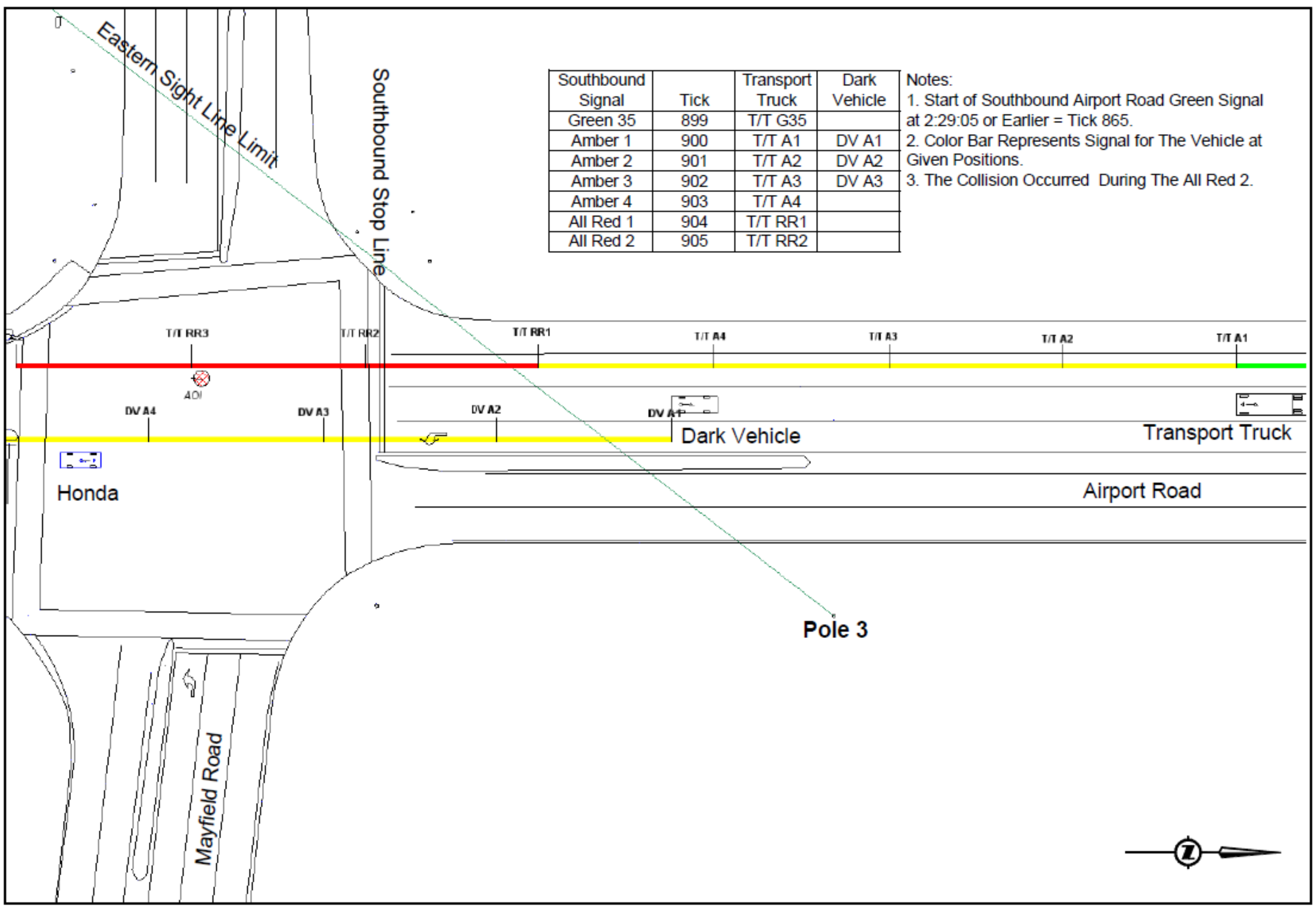


Figure 34
PC Crash analysis diagram showing positions prior to collision.

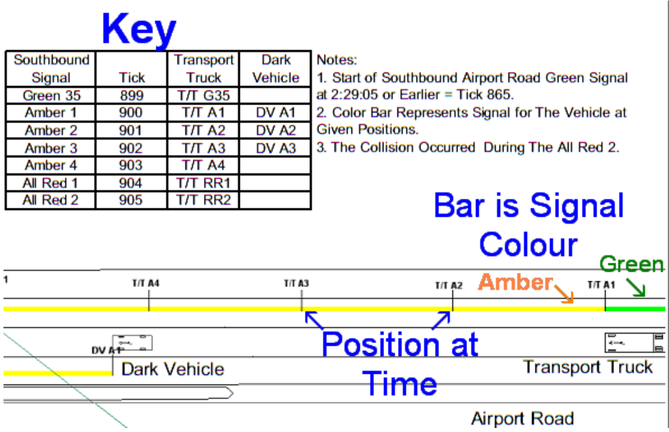


Figure 35
Key to vehicle positions in Figure 34.

2:29:43 because the dark vehicle required 1.5 seconds to travel 30 meters (98 feet) past the Honda's stopped position. This interaction between the dark vehicle and Honda was critical to understanding the context of the collision.

Position of the Tractor/Trailer When It Leaves the Video Screen

From the videograph, the back of the tractor/trailer at the eastern limit of the camera view at 2:29:44.6 can be seen, and given its length of just over 20 meters (65.6 feet), its front end would be at the southbound stop line when it is in Lane 1, as shown in **Figure 37**. At its calculated speed, the tractor/trailer would take another second to travel to the area of impact to the south along the demarcation between Lanes 1 and 2. However, the phase cycle analysis indicated that at Tick 904, 2:29:44, the signal had turned to all-red. Thus, if the truck is entering the intersection boundary at 2:29:44.6 or later, it must have done so in the second portion of the all-red signal. The collision engagement began at 2:29:45.5 during Tick 905, for a vehicle speed of 71 km/h (44 mph) or 19.6 meters per second (64.3 feet/sec). This is within the 2nd second of all-red for the northbound/southbound phase.

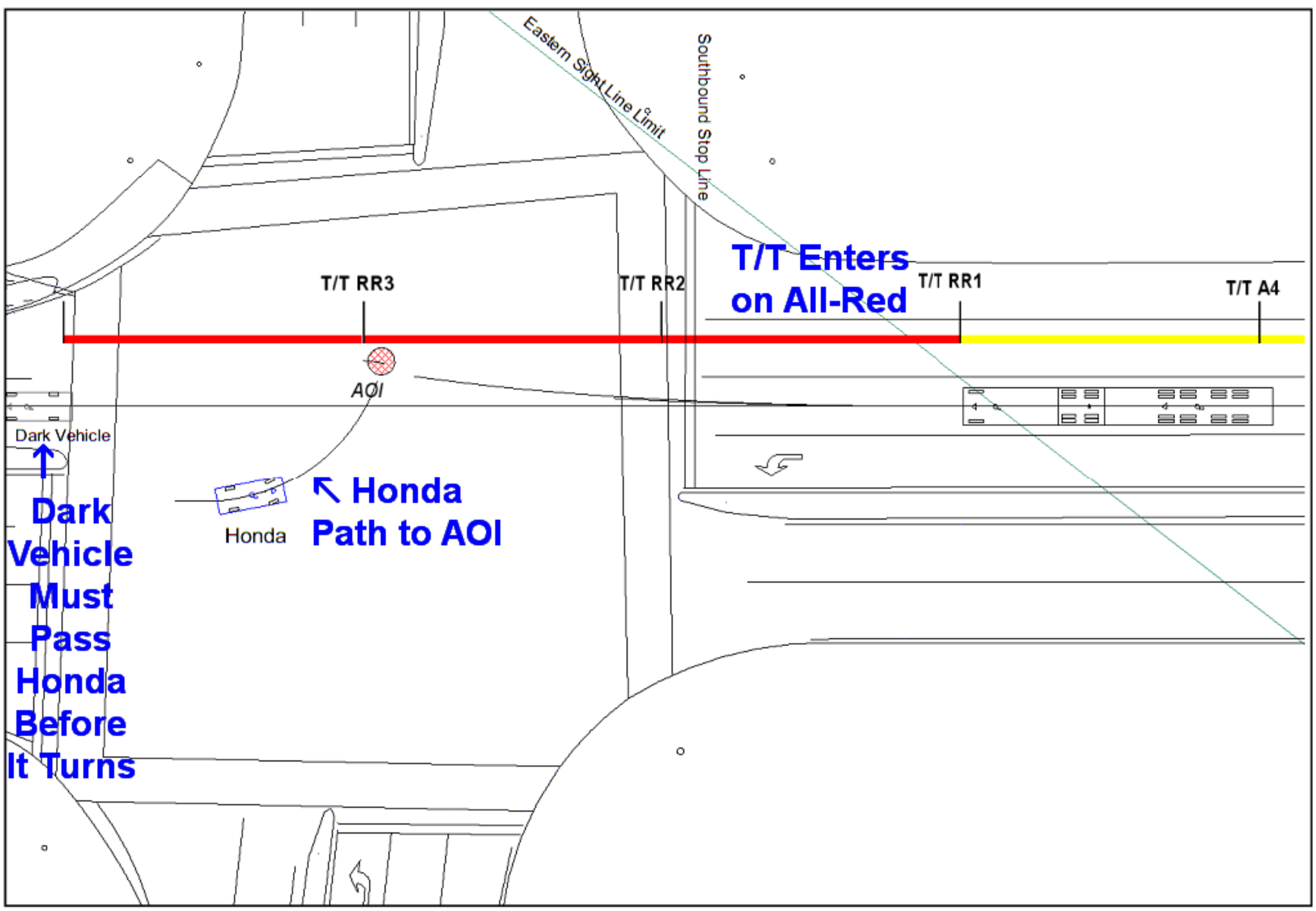


Figure 36
Intersection positions from PC Crash analysis at times listed in Figure 34.

