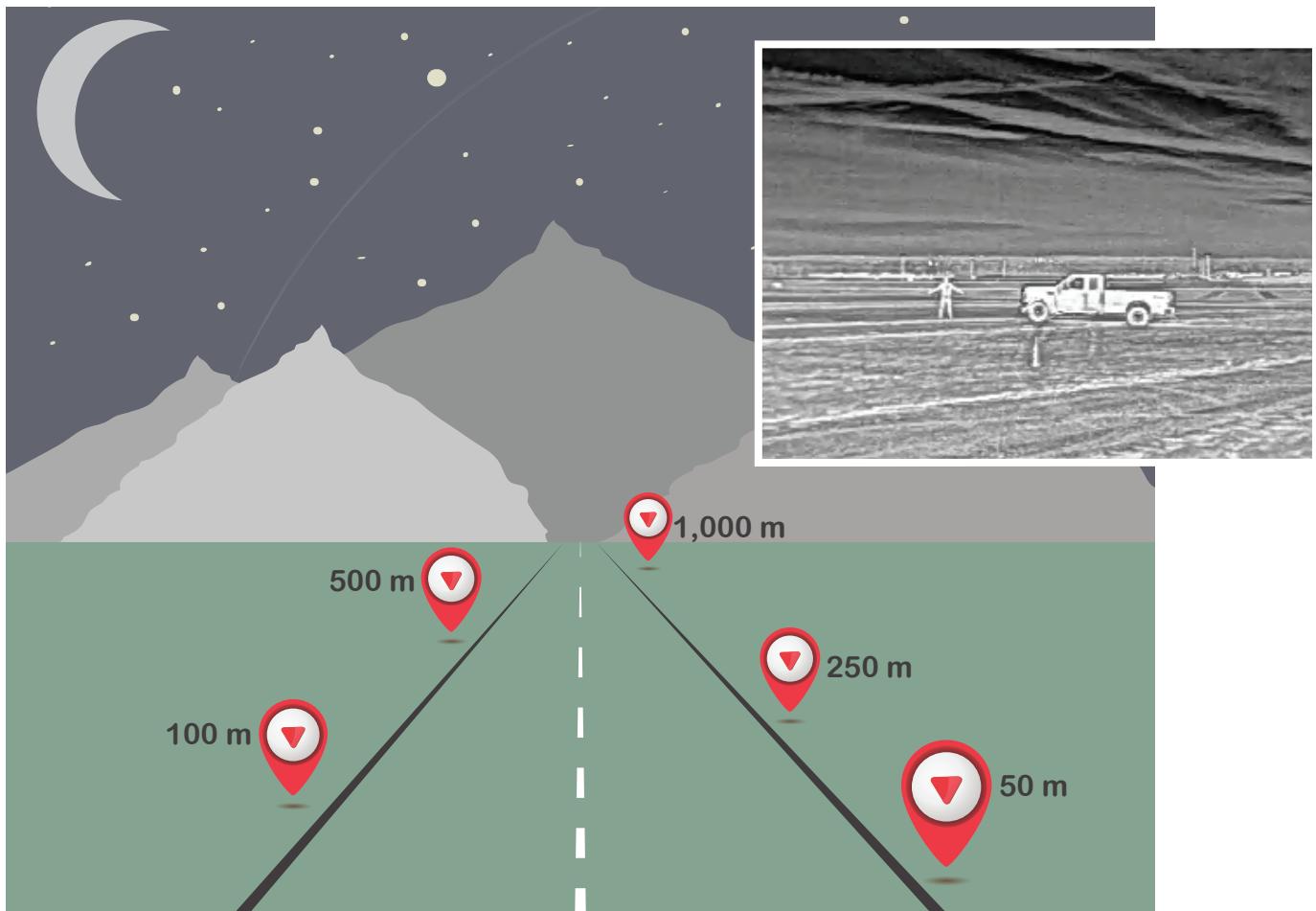


THE TRUTH ABOUT RANGE DATA

HOW TO ASSESS THERMAL CAMERA RANGE CAPABILITY FOR SITE DESIGN PURPOSES

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The Truth About Range Data: HOW TO ASSESS THERMAL CAMERA RANGE CAPABILITY FOR SITE DESIGN PURPOSES

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When laying out a site design for surveillance using currently marketed uncooled thermal cameras, it is important to understand the coverage capability of the cameras under evaluation in terms of field of view (FOV) and range. FOV is easy: the numbers in the specifications are not ambiguous and can be relied upon at face value. Range, on the other hand, is far more complicated. The industry is flooded with conflicting information when it comes to range performance. Every valuation has its merits – some more pertinent than others. Accurately gauging range performance from the onset of the site design may allow one to avoid unintended, and pricey rework costs later. The following white paper explores the various determinants that are needed for thermal camera range capability assessment.

What determines range capability?

Range capability depends on many factors, some of which are easily controlled, and others of which are not. A list of the most prominent appear in Table 1.

Five considerations that determine range capability in the face of all these variables are:

1. Range capability predicted from analysis
2. Range criterion based on displayed size of target
3. Range criterion when using video analytics
4. Impact of weather on range capability
5. Impact of image processing on range capability

For each, a discussion of the issue is followed by information for practical application.

Factors we can control	Factors we cannot control
Task	Weather and atmosphere
<ul style="list-style-type: none"> • What do we want to accomplish? E.g., detection, tracking, assessment? • With what confidence do we want to be able to accomplish the task? <ul style="list-style-type: none"> • Probability of correct detection • Probability of false detection 	<ul style="list-style-type: none"> • Clarity of the air (transmission, humidity) • Obscurants (rain & mist, snow, fog, dust, smoke, and haze) • Atmospheric turbulence caused by solar heating
Design of the camera	Target characteristics
<ul style="list-style-type: none"> • Optics focal length, f-number, aperture size, aberrations, and transmission • Detector pixel pitch, intrinsic sensitivity, array size, pixel uniformity • Image processing to reduce non-uniformity, suppress noise, compensate for blur, and enhance contrast • Display type, size, resolution, viewing distance, gamma, luminance 	<ul style="list-style-type: none"> • Size • Structure • Temperature • Motion • Emissivity
Placement of the camera	Background characteristics
<ul style="list-style-type: none"> • Distance from camera to intended target • Location of the horizon in the scene • Choice of background for intended target 	<ul style="list-style-type: none"> • Temperature • Texture and clutter
How the camera output is to be used	
<ul style="list-style-type: none"> • Will it be displayed on a monitor for a human to interpret? • Will it feed a video analytics processor for automatic detection and tracking? 	

