Sun & Shadow Modelling

in

Accident Reconstruction

Prepared for:

Canadian Association of Technical Accident Investigators and Reconstructionists

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Sun & Shadow Modelling in Accident Reconstruction

Presentation Outline

1. Introduction

Following this presentation you will be better equipped to...

...recognize the role that sun and shade issues play
...understand some of the astronomic principles involved in recreating sun position
...plan for a site (total station) survey of a sun-related accident scene
...carry out a basic sun and shadow analysis
...identify situations that can help reduce re-occurrences
...prepare and present results
...prove or disprove witness statements

2. Impacts of Sun and Shade

blinding
glare and reflection
contrast
illumination and visibility
shade-induced roadway icing
establishing and/or confirming time of day

3. Analysis

sun position defined by altitude and azimuth
sun position determined from its declination and hour angle (from ephemeris)
elliptical orbit and axis tilt
equation of time
trigonometric applications

(cont'd)

4. Ensuring Accuracy

evidence is subject to scrutiny
use historical data for specific date
sun movement - sun moves the equivalent of its diameter every 2 minutes or so
Equation of Time correction factor - ranges 30 minutes (from +16 min to -14 min)
latitude and longitude - GPS
astronomic bearings - public survey records
topo map grid bearing adjustment
true north (astronomic) / grid north / magnetic north
engineering drawings / legal survey plans / survey control

5. Presentation of Results

mounted drawings based on info derived from existing plans and total station survey
plan view showing direction of sun, and shadow patterns
profile view showing sun's altitude, and shadow planes
3D perspectives (e.g. driver's eye view - including sun position and extent of shade)
photos with superimposed sun (need camera lens data and photo enlargement details)
3D models (physical or computer, plus animations)

6. Results of Analysis

sun position can be proven
sun position can be introduced as a possible contributing factor
witness statements can be proven or disproven
identify physical conditions at a specific site that can be improved and/or corrected
apply knowledge gained to other similar sites and circumstances

1. Introduction

Good afternoon ladies and gentlemen. First of all, I must confess and emphasize that I am not an accident reconstructionist. In fact I know very little about the work that you do although what little I know fascinates me, and I hope to become better acquainted with the role of the accident reconstructionist as time goes on.

Now, you might wonder "What am I doing here?" I know I am. Well, it's been said that the definition of an expert is someone who is from out of town. Yes, I am from out of town, but I also know that Bob had a scheduled speaker cancel out on him.

Unfortunately, or from your point of view fortunately, I don't know any accident reconstructionist jokes. But in the lobby I did overhear this discussion about a recent accident.

"What is the difference between a dead skunk and dead lawyer in the middle of a road? The skunk's body has skid marks leading up to it."

AND - it is the one surrounded by a team of investigators!!!!

My background is that of a civil engineer, and backyard astronomer. Odd combination yes, but an appropriate one when it comes to the role that sun & shadow impacts play in the reconstruction process.

- graduated 1976 Queen's University B.Sc. Civil Engineering
- registered as P. Eng. in 1978
- survey science courses at University of Toronto 1976 to 1979 - courses applicable to the science of sun and shadows included astronomy, geodesy, geodetic astronomy - others of help in civil engineering and AR included surveying, photogrammetry, remote sensing (eg air photo interpretation)
- Ontario Land Surveyor registration 1981
- have worked since 1976 in the field of land development engineering (i.e. design of municipal services - sewers, watermains, roads, storm drainage works, site grading, etc.)
- my interest in astronomy led me to search out the formulas and eventually develop computer modelling software that allows me to calculate the sun's position relative to an observer located anywhere on earth - for any date and for any time
- my main goal in all this was to create the perfect sundial - that is, one without the inherent inaccuracies of traditional sundials
- one thing led to another, and soon I found myself preparing shadow impact drawings for architects and developers of high-rise buildings - particularly where projects were challenged by ratepayers groups

- through this I have had the chance to give expert testimony on several occasions before the OMB

- in summary, my hobby has become something that is now applied to my land development engineering life

The purpose of this presentation is to tie together some of the loose ends between the "black box" solar calculations, surveying, topographics, and highway engineering.

Following this presentation you will be better equipped to...