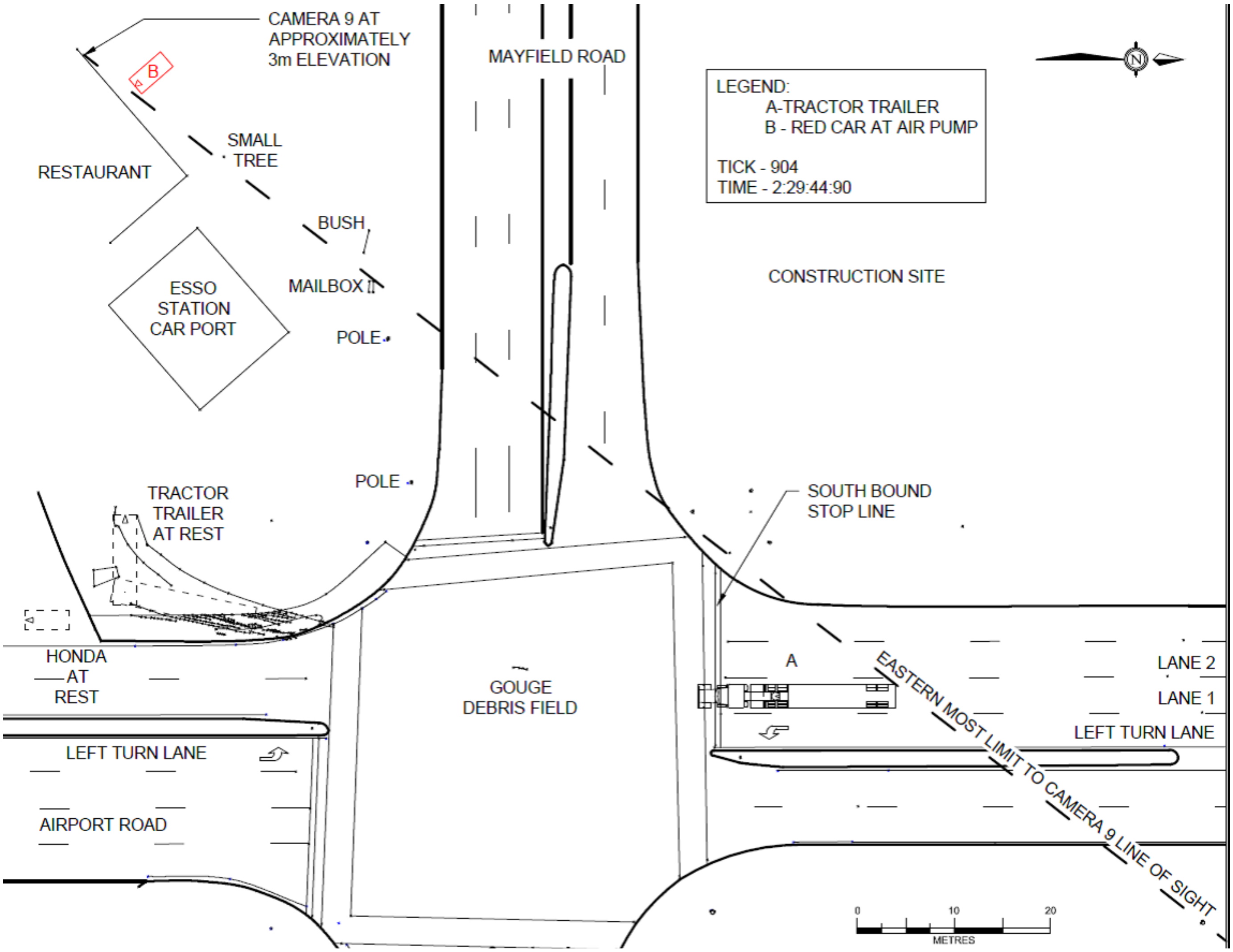


Figure 37
Position of tractor/trailer when it sounded the horn, according to the red vehicle passenger startle reaction analysis.

Supplementary Information from the Videograph Record: Reaction by a Passenger at the Tire-Filling Station

The right front passenger of the red vehicle getting its tires filled, about 70 m (230 feet) away, with the windows down, reacted to an unknown stimulus at 2:29:45.2, according to the frame-by-frame analysis. A few seconds later, she lifted her left arm and pointed to the driver's side of the car.

For a blast sound of a horn to arrive at the right front passenger's position would be approximately 0.20 seconds, at the speed of sound of 342 meters per second (1122 feet/sec) at 20°C (68°F) and one atmosphere pressure. Typical muscular reaction to a startling sound is on the order of 50 milliseconds[2,3], such that the noise that instigated the passenger's reaction would have originated no sooner than 2:29:44.9, in Tick 904, about one half second before the collision event.

Discussion of the Technical Analysis

The technical analysis of the videograph was the basis for discriminating the color of the respective signals for both roads at any given time interval. This was independent of eyewitness information, and therefore was very much less subjective. A variety of rules were used to establish and verify the best estimate of the start of the green signals of the phase cycle prior to the collision.

The findings did not conflict with or contradict any of the witness accounts, with the exception of Witness 5, whose vehicle did not appear on the videograph. The last northbound vehicle seen in the videograph, a red dump-truck, comes into sight at Tick 888, at a position 50 meters (164 feet) north of the intersection. This is more than 15 seconds prior to the ensuing collision at Tick 905. At 20 meters per second (65.6 feet/sec), this vehicle would be 350 meters (1,150 feet) from the intersection at the time of the collision. If this was Witness 5's vehicle, his statement would not align with these facts.

The inferences do have a quantifiable but small margin of error, but by scrutinizing the behavior and position of vehicles, the vehicle behavior could be matched to the inferred signal color. The sources of variation are:

- The unknown correspondence between the signal control time and the video camera time seen on the stamp in the frame;
- The calibration status of the clock on the video camera;
- The choice of the start of tick interval is arbitrary and could be out by half a second;
- The lane position of the dark vehicle (either Lane 1 or Lane 2); and
- The assumptions of vehicle behavior do not account for unexpected inputs such as at Tick 699, less than 4 minutes before the involved collision, where a pickup was observed most likely running a red light in the eastbound direction. This exception may have proved the rule.

An indirect witness, the lady passenger in the red vehicle at the tire filling station, reacted to an unexpected stimulus, which the author assumed to be a loud sound. Since she likely wouldn't react to a stimulus before it happened, her startle reaction gives us the latest time for a loud noise to arrive at her position, some 70 meters (230 feet) away from the area of impact, as 2:29:45.2, in Tick 905. The technical literature on startle responses and the physics of sound indicated that the sound likely originated one quarter second prior at 2:29:44.9. This corresponds closely to the estimated time of entry of the tractor/trailer into the intersection after the start of the all-red signal. It was entirely consistent with multiple witness accounts of first hearing a horn blast or blasts and then seeing a collision.

The method established the commencement of the green signal for southbound traffic prior to the collision. It was determined that the dark vehicle entered and traveled through on southbound amber, followed 4 seconds later by the tractor/trailer entering on the second portion of three of the all-red signal for southbound traffic.

Together with the timing and Total Station, site survey analyses indicated that the transport was 85 to 95 meters (280 to 312 feet) north of the intersection at the start of the amber signal. Using the calculation of the speed as 71 km/h (19.7 m/s, 44 m.p.h.), with the transport at 4.3 seconds travel time to the intersection, an attempt was made to duplicate Figure 20 in Gates et al. (2007), by using its logistic regression Equation 6 and predicted probability Equation 8, with the following values and variables[4]:

- Transport speed of 44 mph (71 km/h);
- Amber (yellow) signal length of 4.0 seconds, as at Airport Road southbound;
- No adjacent vehicles passing through;
- Heavy vehicle type; and
- The presence of an opposing left turn vehicle.

The calculated result of Equation 6 and Equation 8 showed that the probability of the transport going through was 38.8%, and the probability of the transport stopping was 61.2%. This logistic regression function was developed over the nearly 900 observations of vehicles made in that study. The function was plotted with MATLAB, a commercially available validated calculation and graphic program.

This calculated value and corresponding probability is shown in the accompanying **Figure 38** by the intersection of the black arrow and the red curve for heavy vehicles. This was the best-case scenario put forth by another expert (discussed below), while the time/position analysis showed that the travel time was closer to 4.8 seconds, putting probability of stopping near 80%.

