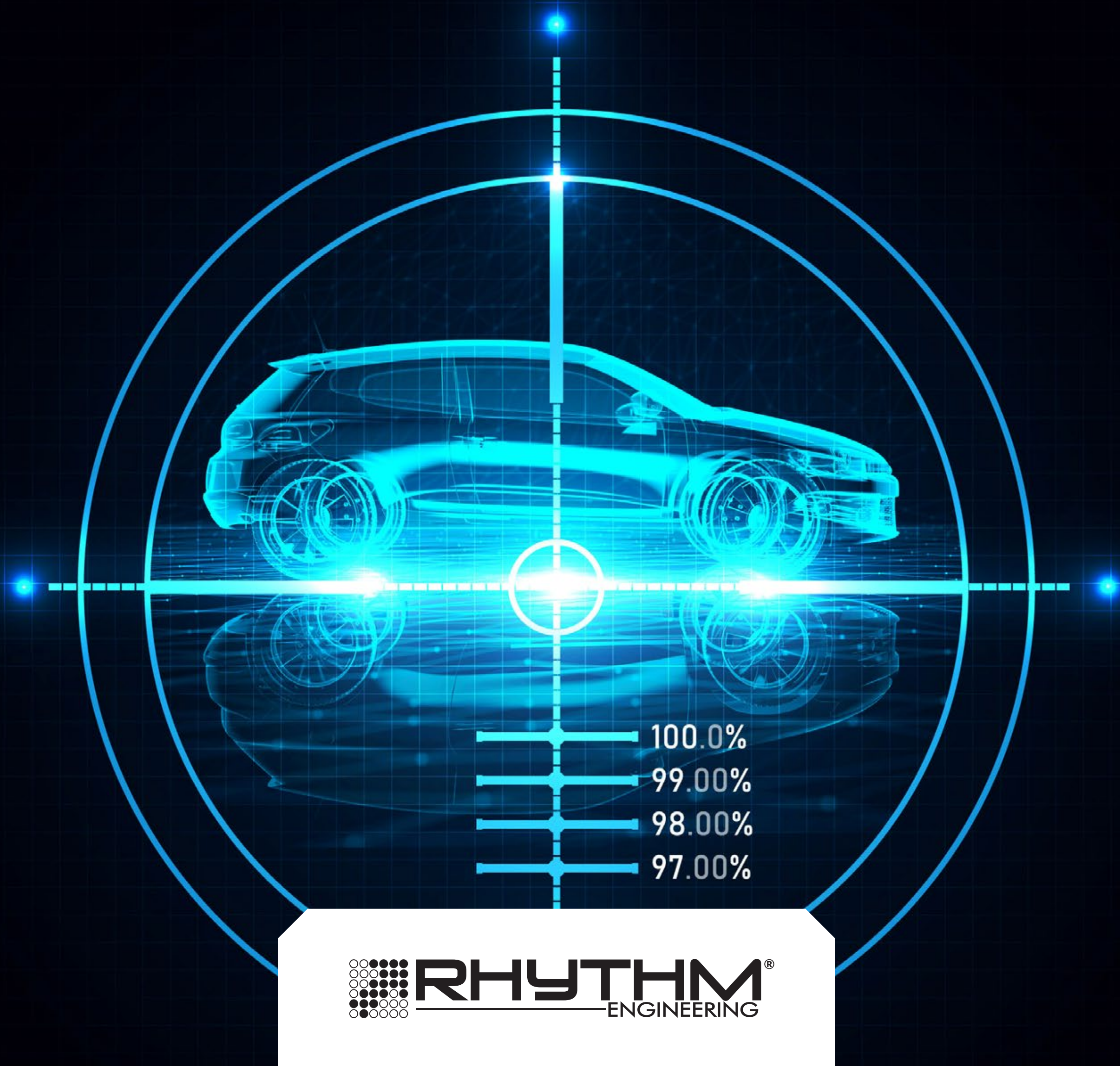
HAWKEYE™
RADAR EVOLVED

Traffic Detection: Accuracy Evolving to 100%?

Reggie Chandra, Ph.D., PE
Rhythm Engineering



RHYTHM® ENGINEERING

Contents

Data Matters: The Role of Vehicle Detection in Traffic Management

Most transportation agencies do not have a comprehensive plan in place to manage traffic signals. The Federal Highway Administration conducted a survey of 378 traffic agencies in 49 states and found that **57% of the agencies do not routinely review their traffic signals** every three years, as advised. Additionally, 68% said they have either no documented management plan for their traffic signal operation, or their plan is simply to respond to intersection problems as they happen.

Meanwhile, the traffic volume and the number of highway miles traveled by motorists annually are increasing exponentially. According to an American Automobile Association (AAA) report, "Between 1980 and 1999, route miles of highways increased 1.5 percent while **vehicle miles of travel increased 76 percen**t." Increased traffic volume results in more congestion and more driver complaints about slow-moving traffic, while highway and arterial infrastructure are not growing in proportion to the growing traffic demand. This is the primary reason for traffic congestion and accidents. Therefore we are left with no other alternative than to **maximize our limited existing infrastructure and resources to optimize traffic flow**.

The primary resource for traffic flow optimization is accurate, real-time data. In order to obtain high quality data, high quality vehicle detectors are necessary. Much of the existing technology that is used for vehicle detection and data collection is fraught with issues.

In the current budget-slashing economic and political climate, transportation agencies are having to make hard decisions. Tax dollars would be better spent creating intelligent traffic management strategies, as laid out by the NTOC in its latest technical report card based on the Traffic Signal Timing Self-Assessment:

> *"Proactive traffic signal management based on objectives-based measurable traffic signal program management plans are critical—our nation's quality of life and the environment depend on it."*

This emphasis on objectives-based solutions was in no doubt prompted by lagging performance goal management regarding traffic flow. While traffic signal operations across the board in the report received a nationwide score of just 69%, in the area of traffic monitoring and data collection the agencies surveyed only scored 52%.

This demonstrates the dire need and opportunity for **putting metrics and data into the hands of traffic professionals so that progress can be made on set objectives**. With these tools in hand, they can efficiently evaluate the systems currently in place, avoid potential pitfalls, determine the viability of upgrading public investment and intelligently measure and report on performance over time.

The Connected Commuter

We live in a connected world. The Internet of Things (IoT) and connected technology has affected every walk of life, including commuting. Gartner predicts that by 2020 there will be **a quarter billion connected car**s on the roadway. These cars will turn into the ultimate IoT devices, as they communicate extremely valuable data both among themselves (V2V) and with the infrastructure (V2I). There is no doubt that this growing interconnectedness is changing many fundamental aspects of modern life. From shopping to stock trading, connectivity has made a very positive impact on our everyday lives.

Everyone is more connected than ever before. The USA alone has about **237 million cellular telephone** subscribers. Smartphone users have come to expect that the most up-to-date information relevant to them is only a tap or swipe away. Real-time travel data reporting from Google Maps, Waze, and other connected applications have both positively disrupted and transformed the way we commute.

Public agencies also provide data, such as **travel time data and Signal Phasing and Timing data (SPaT)** to commuters. Motorists, freight operators and public transit agencies all depend on this disseminated data to set their schedules and plan their routes. Accordingly, the Federal Highway Administration (FHWA) has requested public agencies to improve the quality of travel-time measurement through the use of reliable, real-time data.

However, most vehicle detection methods that public agencies use are **neither accurate nor reliable**. This paper will explore the reasons behind their inadequate results.

How Accurate are These Popular Detection Methods?

Not all detection methods are equally reliable. A multitude of field tests have been carried out with comparisons of many versions of the following methods, but none of them have proven to provide the up-to-the-minute, reliable data which traffic professionals need on the roadways of the future. Some of the most popular types of vehicle detection, both intrusive (in road) and non-intrusive (over road), are **inductive loop, magnetometer, video imaging, thermal imaging and microwave radar**.

Intrusive Vehicle Detection Systems

The most outdated of the group are the **inductive loop detectors**, which operate on the principle of electromagnetic induction. To install loops, the pavement is saw cut and coils of wire are buried under the pavement. Being embedded in the traveled way, they are intrusive and frequently deteriorate along with the pavement, also requiring regular maintenance. Loop detectors lack an instant failover solution since the pavement has to be cut and wires replaced before the detectors can be functional again. Loops also create false detector calls because of their susceptibility to chatter or cross talk.

Magnetometers are intrusive, as well, and for this reason maintenance is an expensive logistical endeavor. They are powered by a long-life battery which can drain itself quickly in colder climates, and they are prone to water damage and wireless interference. Unlike non-invasive, overhead systems (video, thermal and radar detection), magnetometers and loops provide detection for only one lane per device.

Non-Intrusive Vehicle Detection Systems

Traffic detection devices mounted over the way of travel (e.g., on poles or mast arms) do not require the intensive level of maintenance which invasive methods do. The visualization of data which imaging provides, particularly when combined with a live feed, can better assist traffic professionals in their assessment of roadway conditions.

Still, **video detection** relies on a lens that may fail to deliver this data when occlusions are present. Other complicating factors include poor weather conditions, low vehicle-road contrast, shadows, daylight transition periods, sun glare and headlight blooming.

Similarly, **thermal vision** devices can fail to deliver accurate thermal imaging in the event of extreme temperatures or occlusions like thermal shadows and may miscount vehicles with a non-standard heat signature such as electric cars.

There is increasing evidence to support the use of **high-definition radar** technology for vehicle detection and accurate data collection because it does not suffer from any of the issues listed above. In low light, extreme heat or inclement weather, regardless of vehicle type or the deterioration of road surfaces, radar signals can be relied upon to deliver precise results. In Lawrence Klein's 3-state field study, several technologies were evaluated for their application in collecting vehicle count and speed data. Microwave radar data scored the highest level of accuracy in both areas, and also proved to be the least affected by changes in weather.

Why Radar?

History of Radar

Radar stands for **RA**dio **D**etection **A**nd **R**anging. 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 and 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 knowing the direction of the antenna, scientists discovered that they could determine the range and angular location of targets.

Progress during the war was rapid and of great importance, probably 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.

How Radar Vehicle Detection Works

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

The 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.

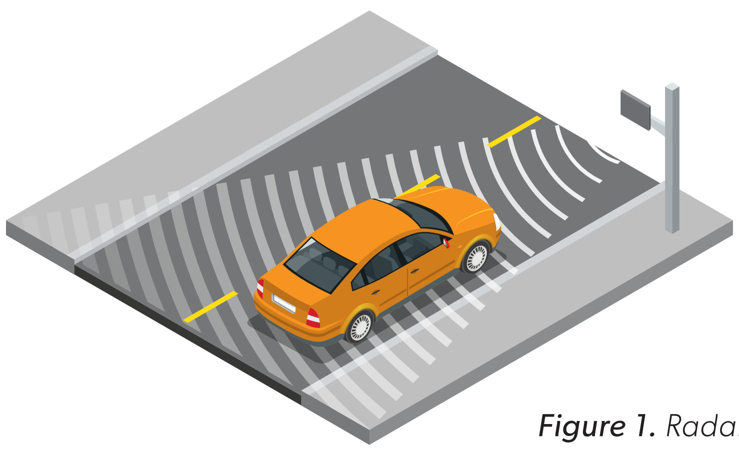


Figure 1. Radar detector

Figure 1 shows a radar device mounted overhead, focused on the traveled way. A 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 radar for 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 and decreases as the vehicle moves away from the radar antenna.

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

$$v = c \times f_D / 2 \times f_C \times (\cos \vartheta)$$

Where

c = speed of light

ϑ = 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.

$$R = c \times T \times \Delta f / (2 \times B)$$

Where

R = vehicle range

Δf = 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:

$$v = d / \Delta T$$

Where

V = vehicle speed

d = distance between leading edges of zones (bins)

ΔT = time between vehicle arrival at the leading edges of adjacent zones/bins

FMCW radars are versatile and may also 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, detect incidents, identify stopped vehicles and provide dilemma zone warning, wrong-way travel warning, etc.

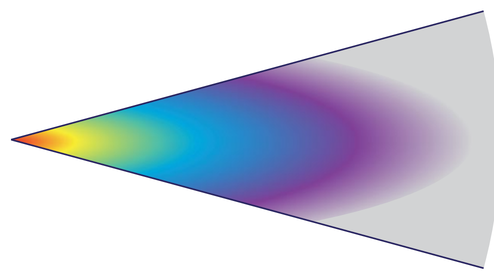
3D-UHD Radar Detection Technology: The Solution

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 of all, the migration to FMCW radars enabled better presence detection because of the radar devices’ ability to detect stopped vehicles.