- develop an awareness of the role that sun/shade issues play
- use some astronomic principles to recreate sun position
- carry out a total station survey of a sun-related accident scene
- carry out a basic sun/shadow analysis
- make recommendations to help reduce future occurrences
- prepare and present results
- apply results in order to prove or disprove witness statements

2. <u>Role of Sun/Shade</u>

The more common situations involving sun and shade include:

- blinding
- glare and reflection
- contrast - pupil adjustment, effect on reflexes
- illumination/visibility - effect on reflexes, special cases (rise/set/twilight)
- roadway icing due to extended periods of shading
- establishing and/or confirming time of day (shadow measurements, sunrise/set, photos)

Again I must emphasize that I am no expert in visibility analysis. My interest lies in the calculation of sun and shadow positions with a view to assisting the reconstructionist in establishing the degree to which this may have contributed to the cause of an accident.

The following comments regarding blinding, glare, and so forth are personal observations only, and they are not based on professional training. Where the comments are attributed to a third party I will indicate so.

2.1 Blinding

We have all found ourselves in the frightening situation where sun blinding has caught us totally off-guard. These situations typically occur just after sunrise or before sunset when the sun is perched just above the horizon and directly in our line of sight. This is unnerving especially when you are confronted by oncoming traffic, or if you know that there is a pedestrian or cyclist just ahead and close to your projected path.

These occurrences are dangerous even if you anticipate them as a result of your prior knowledge of a certain road. Many of these situations could have been avoided.

Dr. Bernard S. Abrams, an optometrist by training, is a highway safety advocate who is no doubt familiar to many of you. Dr. Abrams is a visibility expert who has presented many papers on visibility, night vision, the human eye, sun dazzle, etc. to accident reconstructionists, lawyers, etc.

He has devoted an entire paper to the problem of sun glare at railway level crossings. Dr. Abrams points out that the problem occurs both when the road runs east-west, and when the railway runs east-west.

In the case of a road running east-west, a driver (at sunrise or sunset) may be intent on looking straight ahead and just off-axis to the sun. This of course is in an effort to keep the car on the road, to keep from looking directly into the sun, and to avoid pedestrians and objects near the edge of the road. Under these circumstances very little effort is given to looking left and right to see if a train is coming.

In the case of a road running north-south, drivers can be suddenly blinded as they make the effort to look left or right for a train. You just can't win!!

Blinding leads not only to potential accidents, it also contributes to severe slowdowns and traffic congestion. Just look at the traffic coming into Metro from the Mississauga and Oakville area. These commuters are often hit at both ends of the workday. The result is a time consuming, frustrating and dangerous drive. Slowdowns such as these also contribute to fuel waste and environmental damage.

During the initial stages of an accident investigation, a quick review of the sun's position relative to the accident site is all that is needed. Such a cursory evaluation will help determine whether or not further investigation is warranted.

2.2 Glare and Reflection

While similar to blinding, which I consider to be a direct hit, glare and reflection are more indirect. Both are the result of bright, unobscured sun, although the line of sight is not usually directly from the sun to one's eye.

Glare also causes the visibility of features to decrease - such as the washing out of important signage. This occurs when sunlight strikes a sign at an oblique angle.

Also, the wording on signs can be rendered indiscernible due to the silhouette effect which occurs when the sun is more or less behind it.

I consider glare to differ from direct blinding insofar as the concentration of light is concerned. Direct sun can be compensated for to some extent by focussing on objects slightly offset from the direct line to the sun - avoiding the concentrated point of light.

This, however, isn't so easy in a glare situation. While the intensity of the light may be diffused over a larger area, the level may still cause discomfort - and this time over a much broader zone eliminating the opportunity to offset your focus.

Reflection occurs when the sun's rays are reflected by an object into one's eyes. While the intensity may be nearly the same as direct blinding, its contribution as a cause of an accident may not be as apparent. This of course is due to the fact that the direction from which the reflected rays came is not readily identifiable. Given the direction of vehicle travel relative to sun position, sun blinding may not even be suspected - unless of course the victims point this out.

Reflection is sneaky in that it is not readily anticipated.

Examples include reflections from windows, buildings, signs, chrome bumpers, and, yes, the dreaded chrome strips along the bottom of truck splash guards.

2.3 Contrast

Sudden changes in lighting conditions play havoc with our ability to see. Just think back to those times when you stepped out of the matinee at the movie theatre on a bright afternoon.

Or the opposite - finding your way to your bed after turning out the lights.

Apply these physical effects to the scenario of sitting behind the wheel of a car at 100 kph, and you begin to appreciate the dangers you are exposed to.

Dr. Abrams points out that it takes the eye a full 30 minutes or so to become completely adjusted to a severe change in lighting levels. Not only is this significant in terms of one's ability to see and discern; according to Dr. Abrams, one's ability to react decreases thereby increasing reflex times.

The May/June 1990 issue of the Accident Reconstruction Journal includes an article dealing with a case where a child was struck and killed by a car making a left turn at an intersection. The child walked into the path of the vehicle after stepping off of a sidewalk (which was in shade) and onto the roadway (in sunlight). The driver alleged that his ability to see the child was impaired by the fact that the child suddenly stepped out of darkness. Sun and shadow calculations were carried out in order to establish the limits of sun and shade, and to determine whether or not the driver had opportunity to stop in time.

2.4 Illumination and Visibility

Dr. Abrams has also written on the effect of poor lighting on reflexes. It is well documented that reduced lighting levels decrease one ability to react thereby increasing reflex times. The Lighting Research Centre at Rensselaer Polytechnic Institute in Troy, New York, has conducted experiments on this topic.

Special cases involving reduced lighting occur during the twilight hours. Three categories of twilight are defined by the U.S. Naval Observatory, namely civil, nautical, and astronomical. They are defined to occur when the sun is 6, 12, and 18 degrees below the horizon respectively. I would assume that the accident reconstruction field relies mostly on the "civil" definition.

The U.S. Naval Observatory indicates that during civil twilight terrestrial objects can be clearly distinguished, the horizon is clearly defined, and the brightest stars are visible - all assuming good weather conditions of course. Beyond civil twilight, artificial lighting is normally required to carry on ordinary outdoor activities.

2.5 Shade-induced Roadway Icing
I have just recently begun compiling data on roads where this is a problem. There are many. Some examples include:

Northern Ventura County, California - US-101, ice build-up on curves around north-facing hillsides

Morris County, New Jersey - I-80, new sound barriers installed along south side of highway, now eastbound lanes in perpetual shade, icing a problem now, has contributed to accidents

Roxbury and Mt. Olive Townships, New Jersey - US-206, water draining onto road turned to ice and caused a fatal accident

Dallas, Texas - mesquite trees planted on median, trees retain some leaves and create shading and icing problems

Central Oregon - Highway 97, near Sunriver resort, 3 mile stretch of road shaded by trees, many fatal accidents due to surprise icy section, court battle resulted in trees being removed

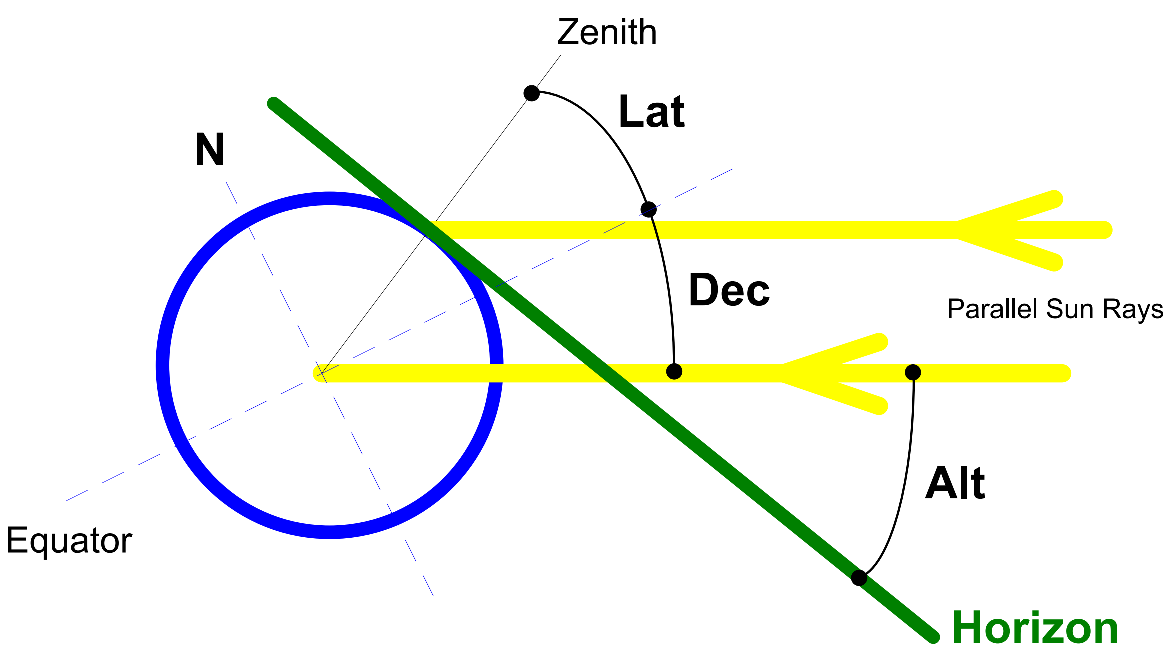
2.6 Establishing/Confirming Time of Day
Sun and shadow modelling can establish and/or confirm times of day. This is particularly true for the event of sunrise or sunset, that is, "Was the sun even up at the time of the accident?"

It can also be applied to alleged shadow positions and help confirm or deny conditions at the time of the accident.

3. Analysis

3.1 Altitude and Azimuth - Refer to overhead

The Sun's Altitude



Alt - Dec + Lat = 90 (degrees)

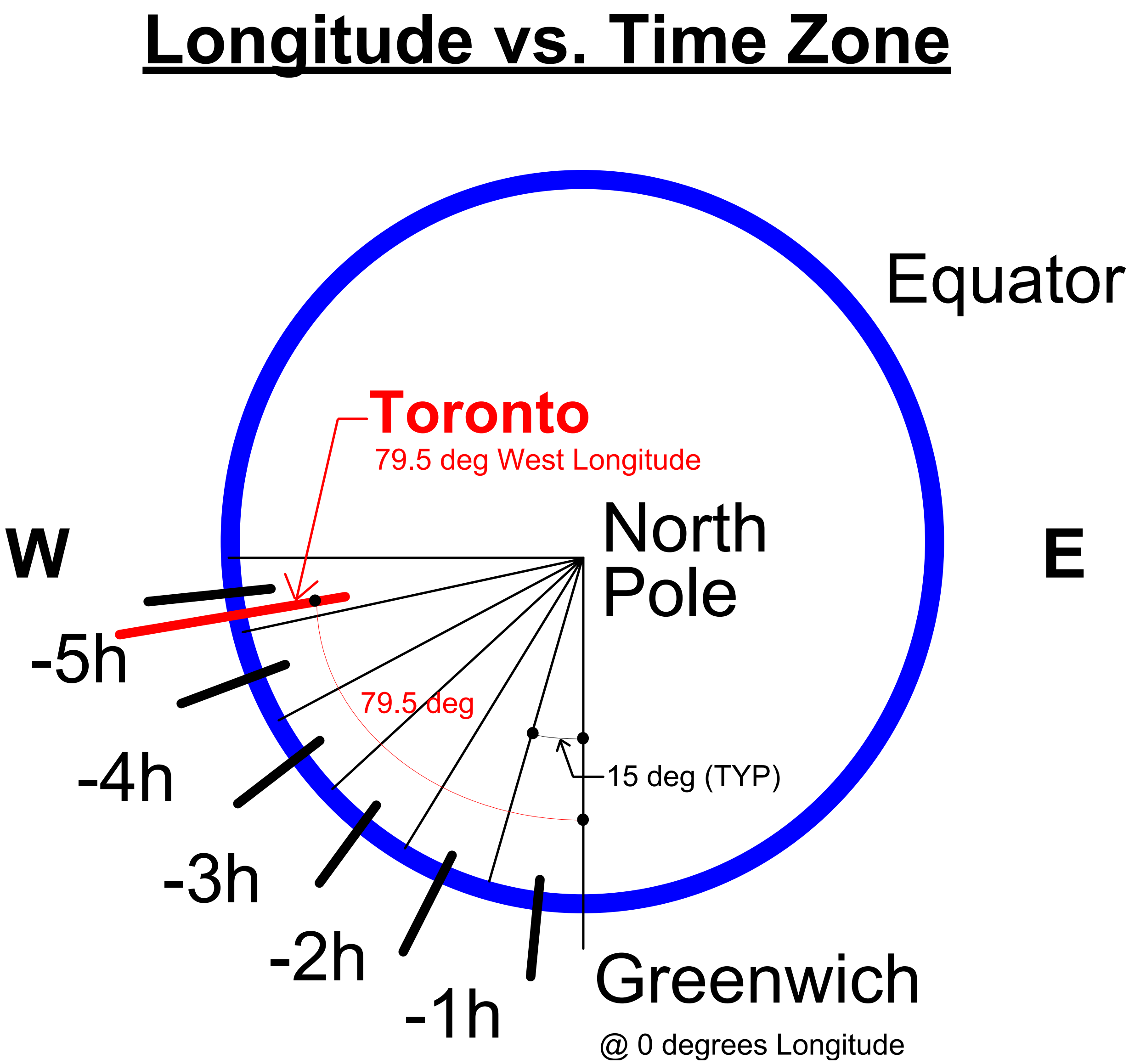
Altitude at Local Solar Noon = 90 - Lat + Dec (degrees)

For Latitude 44 deg North:

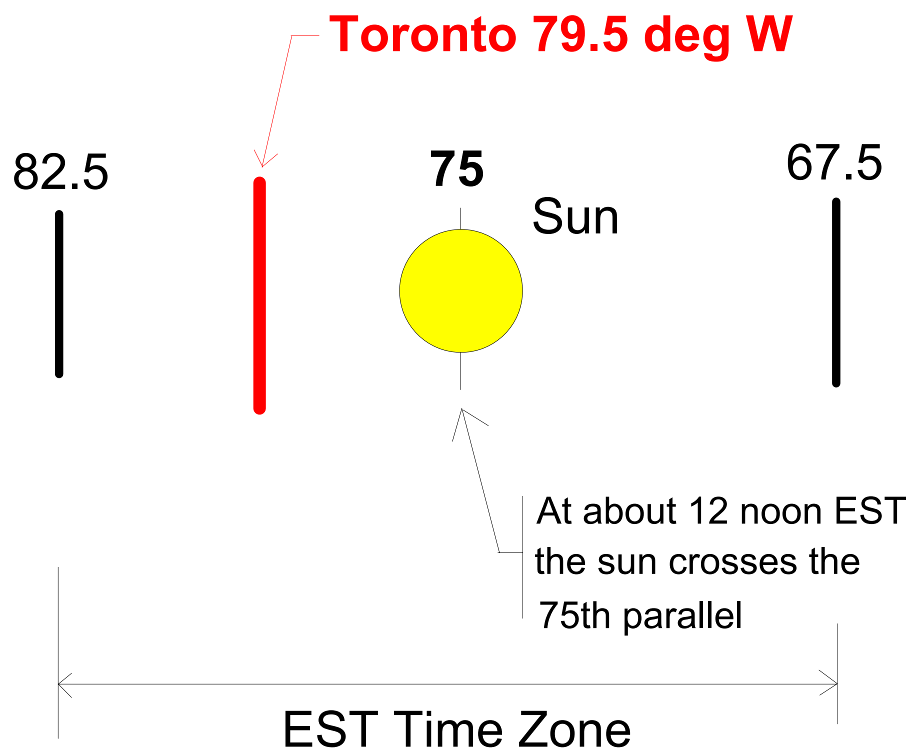
Min Alt Winter = 90 - 44 + (-23.5) = 22.5 degrees

Max Alt Summer = 90 - 44 + (23.5) = 69.5 degrees

3.2 Declination and Hour Angle - Refer to overhead



Standard Time vs. Solar Time



15 deg = 1 hour

Toronto lies about 4.5 deg west of 75th parallel

4.5/15 = 0.30 hours = 18 minutes

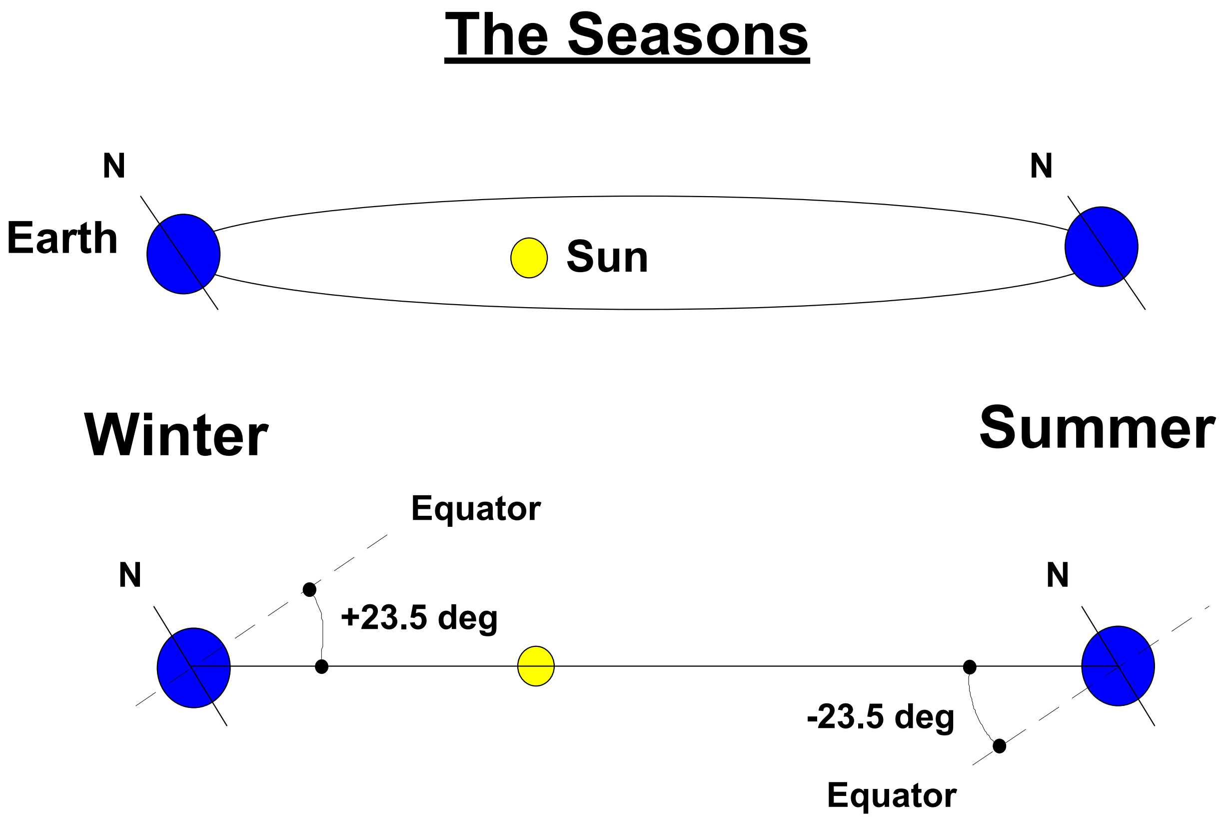
The sun crosses Toronto's meridian about 18 min later

LCT = Standard Time + correction for actual Longitude

TST = LCT + ET

h = 15 x (TST - 12)

3.3 Elliptical Orbit and Axis Tilt - Refer to overhead



3.4 Equation of Time
The Equation of Time is also referred to as the Sundial Correction. It applies a correction of -14 minutes to +16 minutes to Local Civil Time - a range of 30 minutes. This correction compensates for the variation in the earth's velocity as it travels around the sun in its elliptical orbit - i.e. the "slingshot effect".

The length of our day is a convenient average of 24 hours, however, the sun, because of the variation in earth's orbital velocity, runs either ahead of, or behind, our watches based on this average position. The Equation of Time serves to get everything back on track.

3.5 Trigonometric Applications
Once the sun's altitude and azimuth have been calculated, the analysis becomes one of trigonometry. In determining shadow lengths, for example, I use the term Shadow Length Factor to calculate the length of a shadow provided the height of the object casting the shadow is known.

The Shadow Length Factor (SLF) is simply the "inverse tangent of the altitude". As an example, let's assume a sun altitude of 25 degrees, and a building height of 15 metres. The SLF is 1/tan 25, which equals 2.14. Therefore, the resultant shadow length is 2.14 x 15 = 32.17 metres.

4. Need for Accuracy
Accuracy in the calculations and modelling is crucial since the evidence is subject to scrutiny. Historical data for the specific date in question should always be used since there

are changes in sun and shadow position from one year to the next. They may be minimal, but, you don't want to create any uncertainties about your analysis.

Establishing the precise time of an accident is important since the rate at which the sun moves is quite surprising. The sun moves the equivalent of its diameter every 2 minutes or so. This can be critical in an investigation, especially if the sun allegedly just peaked around a certain corner. The handouts include a chart showing the rates of change in altitude and azimuth for several dates. The charts apply to Toronto.

The Equation of Time was discussed earlier. It is apparent that the range of 30 minutes (i.e. from -14 min to +16 min) is significant given that this represents a total of about 15 sun diameters.

Any sun and shadow calculations should be carried out for site specific latitude and longitude. It doesn't suffice to use Toronto data, when in fact the subject site is in Mississauga. Again, the differences may be small, but you don't want to open yourself up to unfavourable scrutiny.

Latitude and longitude are readily obtained from atlases and other forms of maps. Most municipalities have complete sets of reference maps called OBM map sheets (Ontario Base Mapping) which are available at varying scales (e.g. 1:2000, 1:5000, or 1:10000).

GPS systems can also be used to determine the lat and long of a site. Due to the stated limitations in terms of accuracy, I would not recommend using GPS to establish the bearing of a line.

Any bearings used to orientate the site relative to the sun and shadow calculations must be astronomic in origin. Most legal survey plans are prepared on this basis, and the plans include a note entitled "Reference Bearing". This note clearly identifies the reference line to which every other line relates. The note will actually say whether or not the bearings shown on the plan are astronomic.

Highway limits are most always surveyed and the survey plans are public records. They can be viewed, and copies obtained, if not from MTO, from the Land Registry Office. Again, these plans will provide you with the astronomic reference bearings that you need.

During an actual field survey, monuments (e.g. iron bars) shown on the plan can be tied in. This will provide you with the proper orientation relative to astronomic north. To ensure that the monuments you tie in to are reliable, an effort should be made to always tie in to at least 3 bars. In that way, a bar that has been disturbed can be neglected without it throwing all of your calculations off.