The Gates et al. study noted on page 38 that "*most of the red light running vehicles could have stopped comfortably, assuming that the yellow indication was quickly perceived by the driver.*"

Responding Expert's Critique and Analysis

There was general concurrence with the overall analysis of speed by momentum, crush analysis and resting positions in the responding report prepared for counsel of the other party. The tractor/trailer speed of 19.6 meters

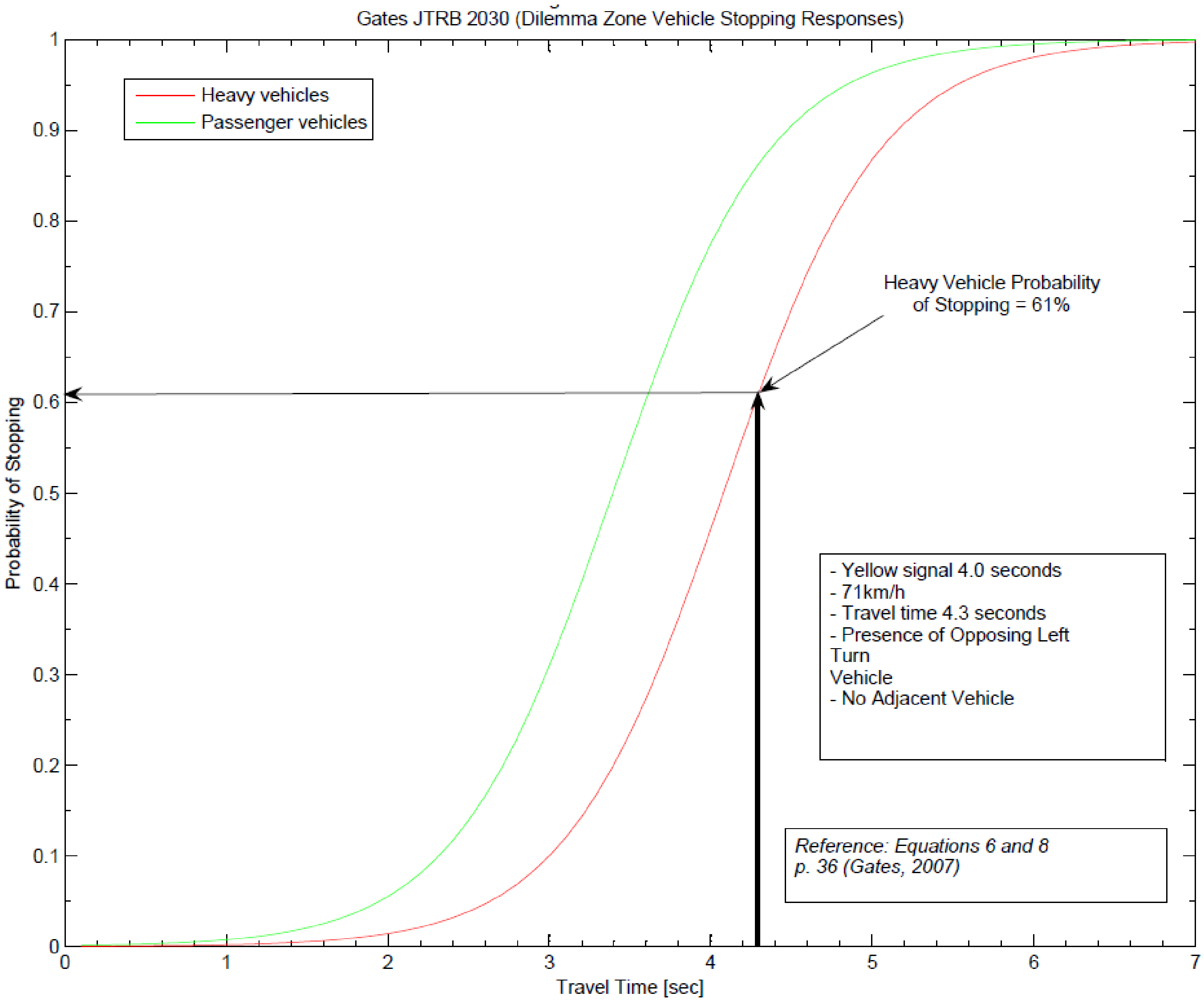


Figure 38
Heavy and passenger vehicle stopping probability from logistic regression.

per second (64.3 feet/sec), or 71 km/h (44 mph), from the videograph techniques compared well with the responding report's "optimal" speed of 69 km/h (43 mph) developed from a suite of widely used reconstruction methods and techniques. These standard techniques were also used by the author and his colleagues during the analysis of the collision. This convergence of speed estimates from technical methods completely contradicted the multiple witness statements clustering around 90 to 100 km/h (56 to 62 mph).

The responding report had differing assumptions pertaining to the start of green for eastbound Mayfield traffic. The principal disagreement concerned the assumption made about the timing of the black car's start-up time as 1.3 seconds before movement at Tick 825 (2:28:25), in contrast with the assumption of a range of 2.2 to 3 seconds based on the author's field trials for second vehicles. The responding report did not account for the presence of the silver pickup in front of the eastbound black car, which could have only delayed the black car's departure. By setting the green signal later than it likely actually was, the amber signal for Mayfield was also moved ahead, inducing an error that cascaded through in the subsequent position analysis.