TABLE 1: FACTORS THAT DETERMINE RANGE CAPABILITY OF THERMAL IMAGERS



Range capability predicted from analysis

Discussion –

No one has more thoroughly researched and developed modeling methods for thermal cameras than the US Army Night Vision and Electronic Sensors Directorate at Fort Belvoir, Virginia. Beginning as early as the 1950's, this organization has produced a string of analytical foundations and computer models of ever-increasing fidelity for predicting range performance in militarily significant scenarios. The latest model is called "NVThermIP2009", usually shortened to "NVThermIP".

The Army models have consistently addressed a specific set of target acquisition tasks, namely

- Target detection – determining that a target is present in the sensor's field of view
- Target recognition – for a detected target, discerning whether it is a tank, truck, or armored personnel carrier (this task is sometimes referred to as a "3 alternative forced choice experiment").
- Target identification – for a recognized tank, truck, or APC, discerning which of 8 different types it is (this task is sometimes referred to as an "8 alternative forced choice experiment").

Example target types are shown in Figure 1. For purposes of our security surveillance needs, where we are looking for people more than military vehicles, it is not intuitively obvious whether the theory built around them applies, but we use it anyway by convention and because it works reasonably well most of the time.

In each case, what is being predicted by the model is the performance of a human viewing a display monitor on which is presented the output of a thermal imaging camera looking through a specified atmosphere at a specified target in front of a specified background scene. By 'performance' what is meant is the percentage of a group of humans attempting the task (detection, recognition, identification) as a function of target range. It is customary to interpret the result as the probability that a single observer correctly performs the task (ergodicity). The result is that the model predicts the probability of successful task accomplishment as a function of target range.

A fascinating and useful concept was tested and promoted by the Army lab in the 1950's, becoming an essential paradigm in all its models up to the present. The paradigm has two key elements: a) that a target of any size, shape, or type has a so-called "critical dimension" that can be used for analysis, and b) that the probability of successful task accomplishment (detection, recognition, identification) correlates strongly with the number of bars in a bar target pattern that can be resolved across the critical dimension of the target. The concept is illustrated in Figure 2. As the target moves farther and farther in range, the angular size of the target gets smaller, as would the equivalent bar

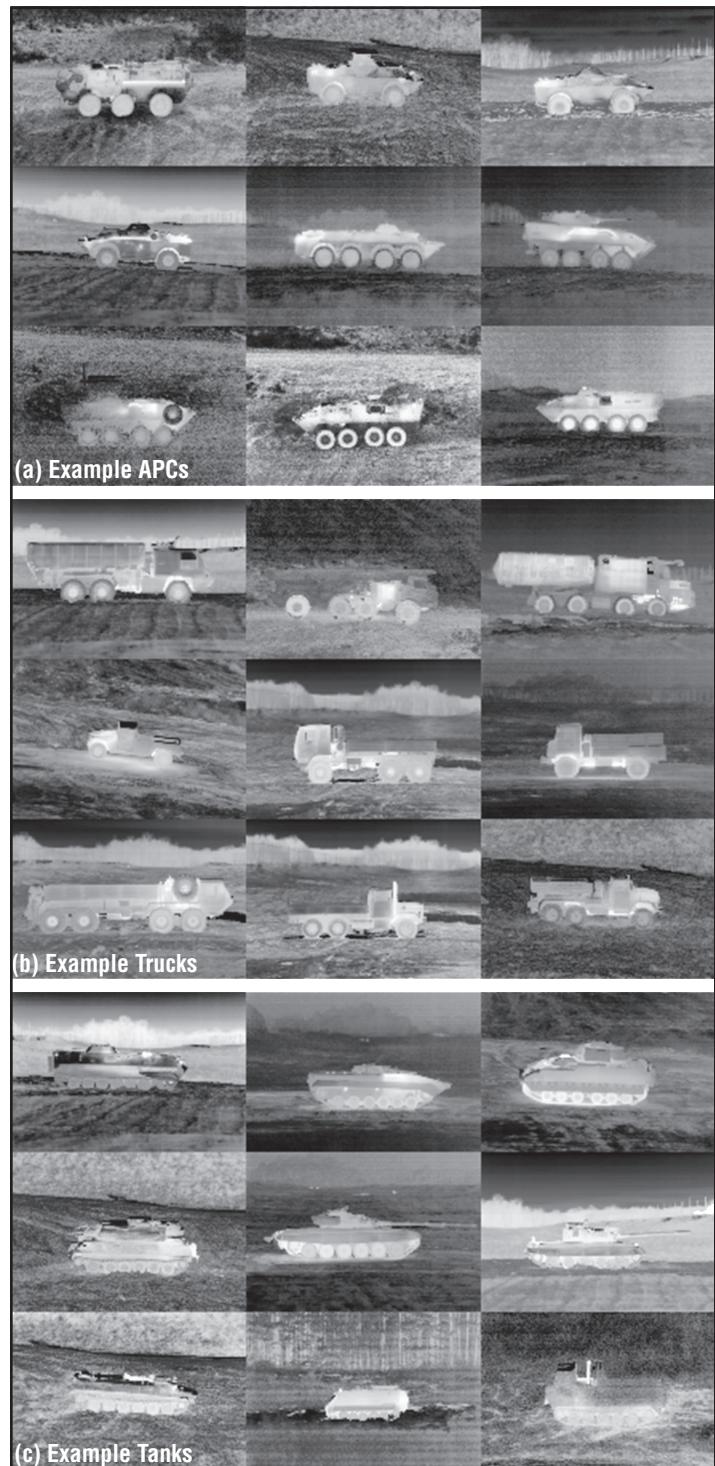


FIGURE 1: EXAMPLES OF TARGETS USED IN ARMY MODEL TESTING

pattern. Just short of the range where the bars become indistinguishable (unresolvable), the bar pattern is said to be at the range limit for that bar pattern frequency (bars per unit of angle). It is the characteristics of the camera-observer combination that determine the range where the bars become not resolvable.

It was this concept (equivalency of actual target to a bar pattern) that led to the ubiquitous Johnson Criteria. A



published paper by John Johnson described the relationship between the number of resolvable bars and the tasks of detection, recognition, and identification for an image intensifier system (See Reference 1). Subsequent analysis has yielded a version of the original criteria as it applies to thermal imaging cameras, which appears as Table 2. For each task, the criterion is the number of resolvable bar cycles subtending the critical dimension of the target, where one bar cycle is one bar and one space, such that the probability of task accomplishment is as indicated.

Resolvable Bar Cycles Required for Indicated Probability of Successful Task Accomplishment

Task	Probability = 50%	Probability = 70%	Probability = 90%
Detection	0.75	0.94	1.34
Recognition	3	3.75	5.37
Identification	6	7.5	10.7

TABLE 2: JOHNSON CRITERIA FOR THERMAL IMAGING CAMERAS

The utility of the bar pattern/target equivalency and the Johnson criteria is two-fold. First, it simplifies the analytical approach since bars are simple and defined whereas real targets are complex and defy definition. Second, it enables performance to be characterized in a laboratory with relatively simple equipment (blackbody source, bar target masks, collimator), instead of having to round up trucks, APCs, and tanks every time one wants to characterize a different camera. Vestiges of this approach are still present in updated version of the Army model (NVThermIP), but the theory has become more sophisticated mathematically to yield more accurate results.

The use of NVThermIP entails specifying a variety of input values characterizing the camera lens, the detector, the framing and sampling electronics, the signal processing electronics, the viewing display, the atmosphere, the target, and the task. The outputs are tables of probability vs. range for each of the tasks of detection, recognition, and identification.

A drawback to NVThermIP is that it is not always possible to know values for all the inputs needed. Furthermore, NVThermIP is not “transparent” in that, with all its variables and the scores of equations relating them, it is often not clear what is really going on.

An alternative to NVThermIP used by many is an approach we will refer to as “pixels on target”. In this approach we make a fundamental assumption that the bar pattern is resolvable when the width of a bar is equal to the angular subtense of a detector pixel, which we call “instantaneous field of view” or “IFOV”. Two adjacent pixels have the angular subtense of a resolvable cycle (i.e., a bar and a space) at the limit of resolvability. Calculations in this approach are done with small angle trigonometry and

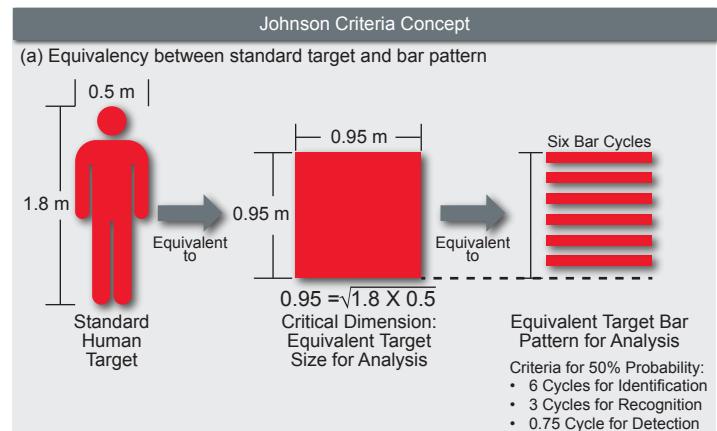


FIGURE 2(A): TARGET EQUIVALENCY TO A BAR PATTERN

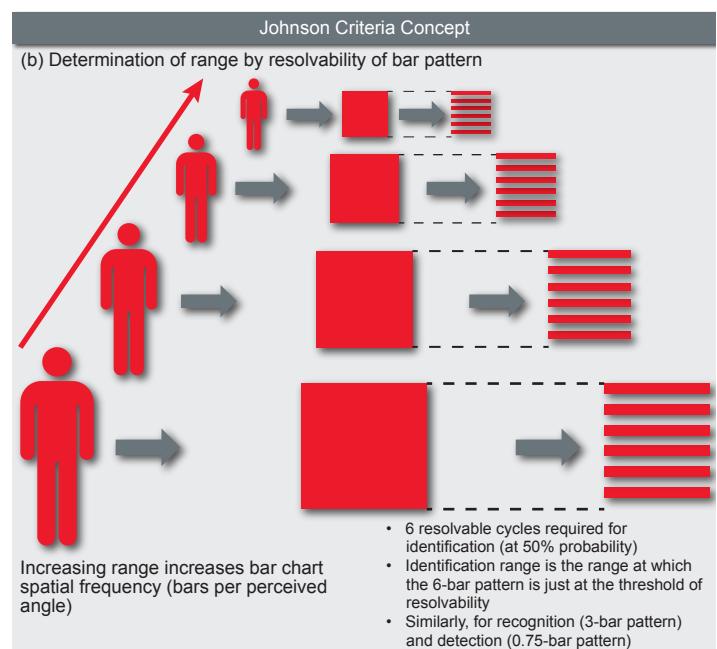


FIGURE 2(B): RANGE RELATIONSHIP TO BAR SPATIAL FREQUENCY

are often simple enough to do in one's head, hence the transparency of the approach.

The pixels-on-target approach requires only the most basic information: target size, detector pixel pitch, and the effective focal length of the camera optics. With these inputs the following four equations are evaluated in sequence to predict the range as illustrated in the example.

EQUATION 1:

$$\text{Target critical dimension (m)} = \sqrt{\text{Target Height (m)} \times \text{Target Width (m)}}$$

EQUATION 2:

$$\text{Pixel IFOV (mrad)} = \frac{\text{detector pixel pitch (\mu m)}}{\text{optics effective focal length (mm)}}$$



EQUATION 3:

$$\text{No. of } \left(\frac{\text{pixels}}{\text{meter}} \right) \text{ req'd. in plane of "PPM" target} = \frac{2 \times \text{No. of req'd cycles from Johnson criterion}}{\text{Target critical dimension (m)}}$$

Note: We use the term "PPM" throughout this article to mean the number of required pixels per meter in the plane of the target.

EQUATION 4:

$$\text{Range (m)} = \frac{(1000 \frac{\text{radians}}{\text{mrad}})}{\text{PPM} \left(\frac{\text{pixels}}{\text{m}} \right) \times \text{Pixel IFOV (mrad)}}$$

Using the example below and the equations, the results shown can be determined.

EXAMPLE:

Variable	Example
Target height	1.8 m
Target width	0.5 m
Detector pixel pitch	17 μm
Optics effective focal length	16.75 mm
Task:	Recognition
Johnson criterion for recognition:	3 resolvable cycles

RESULTS:

Variable	Example
Target critical dimension	0.95 m
Pixel IFOV	1.01 mrad
PPM	6.3 pixels/m
Range (50% probability)	157 m

It is clear that, though simple, the pixels-on-target approach glosses over many important considerations, e.g., weather. However, it works well in many cases. Specifically, it works well when the assumptions listed in Table 3 apply.

Category	Assumption
Signal	<p>There is plenty of signal. The target is sufficiently hotter or colder than the background scene such that the temperature difference is large enough to provide ample signal at the camera aperture.</p> <p>Applies well when the targets are people or operating ground vehicles in front of a bland earth or sky background out to ranges not greater than 5 or 10 km when the air is clear and dry. Does not apply when ranges are longer, the targets are weaker (such as when a vehicle has been sitting without running for a long time), or when the background is cluttered or variegated. It also does not apply at so-called thermal crossover times whereby the daily temperature cycling of earth temperature swings above and below the target temperature, if it does.</p>
Atmosphere	There isn't much atmospheric attenuation. The air is assumed to be clear and dry.
Optics	<p>The optics are assumed to be "well designed", meaning that the blurring effects of diffraction and aberrations are assumed to be substantially insignificant at the spatial frequency range supported by the pixel IFOV. Saying this another way, the pixel IFOV sets the limit of resolvability for the camera, not other blurring effects.</p> <p>Applies well to optics designed for currently marketed uncooled thermal cameras by reputable manufacturers. The diffraction part of the assumption is met for cameras with f-numbers ≤ 1.7, which all are. The aberration part of the assumption is harder to describe, but is generally valid for these cameras.</p>
Detector	<p>Detector noise is sufficiently low that it does not enter the problem (it does not limit range performance).</p> <p>Applies well to currently marketed uncooled cameras because NETD values are typically at or below 50 mK.</p>
Image processing	<p>No performance lift from image processing is accounted for.</p> <p>Currently marketed uncooled cameras sometimes use optional image processing to sharpen images, enhance contrast, suppress large area contrast variability, suppress noise, etc. These are all good things that enhance range, but pixels-on-target does not account for them.</p>
Display	<p>The display is considered "perfect", meaning it does not contribute to performance loss.</p> <p>The display can have subtle effects on range performance, but in today's world of high resolution flat panels, it is rarely much of a consideration. The most significant part of the display assumption is that it doesn't matter how close to, or away from, the display the observer is positioned. Actually, it does matter a little bit, and pixels-on-target does not account for it.</p>
Human observer	The human is considered "perfect", meaning his/her eyesight is adequate, his/her training is adequate, and his/her motivation (attention to task) is sufficient.

TABLE 3: ASSUMPTIONS REQUIRED FOR USE OF PIXELS-ON-TARGET METHOD



Practical Application –

Tables A1 thru A4 (located in Appendix A beginning on page 12) list the predicted ranges for the DRS uncooled camera product line using both NVThermIP and pixels-on-target. The tables list predicted ranges from NVThermIP at probabilities of 90%, 70%, and 50%, for the tasks of detection, recognition, and identification, as the Army defines them. Also listed for each task are the pixels-on-target predictions, which are understood to be ranges for 50% probability. The products are listed by optics effective focal length. The input parameters and assumptions used are:

- Target:
 - Human — 1.8 m high x 0.5 m wide, 2°C temperature contrast to background
 - Vehicle — 1.5 m high x 4.0 m wide, 5°C temperature contrast to background
- Background: bland and at or near room temperature
- Atmosphere: clear and dry, transmission factor is 0.9 per km (Beer's law)
- Optics characteristics: f-numbers range from 1 to 1.6 depending on model; average transmission factors range from 86% to 90%; focal lengths range from 3.8 mm to 65 mm.
- Detector characteristics: pixel pitch is 17 microns in horizontal and vertical directions; array sizes: 640 x 480 and 320 x 240; spectral band of sensitivity: <8 microns to >13 microns; sensitivity: [see system NETD].
- System NETD: 0.05°C
- System gain: displayed dynamic range = 6 X target-to-background contrast
- Image processing: none for special enhancements
- Display: flat panel, pixel size = .03175 cm viewing distance = 53.34 cm average luminance = 10 ft-lamberts
- Human observer: standard eye model; standard training

The DRS products, whether Tamarisk® cores or WatchMaster® IP cameras, are represented in the tables only by their optics effective focal lengths, regardless of whether they use 640 x 480 or 320 x 240 arrays. Since pixel pitch is the same for all, focal length is the primary performance differentiator, which is to say that the additional field of view afforded by the larger array does nothing to increase range performance. That said, however, all pertinent optical properties (e.g., transmission, diffraction, aberrations, f-number) for each product are accounted for in the modeling, not just focal length.

Range criterion based on displayed size of target

Discussion –

In the camera marketplace, range performance is nearly

always listed on data sheets in terms of maximum values. But for the practitioner designing a surveillance plan for an actual site, it is important to consider what maximum range performance looks like and whether that is acceptable. If not, additional design margin should be applied to get the desired result.

Here's an example. From the tables in Appendix A, the maximum listed human detection range for a camera with a 19 mm focal length lens is 850 m (NVThermIP-50%). The height dimension for that person is 1.8 m, meaning that he is only 2.4 pixels high at that range, which is 1% of the vertical field of view of a 320 x 240 image as depicted on the display. The target image is very tiny. This situation is approximated by Figure 3 (the actual range in the figure is 1000 m and the person is 2 pixels high).



FIGURE 3: IMAGE OF HUMAN AT 1000 M USING 19 MM FOCAL LENGTH 320 x 240 IMAGER HAVING 16° HORIZONTAL FIELD OF VIEW

If this is an expected and acceptable image of a person, there is no problem. If not, additional margin is needed in the design range maximum when planning the surveillance site.

Practical Application –

If an adjustment needs to be made, a simple way to make it is to estimate the desired minimum target height in the image in terms of pixels and then to calculate the new design range maximum using the following two equations.

EQUATION 5:

$$PPM \left(\frac{\text{pixels}}{\text{meter}} \right) = \frac{\text{minimum target height displayed (pixels)}}{\text{target height (m)} \times 100\%}$$

where, as earlier, PPM refers to the required number of pixels per meter in the plane of the target. Target height, in this case, is the vertical height of the target, not the critical dimension calculated by Equation 1.


EQUATION 6:

$$\text{Pixel IFOV (mrad)} = \frac{\text{detector pixel pitch (\mu m)}}{\text{optics effective focal length (mm)}}$$

EQUATION 7:

$$\text{Range (m)} = \frac{(1000 \frac{\text{radians}}{\text{mrad}})}{\text{PPM} \left(\frac{\text{pixels}}{\text{m}} \right) \times \text{Pixel IFOV (mrad)}}$$

Note that these equations for Pixel IFOV and for range are the same as used in the pixels-on-target calculations, but with a different value for PPM. They are repeated here for convenience.

EXAMPLE:

Variable	Example
Target height	1.8 m
Optics effective focal length	19 mm
Detector pixel pitch	17 μm
Minimum target height displayed	20 pixels

RESULTS:

Variable	Result
PPM	11.1 pixels/m
Pixel IFOV	0.89 mrad
Range	101 m

At this range, a 1.8 m high target spans 20 pixels head to toe. This reduction in range limit, from the tabulated 850 m down to 101 m, not only makes the target look bigger on the monitor but provides much more definition of the target's shape by increasing the number of pixels in one dimension by a factor of 8. The resulting image would look more like the one in Figure 4.



FIGURE 4: IMAGE OF HUMAN AT 100 M USING 19 MM FOCAL LENGTH
320 x 240 IMAGER HAVING 16° HORIZONTAL FIELD OF VIEW

It is very important to note that this example is somewhat of an exaggeration for illustration purposes. It is not meant to prescribe how much reduction should be taken in the range limit, but only to illustrate the trade that may need to be made.

Range criterion when using video analytics

Discussion –

Video analytics is a wonderful concept for surveillance systems. The idea that hundreds of camera feeds can be tirelessly observed, examined, and archived 24 hours a day without missing intruder alerts and without generating false alerts is a truly remarkable ideal. Of course, the ideal is elusive, but reality is fast approaching it.

For analytics, range criteria are different from those modeled by NVThermalP. Analytics providers have developed sophisticated proprietary algorithms to accomplish their functions, making performance prediction and analysis not at all straightforward. But in the functional "common denominator" of detecting and tracking targets, some generalities can be offered. A useful notion is that a target can be detected and tracked if it spans a certain number of detector pixels.

A survey of product data sheets from 5 prominent video analytics providers reveals that the criterion for detecting and tracking a human target ranges from 4 to 11 pixels/m in the plane of the target, depending on provider, with 6-7 pixels/m being the norm. Since the critical target dimension of a standing human is about 1 meter (see above), an analytics criterion of 6 pixels/m is essentially tantamount to the Johnson criterion for recognition discussed earlier for the pixels-on-target model. However, the more generalized approach is described below.

Practical Application–

Compute the maximum range limit for video analytics using the following equation:

EQUATION 8:

$$\text{Range (m)} = \frac{(1000 \frac{\text{radians}}{\text{mrad}})}{\text{PPM} \left(\frac{\text{pixels}}{\text{m}} \right) \times \text{Pixel IFOV (mrad)}}$$

where, PPM (pixels/m) is the criterion provided by the analytics supplier for the required number of pixels/m in the plane of the target; and, Pixel IFOV (mrad) is calculated as before by the following:

EQUATION 9:

$$\text{Pixel IFOV (mrad)} = \frac{\text{detector pixel pitch (\mu m)}}{\text{optics effective focal length (mm)}}$$



EXAMPLE:

Variable	Example
Detector pixel pitch	17 μm
Optics effective focal length	50 mm
PPM for analytics	6.5 pixels / m

RESULTS:

Variable	Result
Pixel IFOV	0.34 mrad
Range	452 m

The advantage of this approach is that pixel pitch and analytics criterion are explicit inputs, which make it possible to compare products from different suppliers. For example, though all the current DRS products use detectors with 17 micron pixel pitch, other suppliers use pitch values of 25 microns for some cameras. Larger pixel pitch results in shorter range performance, all else being equal.

Impact of Weather on Range Capability

Discussion –

Weather conditions impact the range capability of thermal imagers by attenuating the infrared signal as it propagates from target to camera. Table 8 shows the impact of 3 different conditions that have 3 different levels of severity. The impact can be characterized by the signal transmission over a 1000 meter path, with the good weather value of 0.9 serving as the baseline. The other 3 conditions are high absolute humidity, moderate rain, and heavy rain. The range predictions in Table 8 are found using NVThermIP because the pixels-on-target approach does not account for signal attenuation from weather.

By examining the numbers in the table it is clear that most of the impact is minimal. The largest impact occurs for detection at 50% probability, where the decrease in range from good weather to heavy rain is 40%. Corresponding decreases in recognition and identification are essentially nonexistent. The impact on range is itself a function of range. The longer the range, the more the impact. The

camera represented in table 8 was a camera with a 16.75 mm focal length lens. The weather impact on range for a longer focal length lens is greater. For example, for the camera with 65 mm focal length the decrease in detection range at the 50% probability level is 70%.

Table 4 doesn't address all weather possibilities. Besides rain and humidity, there could be fog, haze, smoke, and snow. All can be characterized in a manner similar to Table 4.

Practical Application –

If the site designer knew what weather conditions he faced, he could apply margin factors to account for the weather losses in range capability using an analysis similar to Table 4. However, there are so many different possibilities, all of which affect performance of the cameras differently depending on their performance in good weather.

The recommended course for site planning would be the following:

- Consider the likely weather conditions at the site and the frequencies they occur (e.g., don't worry about snow in south Texas and don't worry about heavy rain in Denver, etc.).
- Decide which must be tolerated without loss of surveillance capability, and which, if any, may be ignored.
- Use NVThermIP to examine the impact of the conditions that matter to determine a derating factor to be applied to the nominal range capability listed in Tables A1 thru A4.
- Derate tabulated performance accordingly.

Impact of Image Processing on Range Capability

Discussion –

Multiple thermal imaging suppliers (including DRS) incorporate image processing options as part of their products. Some of these features have generic names, such as histogram equalization, automatic gain control (AGC), boost, local area processing (LAP), and multi-frame (MF)

IR Signal Attenuation Over 1,000 meter path	Detection			Recognition			Identification		
	P = 90%	P = 70%	P = 50%	P = 90%	P = 70%	P = 50%	P = 90%	P = 70%	P = 50%
Weather Case: Nominal (good) weather – Temp: 73°F RH: 40% No rain, fog, haze									
0.9	280	486	751	52	92	144	40	71	112
Weather Case: High humidity – Temp: 90°F RH: 68% No rain, fog, haze									
0.5	263	437	637	51	90	140	39	70	109
Weather Case: Moderate rain – Rain rate: 4 mm / h									
0.3	255	413	582	51	89	137	39	69	107
Weather Case: Heavy rain – Rain rate: 25 mm / hr									
0.05	242	379	512	51	88	134	39	69	105

TABLE 4: NVTHERMIP ANALYSIS OF EXAMPLE WEATHER IMPACTS ON DRS CAMERA WITH 16.75 MM FOCAL LENGTH LENS



processing; others have trademarked names such as Image Contrast Enhancement (ICE™) reflecting their proprietary nature.

Our modeling tools (NVThermIP, pixels-on-target) do not enable us to easily assess the benefits of these features, though it is obvious to a casual observer that they do improve the images and extend range capability. They make these enhancements by doing two things: a) sharpening image detail; and b) reducing the large area gray shade range across the field of view. Figures 5 and 6, original and enhanced versions of the same scene, illustrate both characteristics. Figure 6 has sharper detail and a more uniform large area gray shade rendering. Edge enhancing boost brings out detail in both the truck and the human. Contrast enhancement removes the large area shading difference between the sky and earth, allowing the contrast gain to be higher, exposing more detail in both the earth and sky regions.

Industry literature offers some, but limited, help in assessing image processing benefit. Reference 2 indicates that boost

(edge enhancement) when combined with multi-frame processing can increase range performance by as much as a factor of 2 under some circumstances (wavelength, target temperature, etc.), but that if not used with multi-frame processing the benefit is much lower. It also explains that NVThermIP is not capable of directly illustrating that effect. Reference 2 also indicates that local area contrast enhancement can, in fact, be modeled by NVThermIP and explains the technique. When we apply that technique to our DRS imagers we find a range improvement that varies from 17% to 20%.

Practical Application –

Recommendation for the practitioner: Do not factor in the benefits of image processing when designing an installation for a site. There is too much variability that cannot be adequately predicted. Do, however, favor cameras with image processing and plan to use it, because it provides additional margin to the design and it yields images that are significantly easier to interpret.

Summary and Recommendations – Putting it All Together

Throughout this paper we have attempted to be brutally honest about understanding range capability. We have addressed how range capability is specified, how it is determined, and the limits of utility of the results. We have also addressed how range capability is different when video analytics and image processing are used. We have tried to dispel the notion that the range numbers offered on product data sheets (even ours) are definitive and are suitable for use in designing site installations even though they are clearly useful for product comparisons.

We have examined 5 relevant areas:

- How analysis using NVThermIP and/or pixels-on-target can be used to predict range performance for a human observer looking at a display
- How to compute a maximum range based on a minimum required target image on the display
- How to compute a maximum range consistent with the use of video analytics
- The impact of weather on range capability
- The impact of image processing on range capability

For the first 3 items, we cast the range determination problem in terms of a required number of resolvable pixels at the range of the target in the plane of the target. We chose to do it this way so we could standardize the way we get to a range prediction number. The log-log graph shown in Figure 7 is a single tool that allows us to take all 3 items into consideration at the same time, as they relate to the DRS camera portfolio. The graph (Figure 7) plots range on the horizontal axis and the PPM metric on the vertical axis. The diagonal lines each represent a different DRS camera as characterized by its focal length and pixel pitch.



FIGURE 5: HUMAN AND VEHICLE SHOWN AT 25 METERS AND 40° FIELD OF VIEW USING AUTOMATIC GAIN CONTROL



FIGURE 6: HUMAN AND VEHICLE SHOWN AT 25 METERS AND 40° FIELD OF VIEW USING IMAGE CONTRAST ENHANCEMENT (ICE™)

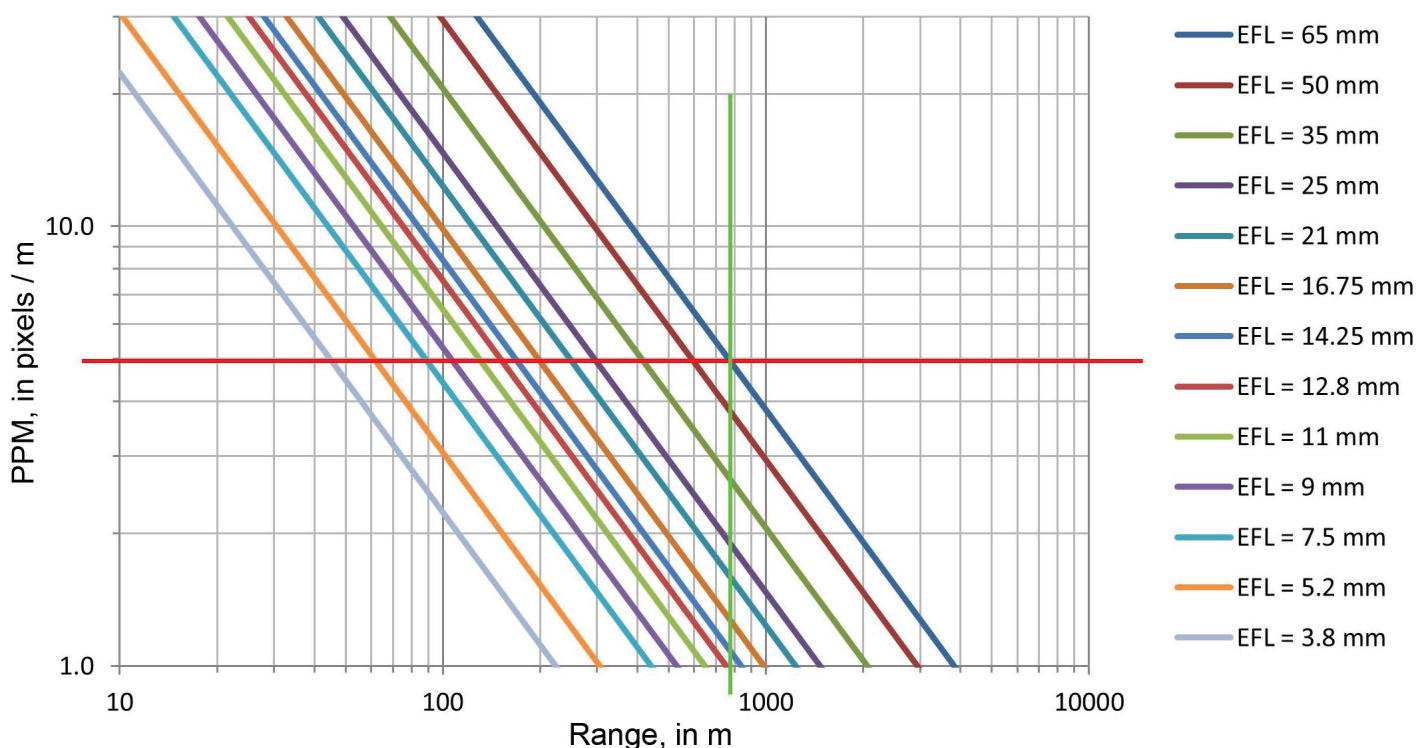


FIGURE 7: GRAPH FOR DETERMINING RANGE CAPABILITY OF DRS' 17 UM PIXEL PITCH CAMERAS AS A FUNCTION OF PPM METRIC

The basic use of the graph is the following: To determine the range prediction for a specific lens given a value for PPM, select the PPM value on the vertical axis, follow it horizontally to where it intersects the diagonal line for the lens of interest, and then follow it vertically to the horizontal axis to determine the range value.

Example –

For a PPM value of 5 (indicated by the red line), and for the camera having the 65 mm focal length lens (indicated by the right-most dark blue diagonal line), follow down the vertical green line and read 760 m where it crosses the horizontal axis.

To illustrate an actual problem solution, consider the following example.

Given:

- A surveillance system needs to be laid out for a long straight fence line around a moderately sensitive site (such as an industrial facility, as opposed to a nuclear materials depot, which would have much greater sensitivity).
- Human observers will watch displays to detect intruders, which are taken to be humans on foot.
- It is judged that intruder detection requires “recognition” and that the confidence level (probability of correct task accomplishment) needs to be at least 70%.
- It is judged that weather in the form of moderate rain will be a factor but only 5% of the time or less.

- It is noted that at some future date (under a future budget, perhaps) video analytics will be added to the installation and that the analytics choice would require a PPM metric of 8 pixels/m in the target plane.
- It is judged that the minimum size of a person in the display should be no smaller than the equivalent of 15 detector pixels to provide good human comfort with the images.

Query –

What camera or cameras are suitable from a range performance perspective and what maximum ranges should we adopt when laying out the site?

Solution –

- Since we are watching for human intruders, we assume the target height is 1.8 m and the target critical dimension is 0.95 m (see Equation 1).
- Since the system involves human observers looking at monitors, and that the task is taken to be “recognition” at 70% probability, we calculate the PPM metric thus:
 - The Johnson criterion for recognition at 70% probability is 3.75 resolvable bar cycles (see table 2).
 - The PPM is calculated to be 7.9 pixels/m in the plane of the target (see Equation 3).
- Since the minimum displayed target height (for a person standing erect) is 15 pixels, we compute the PPM metric for this condition to be 8.3 pixels per meter in the plane of the target (see Equation 5).



- Since we anticipate the use of video analytics requiring a PPM metric of 8 pixels/m, we simply take note of the fact.
- Now, we look at the three values of PPM metric and select the largest, which is the most demanding. In this case it is the 8.3 pixels/m required by the minimum target display height. For this problem, they are all almost the same, so we don't really need to re-rationalize the requirements.
- Using the graph in Figure 7, we determine the following ranges (for the cameras with the 5 longest focal lengths):

Camera EFL	Range
65 mm camera	420 m
50 mm camera	325 m
35 mm camera	225 m
25 mm camera	160 m
21 mm camera	130 m

- Since the primary weather issue is moderate rain occurring infrequently, and because the impact is generally light at these ranges (see Table 8), and because the sensitivity of the site is not at the highest levels, we choose to ignore the rain impact.
- We will, however, plan to take advantage of optional image processing to give ourselves additional design margin, but we will not change our range predictions.

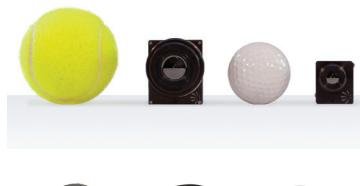
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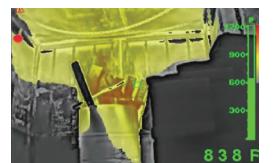
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Appendix A: Predicted Range Tables for DRS Products for Human and Vehicle Targets (Meters and Feet)

Analytical Modeling Predictions for Range Capability of DRS Thermal Imaging Products Target is Human. Other Assumptions Apply. (See Text) Ranges in meters.														
EFL (mm)	Pixel IFOV (mrad)	Detection Range (m)				Recognition Range (m)				Identification Range (m)				Pixels- on- target- 50%
		NVThermIP- 90%	NVThermIP- 70%	NVThermIP- 50%	Pixels- on- target- 50%	NVThermIP- 90%	NVThermIP- 70%	NVThermIP- 50%	Pixels- on- target- 50%	NVThermIP- 90%	NVThermIP- 70%	NVThermIP- 50%	Pixels- on- target- 50%	
65	0.26	1072	1811	2707	2418	209	364	564	605	161	282	438	302	
50	0.34	821	1400	2112	1860	158	276	430	465	122	214	333	233	
35	0.49	555	954	1456	1302	105	185	288	326	81	143	223	163	
25	0.68	390	674	1037	930	73	129	202	233	56	100	156	116	
21	0.81	348	603	929	781	65	115	180	195	50	89	139	98	
19	0.89	317	551	850	707	60	105	164	177	46	81	127	88	
16.75	1.01	280	486	751	623	52	92	144	156	40	71	112	78	
14.25	1.19	239	417	646	530	45	79	123	133	34	61	95	66	
12.8	1.33	209	365	566	476	38	69	108	119	30	53	83	60	
12.8	1.33	204	356	553	476	38	67	105	119	29	52	81	60	
11	1.55	187	327	508	409	34	61	97	102	26	47	74	51	
9	1.89	147	256	399	335	26	48	75	84	20	37	58	42	
7.5	2.27	132	231	360	279	23	43	68	70	18	34	53	35	
7.5	2.27	125	219	341	279	22	41	65	70	17	32	50	35	
7.65	2.22	145	253	395	285	26	48	74	71	20	37	58	36	
5.3	3.21	92	162	253	197	17	30	48	49	15	24	37	25	
3.8	4.47	69	122	191	141	15	23	36	35	15	18	28	18	

TABLE A1: PREDICTED RANGES FOR DRS PRODUCTS FOR HUMAN TARGET, LISTED IN METERS

Analytical Modeling Predictions for Range Capability of DRS Thermal Imaging Products Target is Human. Other Assumptions Apply. (See Text) Ranges in feet.														
EFL (mm)	Pixel IFOV (mrad)	Detection Range (ft)				Recognition Range (ft)				Identification Range (ft)				Pixels- on- target- 50%
		NVThermIP- 90%	NVThermIP- 70%	NVThermIP- 50%	Pixels- on- target- 50%	NVThermIP- 90%	NVThermIP- 70%	NVThermIP- 50%	Pixels- on- target- 50%	NVThermIP- 90%	NVThermIP- 70%	NVThermIP- 50%	Pixels- on- target- 50%	
65	0.26	3517	5942	8881	7934	686	1194	1850	1983	528	925	1437	992	
50	0.34	2694	4593	6929	6103	518	906	1411	1526	400	702	1093	763	
35	0.49	1821	3130	4777	4272	344	607	945	1068	266	469	732	534	
25	0.68	1280	2211	3402	3051	240	423	663	763	184	328	512	381	
21	0.81	1142	1978	3048	2563	213	377	591	641	164	292	456	320	
19	0.89	1040	1808	2789	2319	197	344	538	580	151	266	417	290	
16.75	1.01	919	1594	2464	2044	171	302	472	511	131	233	367	256	
14.25	1.19	784	1368	2119	1739	148	259	404	435	112	200	312	217	
12.8	1.33	686	1198	1857	1562	125	226	354	391	98	174	272	195	
12.8	1.33	669	1168	1814	1562	125	220	344	391	95	171	266	195	
11	1.55	614	1073	1667	1343	112	200	318	336	85	154	243	168	
9	1.89	482	840	1309	1099	85	157	246	275	66	121	190	137	
7.5	2.27	433	758	1181	915	75	141	223	229	59	112	174	114	
7.5	2.27	410	719	1119	915	72	135	213	229	56	105	164	114	
7.65	2.22	476	830	1296	934	85	157	243	233	66	121	190	117	
5.3	3.21	302	531	830	647	56	98	157	162	49	79	121	81	
3.8	4.47	226	400	627	464	49	75	118	116	49	59	92	58	

TABLE A2: PREDICTED RANGES FOR DRS PRODUCTS FOR HUMAN TARGET, LISTED IN FEET



Analytical Modeling Predictions for Range Capability of DRS Thermal Imaging Products Target is Vehicle. Other Assumptions Apply. (See Text) