TOP 10 Reasons to Use Radar Vehicle Detection

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Problem with Existing Vehicle Detection Methods

Traffic engineers and planners are fully aware of the limitations of existing vehicle detection methods. The Federal Highway Administration (FHWA) has funded several studies, and departments of transportation have expressed dissatisfaction with these methods. The entities have also explored new methods for detecting vehicles and collecting data.

The absence of a precise method to detect vehicles and collect accurate data at intersections directly impacts the way traffic signal timing is calculated and optimized for traffic flow. A National Transportation Operations Coalition (NTOC) study recently gave US signal timing operations a failing grade of D+. About 70%-90% of traffic signals in the US are not properly timed or synchronized.

The primary reason for this inability to keep traffic signals in the US synchronized is the absence of adequate methods of vehicle detection and data collection.

Most Popular Vehicle Detection Methods

This paper will discuss the most popular methods used for vehicle detection and data collection as well as the obstacles limiting said methods. We will then introduce the latest revolutionary 3D-UHD radar technology, how it works, and the top 10 reasons to adopt it for vehicle detection.
Inductive Loop Detection

How it Works

**Inductive Loop Detectors** are the oldest and most common type of sensor used in the traffic management industry. They are physics-based detectors that work on the principle of electromagnetic induction. One or more turns of insulated wire are buried and sealed within shallow saw cuts in the roadway to form wire coils or loops. When a vehicle passes over the loop, the vehicle’s metal mass causes the inductance of the loop to decrease. The electronic circuit senses this change and sends a signal to the traffic controller.

**Issues with Loop Detection**

One problem with Inductive Loop Detectors is that they are *invasive*. The road surface has to be saw cut to embed the wire inside. Another major issue is that the loops can break; the wires can also easily be cut. Replacing broken loops is very *time consuming* and disrupts traffic since this remedial work has to happen in the traveled way.

There is no instant failover solution to a broken loop. What happens is that the traffic signal gets a maximum recall for the direction in which the loop was operating as a sensor. This is very *disruptive to traffic flow*. The signal rests in green, even when there aren’t any cars, due to the broken loop.

Sometimes loops are known to call up green for a particular direction even when there aren’t any cars. This is known as *chatter or cross talk* and is due to unsuppressed electrical interference.

Other causes for loops’ poor reliability include *improper installation*, failure to twist the wire pairs correctly, faulty saw cuts and improper sealant application. Embedding in poor-quality road coverings also reduces the life of a loop detector. Loop failure is a common occurrence, and agencies spend quite a bit of their operations budgets to fix broken loops. The Illinois Department of Transportation reports that on any given day *about 10% of its loop detectors are reported as failed*.

Due to these reasons, more and more traffic practitioners have moved away from Inductive Loop Detectors in favor of other types of vehicle detection.
Wireless Magnetometers

How they Work

Magnetometers are passive devices which detect vehicles by sensing changes in the earth’s magnetic field as a car (metal object) passes over the magnetometer. Since the passage of the vehicle induces a voltage in the circuit, the magnetometer senses the distortion of the earth’s magnetic flux lines.

The magnetometer unit is made waterproof by sealing it inside a plastic container. The battery-powered unit transmits data via wireless signals to a radio receiver unit. Most manufacturers claim a 10-year lifespan for the battery. Once the battery runs out, the unit is discarded, and a new one is installed.

Installation involves making a core cut into the road surface and embedding the magnetometer below the pavement in the lane. A waterproof sealant is applied to hold the magnetometer unit in place and seal the cut.

These detectors provide volume, lane occupancy, and vehicle presence information.

Issues with Wireless Magnetometers

The primary issue is that the battery’s longevity gets exponentially lower in cold climates. Users have also reported water damage to the magnetometers. The magnetometer’s life is also shortened when installed on deteriorated surfaces or during pavement milling and resurfacing operations.

Another issue with magnetometers is that their installation requires road cuts and is therefore invasive. This requires lane closures and consequently interferes with traffic flow.

Wireless interference hinders the transmission of data from the sensors. Since they have a very narrow detection range, each lane requires the installation of a dedicated detector.
Video detection technology has been around since the late 1990s. This technology was what traffic practitioners who had become disillusioned with loop detectors turned to out of sheer desperation.