In the CAM 9 video, two vehicles were observed coming to a stop and waiting in line behind the eastbound Mayfield Road stop line in the moments up to 2:28:20 (a silver pick-up truck and a black car behind it). The black car was in motion in the video at 2:28:25.4. Since there was another vehicle in front of it, it was estimated that the black car began its forward motion at 2.2 to 3.0 seconds after the green ball, to correspond with the field observations of the departure times of second vehicles in line at an intersection.

Underlying this was the assumption that the first-in-line silver pick-up truck would move forward in the typical 1.3 to 2 seconds shown in SAE 2001-01-0045, which published a mean value of 1.66 seconds with a standard deviation of 0.69 seconds for first vehicle reactions to green ball appearance at one intersection and 1.42 seconds with a standard deviation of 0.58 seconds at another intersection.

Given the lack of published data with respect to the mean and standard deviations of departure times for second vehicles waiting at traffic signals, a program was set up to generate field data. The author and colleagues measured the time from the change to a green ball signal to the first detectable motion of the wheel of a vehicle, which would be late in the first phase of acceleration. That motion was for a quarter-to-half rotation of a wheel. First movement of the vehicles in this experiment was being compared with first movement of the vehicles in the video frame analysis, to determine the likely time of the beginning of the green phase for eastbound and westbound. The data can be found in the **Tables A2** and **A3** of **Appendix A**.

The 34 data points for second vehicle departures have a mean value of 2.50 seconds with a standard deviation of 1.15 seconds. Removing the two fastest and slowest times as outliers changes the mean to 2.41 seconds, with a standard deviation of 0.78 seconds. Assuming a normal distribution of points, 68% would be expected to fall between 1.63 seconds and 3.19 seconds. The chosen values of 2.2 to 3.0 seconds fell within this range, and the selection of 2.4 seconds for the analysis of the eastbound green ball timing reflects the distribution of data clustered around that value.

Accordingly, the green ball start value was set to 2.4 seconds prior, that is 2:28:23 (Tick 823), and the calculated arrival time at the southbound Airport Road stop line was during the 2nd second of all-red interval (2:29:45, Tick 905).

Note that the average response by "anticipators" was 1.6 seconds, with a range of 1.3 to 2.3 seconds. These responses were very similar to the 1.3 seconds suggesting that the responding report focused on an anticipated reaction by the driver of black car. This was a specific rather than a general case, and gave the best possible outcome for the transport driver, with respect to whether or not he had entered on a red signal.

The overall analysis of the behavior of the vehicles in the CAM 9 video strengthens the opinion that the eastbound green ball signal occurred at 2:28:23 (Tick 823). This directly underpins a conclusion that the transport entered the intersection during the 2nd second of the all-red interval — the tractor/trailer driver ran a red light.

The interaction between the Honda and the dark vehicle was critical to the context of the collision, but was not discussed by any other technical investigators in their reports or testimony. The Honda's path to westbound Mayfield necessarily passed behind the dark vehicle, or they would have engaged. The Honda started from a stopped position at Tick 902, and moved into Lane 1 southbound after the dark vehicle passed by — well into the third of fourth portions of the southbound amber signal. The Honda was clearing the red signal when it was hit broadside.

As a matter of course, typical drivers assess the gap between their own vehicle and oncoming vehicles, and often pay attention to one oncoming vehicle but not others when making turns. Certainly, the reconstruction analysis showed that the Honda could not have turned sooner than it did, due to the presence of the oncoming dark vehicle. This constraint set the immediate conditions prior to the arrival of the tractor/trailer, and therefore was part of the circumstances of the collision event.

Summary of Contributions of the Method to the Collision Reconstruction

The original goal was to add more information to assist the triers of fact, using the indirect security camera video footage of the collision incident. The forensic team used the eight steps of the rule-based triage method to get to the essence of the matter, which had been obfuscated by the multiple conflicting witness statements. There were four contributions of the method:

- Determination of green ball timing to within 0.5 seconds (0.6% nominal error);
- Resolving the most probable color of the southbound signal at tractor/trailer entry;
- Incorporating the influence of the dark vehicle on the collision dynamics; and

- Allowing assessment of the probability of the tractor/trailer going through in the given set of circumstances.

Based on close scrutiny of the videograph of Camera 9 of the behavior of vehicle traffic for 6 minutes prior to the collision, with a match of 96.4% of observations, the analysis determined that the green ball for eastbound traffic on Mayfield Road illuminated at 2:28:23 (Tick 823), and the green ball for southbound traffic on Airport Road illuminated at 2:29:05 (Tick 865).

It was shown to be more probable than not that the southbound tractor/trailer entered on a red signal, by the analysis of the motion of other vehicles in response to the traffic signal phases at the intersection of Mayfield and Airport Roads. The southbound tractor/trailer entered the intersection after the illumination of the all-red signal, after the first full second (Tick 904) of the 2.9 second duration of this signal, at 2:29:44.6 on the videograph from Camera 9, with its position confirmed by site geometry based on Total Station measurements. The collision between the southbound tractor/trailer and the left-turning Honda occurred at 2:29:45.5, (Tick 905), which was during the 2nd second portion of the 2.9 second duration all-red signal.

The videograph analysis process indicated that a dark vehicle progressed southbound at a speed between 69 and 74 km/h (43 to 46 mph) through the intersection, entering on the second part of the 4-second-long amber signal (Tick 901), whereas this had not been previously considered by the investigators. To begin to make its left-turn to clear the intersection, the Honda passed behind the dark vehicle as it went by during the third second (Tick 902) of the amber signal.

Once the timing had been established, it was demonstrated that the calculated probability of a tractor/trailer combination driver stopping, based on the function in Gates, was 61.2%, in the same circumstances stopping when faced with the amber light at 4.3 seconds travel (equivalent to 85 m or 280 feet) from the stop line, as determined by the videograph. For longer travel times depicted in the time/position analysis diagrams, the probability of stopping would be higher (80%).

Epilogue

In the Province of Ontario jurisdiction under the Highway Traffic Act and its regulations, the onus falls on a left-turning driver to act carefully, and 100% of the liability for a collision that occurs during such a maneuver is assigned to the left-turning driver.

In the criminal case for charges of careless driving against the tractor/trailer driver, the court rendered an acquittal. The subsequent civil case between the truck driver and the family of the left-turning driver settled out of court, but the third-party action between the truck driver and the owner of the vehicle continued, and was tried to determine whether a loss transfer would occur between respective insurance companies. By jury decision, the liability of the left-turning driver was lowered to 70% and that of the truck driver increased to 30%.

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APPENDIX A

Second Vehicle Test Data Tables – February 13, 2012, Toronto

Methodology – time measured by electronic stopwatch from the change to a green ball signal, to the detectable quarter-to-half rotation motion of the vehicle wheel, noting vehicle type and positions

Table A1 - Coded Data Key for Vehicle Departure Study

Vehicle Position		Response	Coded	Vehicle Type	Coded
Lead Vehicle	Column 2	Delay	1	Car	1
Second Vehicle	Column 3	Neutral	0	Pick-up	2
Gap Presence = 1	Column 4	Anticipation	-1	SUV	3
Lane	Column 6			Van	4
				Truck	5
				Bus	6

Table A2 – Coded Data Summary – Second Vehicle Departures

Data Point	Time (sec)	Lead	Second	Gap	Delay/ Anticipation	Lane	Comment
1-1	2.1	5	4	1	0	2	VAN BEHIND TRUCK, ONE CAR LENGTH +; L2 STRAIGHT THROUGH
1-2	3.3	1	1	0	0	3	HONDA CAR BEHIND TAXI L3
1-4	2.9	1	3	0	0	2	SUV BEHIND CAR
1-6	2.2	1	3	0	0	2	SUV BEHIND CAR L2
1-7	2.9	1	6	0	0	3	BUS BEHIND CAR L3
1-8	1.3	1	1	1	-1	3	GAP 5M MOVED BEFORE SIGNAL CHANGE
1-10	2.3	1	1	0	0	3	CAR BEHIND CAR
1-11	2.3	6	1	1	-1	3	BUS IN FRONT OF CAR, ANTICIPATED; STOP, START, 8M GAP
1-13	1.5	4	1	0	-1	3	CAR BEHIND VAN; VAN ROLLED BEFORE GREEN SIGNAL
1-15	1.7	1	3	0	-1	3	SUV BEHIND CAR - CAR MOVED IN ANTICIPATION
1-17	1.7	1	4	0	0	3	VAN BEHIND CAR L3
1-18	1.8	1	1	0	0	2	CAR BEHIND CAR L2
1-19	2.4	3	2	1	0	3	5M GAP PICKUP BEHIND SUV
1-20	1.9	4	1	0	0	2	CAR BEHIND VAN L2
1-21	2.1	3	1	0	0	3	CAR BEHIND SUV L3
1-22	1.8	1	1	0	0	1	CAR BEHIND CAR L1
1-23	1.6	3	3	0	0	3	SUV BEHIND SUV
1-25	1.7	1	6	0	0	3	WHEELTRANS BEHIND CAR L3
1-26	2.0	3	1	0	0	3	CAR BEHIND SUV L3
1-27	1.6	4	3	0	0	3	SUV BEHIND VAN L3
1-28	4.1	6	1	1	1	3	CAR BEHIND BUS GAP 8M BUT CLEARING NTHBND TRAFFIC
1-29	4.4	1	1	0	1	3	CAR BEHIND CAR L3 DELAYED DEPARTURE
1-30	1.8	4	1	0	0	3	CAR BEHIND VAN
2-1	1.9	1	1	0	0	3	CAR BEHIND CAR L3

2-3	1.3	1	1	0	-1	3	CAR BEHIND CAR SECOND VEHICLE MOVED BEFORE FIRST AT GREEN
2-5	1.6	1	1	0	0	2	CAR BEHIND CAR L2
2-6	3.4	1	1	0	1	3	CAR BEHIND CAR L3 SLOW START BY VEHICLE ONE
2-7	2.7	1	2	0	1	3	PICKUP BEHIND CAR; PICKUP DELAYED START
2-9	6.8	1	4	0	1	2	VAN BEHIND CAR L2 LONG DELAY BY VEHICLE ONE
2-10	3.9	3	6	0	0	3	TTC BUS BEHIND SUV L3
2-11	1.8	3	6	0	0	3	TTC BUS BEHIND SUV L3
2-12	4.1	6	3	1	1	3	CAR, GAP OF 10 M, TTC BUS - DELAY FOR CLEARING TRAF-FIC
2-13	3.3	1	1	0	1	3	CAR BEHIND CAR SLOW VEHICLE ONE START L3
2-14	2.9	1	3	0	0	2	SUV BEHIND CAR L2

Table A3 – Coded Data Summary – Second Vehicle Departures Sorted by Duration

Data Point	Time (sec)	Lead	Second	Gap	Delay/ Anticipation	Lane	Comment
1-8	1.3	1	1	1	-1	3	GAP 5M MOVED BEFORE SIGNAL CHANGE
2-3	1.3	1	1	0	-1	3	CAR BEHIND CAR SECOND VEHICLE MOVED BEFORE FIRST AT GREEN
1-13	1.5	4	1	0	-1	3	CAR BEHIND VAN; VAN ROLLED BEFORE GREEN SIGNAL
1-23	1.6	3	3	0	0	3	SUV BEHIND SUV
1-27	1.6	4	3	0	0	3	SUV BEHIND VAN L3
2-5	1.6	1	1	0	0	2	CAR BEHIND CAR L2
1-15	1.7	1	3	0	-1	3	SUV BEHIND CAR - CAR MOVED IN ANTICIPATION
1-17	1.7	1	4	0	0	3	VAN BEHIND CAR L3
1-25	1.7	1	6	0	0	3	WHEELTRANS BEHIND CAR L3
1-18	1.8	1	1	0	0	2	CAR BEHIND CAR L2
1-22	1.8	1	1	0	0	1	CAR BEHIND CAR L1
1-30	1.8	4	1	0	0	3	CAR BEHIND VAN
2-11	1.8	3	6	0	0	3	TTC BUS BEHIND SUV L3
1-20	1.9	4	1	0	0	2	CAR BEHIND VAN L2
2 -1	1.9	1	1	0	0	3	CAR BEHIND CAR L3
1-26	2.0	3	1	0	0	3	CAR BEHIND SUV L3
1-1	2.1	5	4	1	0	2	VAN BEHIND TRUCK, ONE CAR LENGTH +; L2 STRAIGHT THROUGH
1-21	2.1	3	1	0	0	3	CAR BEHIND SUV L3
1-6	2.2	1	3	0	0	2	SUV BEHIND CAR L2
1-10	2.3	1	1	0	0	3	CAR BEHIND CAR
1-11	2.3	6	1	1	-1	3	BUS IN FRONT OF CAR, ANTICIPATED; STOP, THEN START, 8 M GAP
1-19	2.4	3	2	1	0	3	5M GAP PICKUP BEHIND SUV
2-7	2.7	1	2	0	1	3	PICKUP BEHIND CAR; PICKUP DELAYED START
1-4	2.9	1	3	0	0	2	SUV BEHIND CAR

1-7	2.9	1	6	0	0	3	BUS BEHIND CAR L3
2-14	2.9	1	3	0	0	2	SUV BEHIND CAR L2
1-2	3.3	1	1	0	0	3	HONDA CAR BEHIND TAXI L3
2-13	3.3	1	1	0	1	3	CAR BEHIND CAR SLOW VEHICLE ONE START L3
2-6	3.4	1	1	0	1	3	CAR BEHIND CAR L3 SLOW START BY VEHICLE ONE
2-10	3.9	3	6	0	0	3	TTC BUS BEHIND SUV L3
1-28	4.1	6	1	1	1	3	CAR BEHIND BUS GAP 8M BUT CLEARNG NORTHBOUND TRAFFIC
2-12	4.1	6	3	1	1	3	CAR, GAP OF 10 M, TTC BUS - DELAY FOR CLEARING TRAFFIC
1-29	4.4	1	1	0	1	3	CAR BEHIND CAR L3 DELAYED DEPARTURE
Average	2.5						Average for all data points
Std. dev.	1.15						
Average	2.41						Removed two highest and two lowest data points
Std. dev.	0.78						