I recognize that not all surveys need to relate to true north. If the sun is not a factor to be considered in the investigation, then an arbitrary north can be set, and you don't necessarily need survey plans, etc.

A word about topo maps. The gridlines shown on these kinds of maps are not necessarily true north-south and east-west. One can calculate the "grid bearing" of a section of highway from the coordinates of several key points, however, this bearing must be corrected before it can be used as an astronomic bearing. The simple explanation for this is the fact that true meridians (i.e. lines of longitude) are not parallel, but converge as you move northward. In fact, the separation distance between these lines is zero at the north and south poles. If you know your latitude and the difference in longitude between the 2 endpoints of a reference line, the correction to be applied to grid bearings is “Delta Longitude x sin Latitude”.

Magnetic north compass readings should be avoided like the plague. The results are not very reliable since the compass needle can be adversely affected by many local influences.

A word about engineering drawings. We have touched on legal survey plans in terms of site orientation, but engineering drawings can provide a wealth of topographic information. Obtaining copies of engineering drawings can save you a lot of time and effort in surveying. You may simply confirm details shown on the drawings and supplement them as needed. These drawings will also provide you with the bench marks needed to establish elevations.

Care should be taken in applying the altitude of the sun to the accident site. Is the stretch of road flat, or does it have a grade that would alter the “apparent” altitude of the sun? This should be carefully reviewed. The handouts include a chart which compares altitude angles to commonly used road grades.

Survey control (i.e. in 2D plan only) is provided by the monuments referred to in the paragraph dealing with legal surveys. If the accident survey is carried out before existing plan documentation is obtained - not to worry. Provided you leave yourself control points (e.g. nails in pavement, corners of sidewalks, or anything else that is durable) you will be able to return to the site at a later date (with a collection of plans) in order to tie the accident survey in to the plan information.

5. Presentation of Results

Mounted drawings can be prepared. These can be based on info derived from existing plans in addition to accident details obtained by site survey (e.g. total station survey).

Such drawings can include a plan view showing the direction of the sun as well as shadow patterns. Profiles show the sun’s altitude, obstructions, and shadow planes. Sophisticated 3D perspectives can portray the driver’s eye view at the time of an accident.

Photographs can be enhanced by superimposing the sun onto the photo. In this case you will need camera lens data and photo enlargement details. If your detailed survey includes features which are clearly identifiable in the photo (in terms of location and elevation) then you can use the principles of photogrammetry to reasonably orientate the photo in 3-dimensional space. This would then allow you to superimpose the sun with a reasonable degree of accuracy.

3D models can be created for the accident scene. These can be physical models or computer renditions. With a computer model, the sun’s positional data can be inserted and reliable representations made. The ultimate, of course, is computer animations, although I understand that these are slow to be accepted in the Canadian courts.

6. Results of Analysis

A careful analysis of the site and sun's position can be indispensable if the sun is claimed to be a factor in the accident. Its position can be proven, or disproved, as the case may be. A negative influence by the sun can be introduced as a possible factor even if sun position was not previously recognized by the parties involved in the accident. This is where the awareness factor comes into play.

It goes without saying that witness statements can be proven or disproven.

An item that should not be over-looked is the knowledge gained during the analysis of sun position. It may allow you to identify site problems and to recommend physical improvements at a site that would otherwise go undetected. Such actions could possibly contribute to the saving of future lives not only at the subject location; the knowledge gained could also be applied to similar sites and circumstances elsewhere.

I hope that this presentation has provided you with some food for thought, and that it has shed some "light" on the subject of sun and shadow modelling. Technology is changing daily, and the ability to account for all sorts of factors is becoming easier all the time. We should strive to make use of this ability so that answers can be found to questions that may not even have been asked in the past.

Rules of Thumb

The following “rules of thumb” are useful in order to visually estimate the sun’s altitude (order of magnitude).

The thumb and palm can be used to estimate sun angles, especially when the sun is low in the sky. Their widths, with fully extended arm, represent subtended arcs approximately as follows:

Thumb -	**2 degrees**
Palm of hand -	**8 degrees**

The sun’s diameter subtends an arc of about 0.5 degrees.

Other Interesting Facts

One degree of longitude represents about 110 km at the equator; due to the convergence of the meridians, this reduces to about 80 km in this area (at latitude 44 degrees north).

Since each degree of longitude represents 4 minutes of time, solar time changes by 1 minute for each 20 km east-west at latitude 44 degrees north.

On average, in about 2 minutes the sun moves the equivalent of its own diameter (depending on the incline of the plane of the sun’s path).

Sun Altitude and Azimuth

Rates of Change

(degrees per hour)

Time EST	Altitude				Azimuth			
	Mar 21	Jun 21	Sep 21	Dec 21	Mar 21	Jun 21	Sep 21	Dec 21
6		9.8				9.8		
7		10.4				9.4		
8	10.6	10.8	10.5		10.8	9.8	11.1	
9	10.0	10.8	9.8	8.3	12.1	11.0	12.6	11.0
10	8.8	10.4	8.4	6.7	14.3	14.1	15.0	12.3
11	6.7	9.0	6.1	4.7	17.4	20.8	18.3	13.6
12	3.6	5.4	2.7	2.1	20.5	32.6	21.2	14.6
13	-0.3	-1.3	-1.3	-0.7	21.7	38.4	21.7	14.9
14	-4.2	-7.0	-5.0	-3.4	20.0	28.0	19.4	14.2
15	-7.1	-9.7	-7.7	-5.7	16.8	17.8	16.1	13.0
16	-9.0	-10.6	-9.4	-7.5	13.9	12.7	13.3	11.7
17	-10.1	-10.8	-10.3		11.8	10.4	11.5	
18	-10.7	-10.7	-10.8		10.7	9.6	10.5	
19		-10.2				9.5		

Observations:

Altitude:

1. The sun's altitude changes most rapidly during early morning and late afternoon hours.

   ...typically about 1 degree per hour around noon

   ...up to about 11 degrees per hour early and late in the day

2. The rate of change is greater in summer than winter.

Azimuth:

1. The sun's direction changes most rapidly around noon.

   ...typically about 10 degrees per hour early and late in the day

   ...up to about 38 degrees per hour at noon on June 21

2. The rate of change is much greater in summer than winter.

Road Grade Corrections

Based on typical road grades between 0.5% and 10.0%

Road Grade (%)	Equivalent Angular Slope (degrees)
0.5	0.29
1.0	0.57
1.5	0.86
2.0	1.15
2.5	1.43
3.0	1.72
3.5	2.00
4.0	2.29
4.5	2.58
5.0	2.86
5.5	3.15
6.0	3.43
6.5	3.72
7.0	4.00
7.5	4.29
8.0	4.57
8.5	4.86
9.0	5.14
9.5	5.43
10.0	5.71

Glossary

Altitude - the angular distance, measured in degrees, between the horizon and the centre of the sun's disk (positive above horizon).

Azimuth - the bearing, or direction of the sun, as viewed by an observer, measured in degrees clockwise from north (e.g. North = 0, East = 90, South = 180, West = 270)

Daylight Saving Time - Standard Time adjusted by adding 1 hour.

Declination - the angular distance, measured in degrees, between the celestial equator and the direction of the observer to sun. It is equivalent to latitude. By convention, when the sun lies north of the equator, declination is positive (Mar 21 to Sep 21); similarly, south of the equator is negative (Sep 21 to Mar 21). Maximum of +23.5 degrees occurs about Jun 21; minimum of -23.5 degrees occurs about Dec 21.

Equation of Time - also known as the "Sundial Correction", this time correction factor takes into account the variations in the earth's velocity as it travels through its elliptical orbit.

Hour Angle - the angle between an observer's meridian and the sun's meridian. Measured from south; west of south is positive, east is negative.

Latitude - the angular distance, measured in degrees, between the equator and an observer's location. North of the equator is positive; south is negative.

Local Civil Time - Standard Time corrected for one's actual location based on longitude east or west of the time zone's central meridian. (Correction applied at the rate of 4 minutes per degree.)

Longitude - the angular distance, measured in degrees, between the Prime Meridian (0 degrees Longitude at Greenwich, England) and an observer's location. West of Greenwich is negative; east is positive.

Meridian - a line of longitude.

Prime Meridian - Longitude “zero” which runs through Greenwich, England.

Standard Time - the time within a specified time zone. Usually varies from Greenwich Civil Time (Universal Time) by an even number of hours. (Example: EST = UT -5)

Time Zone - a 15 degree wide zone within which all watch times are the same for the sake of convenience. Each zone represents one hour, and they are measured in about 15 degree increments east and west from the Prime Meridian, which is the centre of the first zone. (The central meridians of some sample time zones occur at longitudes 15, 30, 45, 60, 75 degrees west, etc. We are in the Eastern Standard Time zone centred on longitude 75 degrees west. Since each 15 degrees represents one hour, EST is 5 hours behind Greenwich Time.)

True Solar Time - local civil time + equation of time