The system consists of cameras that are mounted overhead and aimed at the approaching traffic. Each camera sends image information to a processing unit in the traffic signal cabinet. The processor **analyses the images and segments out the objects of interest** (vehicles).

There are two common methods of segmentation: **object-tracking algorithms and background subtraction**.

With an object-tracking algorithm, a vehicle is identified as a unique blob of pixels and tracked through the entire region of interest. Sub-algorithms, like edge detection, may be used to identify the unique blobs.

In background subtraction, the processor slowly learns the background of the camera image over time by absorbing unchanging pixels. Once the background image is learned, the processor **subtracts the current image (foreground image) from the background image** to segment out the moving parts or vehicles.

Video detectors provide **count, presence, occupancy, and classification data**. Of these, only the presence data is reasonably accurate as the validity of all other data is negatively affected by occlusion and the issues listed below.
Issues with Video Detection

The main issue with video detection is that if the camera’s view is obstructed, the sensor is rendered useless. Rain, fog, snow, icicles, dirt may very easily blind the camera. In extremely cold conditions in cities like Chicago, the brine solution sprayed by road crews to combat ice on roadways freezes regularly on camera lenses, blinding detection cameras.

Vehicle colors, such as gray and silver, which resemble pavement which resemble pavement may often prevent cars from being detected. There have been cases reported where stopped vehicles were mistakenly “learned” into the background.

Shadows of moving vehicles and images of vehicles encroaching into another lane can result in false positive detections due to camera angle. Moving clouds and shadows that elongate or shorten due to the sun’s position also can cause false positives.

Dawn and dusk are challenging times for video detection due to daylight’s transition. False positives and false negatives are common during this period.

Sun on the horizon can also blind east and west-facing cameras. Light reflected onto wet pavement causes blooming and camera blindness.

These issues with video detection have prompted several public agencies to turn away from video detection and adopt policies not to deploy it.

Other Forms of Detection

There are several less popular vehicle detection systems available on the market, such as laser detection, passive infrared, ultrasonic, passive acoustic array. Since they are rarely used by practitioners, we will not spend time here on their description and analysis.
Radar stands for RAdio Detection And Ranging. In the late 19th century, Heinrich Hertz demonstrated that radio waves are reflected by metallic objects, and by the early 20th century, German inventor Christian Hülsmeyer had started using them to detect ships, thus avoid ship collisions.

The technology was refined during World War II to send short pulses of radio energy, timing the pulses on an oscilloscope. With this information, combined with the direction of the antenna, scientists discovered that they could determine the range and angular location of targets.

Progress in the development of radar during the war was rapid and of great importance, ending up as one of the decisive factors in the Allied victory. Decades later, this technology has gained further relevance in multiple applications, including the detection of vehicles.
There are two types of microwave radar sensors used in vehicle detection applications. They are **continuous wave (CW) Doppler radar** and **frequency modulated continuous wave (FMCW) radar**.

### Doppler Effect

*In 1842, the Austrian physicist Christian Doppler described the phenomenon of an increase or decrease in the frequency or wavelength of a wave (light, sound, etc.) as a source and its observer move toward or away from each other.*

In Doppler radar, the speed of a vehicle is proportional to the change in frequency between transmitted and received waves. This phenomenon can also be used to detect vehicles and collect other traffic data by **measuring the Doppler frequency shift** from reflected vehicles.

*Figure 1 shows a radar device mounted overhead, focused on the traveled way. The vehicle’s reflected signal can be utilized to measure presence, passage, volume, speed, gaps, and classification as well as provide dilemma zone warning, collision avoidance warning, presence of stopped vehicles, wrong-way travel warning, etc.*

The Federal Communications Commission (FCC) has designated frequency intervals of **10.5 GHz, 24.0 GHz and 34.0 GHz** to the operation of roadside applications. The higher the frequency, the greater the spatial resolution (larger change in frequency) of the radar for a given antenna’s size. End users need not worry about frequencies or FCC compliance, since manufacturers are required to satisfy all requirements.
CW Doppler Radar

CW Doppler radar transmits a constant frequency waveform. Using the Doppler principle, a constant transmission of frequency over time permits the speed of the reflector (vehicle) to be calculated. The frequency of the reflected waveform increases as the vehicle approaches the radar, and the reflected frequency decreases as the vehicle moves away from the radar antenna.

The relationship between speed, transmitted frequency, and Doppler frequency in CW Doppler radar can be expressed as:

\[ v = \frac{c \times f_D}{2 \times f_c \times \cos \theta} \]

Where

- \( v \) = speed
- \( c \) = speed of light
- \( \theta \) = angle between direction of radar wave propagation and direction of vehicle
- \( f_c \) = carrier frequency
- \( f_D \) = Doppler frequency

One major inherent drawback of CW Doppler radar is that it cannot detect the presence of stopped vehicles.
FMCW Radar

With **Frequency Modulated Continuous Wave radar**, the wavelength frequency changes constantly with respect to time. The benefit of frequency modulation is that the radar device can detect the presence of stopped vehicles and also has great precision in its vehicle presence detection.

Vehicle range is proportional to the difference in transmitter frequency at the time it was detected and the time it was received, and is expressed as:

$$ R = \frac{c \times T \times \Delta f}{(2 \times B)} $$

Where

- $R$ = vehicle range
- $\Delta f$ = instantaneous difference in frequency between signal transmission and receipt
- $B$ = RF modulation Bandwidth
- $T$ = period time or modulation period

The FMCW radar calculates a vehicle’s travel speed by dividing the lanes of the traveled way into zones or bins of a known length. Vehicle speed is expressed as:

$$ v = \frac{d}{\Delta T} $$

Where

- $v$ = vehicle speed (extracted by measurement of the Doppler shift. This is done either by up/down ramps or by processing a Doppler FFT, or by matching consecutive measurement cycles)
- $d$ = distance between leading edges of zones (bins)
- $\Delta T$ = time between vehicle arrival at the leading edges of adjacent zones/bins

FMCW radars are versatile and also may use the Doppler effect to calculate the speed of vehicles.

FMCW radars outperform CW radars in vehicle detection and data collection. **They can accurately determine presence, speed, estimated time of arrival, occupancy, vehicle classification and queue length as well as detect incidents, identify stopped vehicles, and provide dilemma zone warning, wrong-way travel warning, etc.**
Understanding 3 Generations of Radar Technology in Vehicle Detection

The technology behind radar vehicle detectors has made quite a few advancements in recent years. First, the migration to **FMCW radars enabled better presence detection** because of the radar devices’ ability to detect stopped vehicles.

> **STANDARD TECHNOLOGY**
> - SEPARATION IN FREQUENCY
> - SLOW SPEED MODULATION

> **2D-HD**
> - SEPARATION IN SPEED
> - SEPARATION IN RANGE
> - HIGH SPEED MODULATION

> **3D-UHD**
> - SEPARATION IN SPEED
> - SEPARATION IN RANGE
> - SEPARATION IN ANGLE
> - HIGH SPEED MODULATION
> - ADAPTIVE BEAMS

*Figure 2. The three generations of radar vehicle detection*
First-Generation Radar Technology

The evolution of this technology has featured three giant leaps forward in radar vehicle detection. First-generation radar used slow-speed modulation, detecting vehicles using a combination of range and speed. Since vehicle separation was based on this same combination, two vehicles traveling at the same speed within the same range could not be separated or classified.

Second-Generation Radar Technology

Second-generation or 2D-HD radar became more accurate than its predecessor by separating speed and range with high-speed modulation. This yielded higher precision in separating vehicles. Here, two vehicles could be traveling at the same range, but would be separated if they had different speeds.

Third-Generation Radar Technology

The third-generation or 3D-UHD evolution of radar has been able to produce the most accurate results. Here, radar not only separates vehicles by range and speed, but also by the angle. This version of radar also uses adaptive beams and high-speed modulation. The radar detector is front firing and offers a range of about 1,000 feet. It is able to accurately track vehicles throughout the range of its sensors. It can accurately detect stopped vehicles and vehicles traveling in the wrong direction, as well as warn of vehicles in the dilemma zone that are not likely to be able to stop when the light switches from yellow to red.

3D-UHD radar is able to provide the following accurate metrics in vehicle detection: presence detection, advanced detection of up to 1,000 feet, vehicle counts, queue length per lane, speed measurement, estimated time of arrival, lane occupancy, vehicle headway, vehicle gap, wrong-way detection and warning, dilemma zone detection and warning, incident detection, stopped vehicle in the traveled way, high-resolution data for analytics (like Purdue Metrics) and intersection delay and level of service (LOS) in real time.

This radar technology has 24+ synchronous, simultaneous beams to detect and separate vehicles. It employs advanced tracking algorithms enhanced with artificial intelligence (AI) to separate, classify, and track vehicles through the scene of interest. As soon as a vehicle appears within the radar’s range, it is tagged with a unique ID and this ID is tracked through the scene of interest until the moment it vanishes past the stop bar.
Here is a list of 10 reasons why 3D-UHD radar technology offers the best available detection of vehicles at intersections.

1. **Offers the best presence detection accuracy**

3D-UHD detectors offer nearly **100% accuracy**. Unlike video detection, radar is not affected by weather, sun position, shadows, pavement colored vehicles, etc. Since the radar device separates objects by range, speed, and angle of travel, it offers the most precise and reliable presence detection on the market today.

2. **Provides advanced detection range of around 1,000 ft**

The device can view and separate objects at about **1,000 feet**. This is the point where it detects and separates a vehicle, tags it with a unique ID, and tracks it through the entire scene of interest. No other form of detection has this range for advanced detection.

3. **Tracks vehicles from entry all the way past the stop bar**

Tracking algorithms coupled with artificial intelligence (AI) enable the **highly accurate tracking of vehicles** and avoidance of missed vehicles. Effective tracking through a range of 1,000 feet significantly enhances the accuracy of the data collected by the radar detector.

The unprecedented, extended range offered by the 3D-UHD detector permits traffic professionals to **collect data at multiple points along the traveled way**. The quality of proactive traffic management is directly proportional to the quality of data available for the design and operation of the transportation system.

4. **Highly accurate count detection**

3D-UHD radar’s **24+ synchronous, simultaneous beams**, separation into **3 dimensions**, and advanced tracking algorithms all enhance the quality of detection and help deliver almost **100% precision** in count detection.

This measurement is important for the development of **traffic signal timing**, whether through creating manual signal timing plans or adaptive signal operations. It is well established in the relevant literature that traffic signal operations are only as effective as data collection. This superior data collection method facilitates the development of outstanding signal timing methodology.
5. Speed estimation and dilemma zone detection and warning

HAWKEYE 3D-UHD radar detectors are able to capture vehicle speed with accuracy approaching 100%. They meet the stringent requirements of a speed enforcement radar.

6. Increases intersection safety

According to the FHWA, more than one-fifth of roadway fatalities and around one-half of serious injuries in the American roadway system occur at intersections. With improved detection and data collection, radar technology is leading the way in lowering these tragic statistics. A case in point, one Texas A&M University study discovered that with advanced detection in the Texas DOT network, red-light violations decreased by 58% and intersection crashes reduced by 39%.

7. Vehicle identification and classification

3D-UHD radar devices are not affected by occlusion like video detection systems. Unlike video detection, which relies on object-tracking or background subtraction, radar detection is almost unaffected by weather conditions (such as rain, fog, and ice) or false positives resulting from moving vehicles, clouds, or shadows.

8. Incident detection

3D-UHD radar can detect stopped vehicles in the scene of interest. This allows for vehicle crashes or stalled vehicles to be detected very quickly. Quick detection and reporting of incidents permit quicker responses and the mitigation of such incidents’ detrimental effects on the roadway network.

9. High-resolution data for real-time analysis

With the advent of connected vehicles and high-performance computing, high-resolution data analysis in near real-time is no mere luxury. With 3D-UHD radar, precise, high-resolution, real-time data is available for analysis. This data also covers a wide range across multiple intersection approaches.

10. Unaffected by environmental conditions

Unlike cameras, 3D-UHD radar is unaffected by environmental conditions. It offers high-precision data regardless of day or night conditions, and is unaffected by shadows or sun glare (unlike video detection). Its quality of detection is not subject to the presence or lack of vehicle/roadway contrast, neither does vehicle color affect detection.
Hawkeye radar detection from Rhythm Engineering solves most of the challenges faced by legacy vehicle detection systems. The system delivers unprecedented, nearly 100% accurate vehicle detection and data collection. The system also delivers unprecedented lane coverage (up to 8 lanes with a range of 1,000 feet) and offers accurate detection and tracking throughout this range. Without a doubt, 3D-UHD radar offers the detection accuracy of the future today.
References