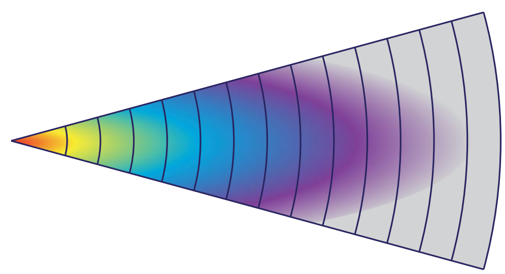
STANDARD TECHNOLOGY

- 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 MODULATON
- ADAPTIVE BEAMS

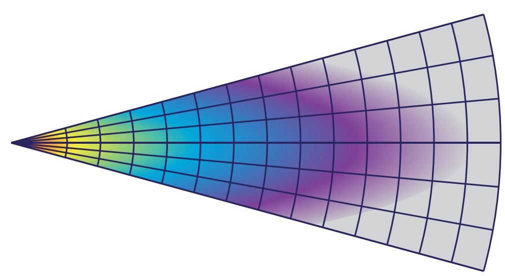


Figure 2. The three generations of radar vehicle detection

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, the radar not only separates vehicles by **range and speed but also by the angle of travel**. This version of radar also uses **adaptive beams and high-speed modulation**. The radar is front-firing and offers a **range of about 1,000 feet**. It is able to accurately track vehicles throughout the range of its sensor. 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 amber to red.

How HAWKEYE Delivers Nearly 100% Accurate Detection

Transmitter and Receivers

The HAWKEYE antenna houses a powerful **3D-UHD** transmitter that uses radar energy to light up the field of view. The antenna also has a matrix of receivers to intercept and analyze the reflected waves. The front-firing device covers up to 8 lanes with an incomparably wide range of 1,000 feet.

The Technology behind HAWKEYE

The technology behind HAWKEYE was developed for **mission-critical military operations** and, while its core design was modified for use in traffic management, the device's **military-precision level** of accuracy remains uncompromised.
This technology fulfills all stringent requirements for speed-enforcement radar.

At the heart of HAWKEYE lies a formation of **24+ adaptive beams working simultaneously**. These beams have been crafted to be adaptive in order for the best form of detection to be captured within the radar's footprint.

These adaptive beams are **sliced based on range** and then sliced again to determine the **angle** of the vehicle in relationship to the radar's field of view. Once a vehicle is detected in the field of vision, it is tagged with a unique identifier and tracked until it has disappeared beyond the beams' limits.

While our radar was primarily developed for the military to **detect humans**, the technology has been fully reconfigured to be applied in vehicle detection.
One advantage of this is that HAWKEYE radar can detect, classify and track pedestrians and bicycles with a very high degree of accuracy. This detection and classification is not affected by lighting conditions. The radar functions flawlessly both during the day and at night.

Unique Benefits of HAWKEYE

- HAWKEYE has a built-in lane model that can **track vehicles by lane** throughout the field of view. It can also precisely track vehicle lane-changing maneuvers.This lane-specific advance detection provides extremely useful data to real-time adaptive traffic signal systems like In|Sync.

- HAWKEYE has **24+ simultaneously firing**, adaptive beams that work in parallel with one another to scan and collect data. The number of beams in action, along with their angles, will change adaptively based on the elements in the field of view. One of the reasons for HAWKEYE's almost 100% accuracy is its ability to adaptively manage this **simultaneous Digital Beam Formation (DBF)**. All other radars on the market offer fixed beams that sequentially scan one beam at a time.

- HAWKEYE is the only detection system to offer **advance detection (up to 1,000 feet)** in combination with stop-bar detection.

- Only HAWKEYE offers its users the data needed to calculate **real-time intersection delay** using the Highway Capacity Model (HCM) methodology. This is possible because HAWKEYE can measure the accurate queue length for each lane up to a range of 1,000 feet.

- No other detection system on the market can provide either the level of accuracy or the number of metrics that HAWKEYE can: **presence detection, advance detection 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 vehicles in the traveled way, high-resolution data for analytics (like Purdue Metrics) and intersection delay and level of service (LOS**) — all in real time.

- HAWKEYE is the only radar device which supports the monitoring and tracking of **vehicle activities at the center of the intersection**.

- HAWKEYE is the only detection system that accurately detects and classifies vehicles according to **range, speed and angle of travel**.

- HAWKEYE is the only detection system that can **detect, track, and classify pedestrians and bicycles** over a range of 1,000 feet.

Conclusion

With the increase in connected commuters and adaptive traffic signal systems, accurate vehicle detection methodologies have become indispensable. Multiple vehicle detection methods have been put to work by the traffic industry over the years, but none of them have been able to provide the level of accuracy or dependability that the job requires. **Environmental conditions, durability of road surfaces, visibility and weather** have consistently proven to negatively impact the accuracy of these legacy systems' detection.

In recent years, technologies that were originally developed for military applications have been finding their way into civilian life. **3D-UHD** radar is one such technology, one that has the potential to revolutionize and improve the quality of vehicle detection to a degree never before possible. It eliminates all of the shortcomings which have accompanied existing methods, offers the largest detection range of 1,000 feet and features unparalleled accuracy in detecting and classifying vehicles and pedestrians.

HAWKEYE
RADAR EVOLVED

References

American Automobile Association (March 2008). *Crashes vs. Congestion: What's the Cost to Society?* Retrieved from http://www.virtualadjacency.com/wp-content/uploads/2008/01/33b-2-Crashes-vs-Congestion-AAA-report-Mar08-Full.pdf

Berners-Lee, T. (February 2009). *The Next Web of Open, Linked Data*. TED 2009 conference, TED Talks. Retrieved from YouTube, https://www.youtube.com/watch?v=OM6XIICm_qo#

Grone, B. (May 2012). *An Evaluation of Non-Intrusive Traffic Detectors at the NTC/NDOR Detector Test Bed* (master's thesis). Graduate College, University of Nebraska, Lincoln, NE. Retrieved from Digital Commons, https://digitalcommons.unl.edu/cgi/viewcontent.cgi?referer=https://www.google.bg/&httpsredir=1&article=1047&context=civilengdiss

Mimbela, L.E.Y., Klein, L., et al. (August 2007). Summary of Vehicle Detection and Surveillance Technologies Used in Intelligent Transportation Systems. Las Cruces, NM: The Vehicle Detector Clearinghouse, Southwest Technology Development Institute, New Mexico State University.

Mimbela, L.E.Y., Klein, L., et al. (August 2017). A Summary of Vehicle Detection and Surveillance Technologies use in Intelligent Transportation Systems (updated version). Retrieved from https://www.fhwa.dot.gov/policyinformation/pubs/vdstits2007/

Schrank, D. & Eisele, B, et al. (August 2015). *2015 Urban Mobility Scorecard*. Inrix, Kirkland, WA & Texas A&M Transportation Institute, The Texas A&M University System, College Station, TX. Retrieved from https://static.tti.tamu.edu/tti.tamu.edu/documents/mobility-scorecard-2015-wappx.pdf

Scholler, J. & Wu, J. (June 2017). *Design Vehicle Detection System for Better Data Accuracy* (presentation). 2017 Florida Department of Transportation Design Training Expo. Retrieved from the FDOT website, http://www.fdot.gov/design/training/DesignExpo/2017/Presentations/2017-JillianScholler-DesignVehicleDetectionSystemforBetterDataAccuracy.pdf

2012 National Traffic Signal Report Card: Technical Report (May 2012). Retrieved from The Institute of Traffic Engineers library, http://library.ite.org/pub/e265477a-2354-d714-5147-870dfac0e294

Wang, Y. & Araghi, B.N., et al. (June 2014). *Error Assessment for Emerging Traffic Data Collection Devices* (research report). Department of Civil and Environmental Engineering, University of Washington, Seattle, WA. Retrieved from the Washington State Department of Transportation website, https://www.wsdot.wa.gov/research/reports/fullreports/810.1.pdf

RHYTHM ENGINEERING

14019 W 95th St
Lenexa, Kansas 66215

Phone: 913-674-9846

info@rhythmtraffic.com

HAWKEYE™
RADAR EVOLVED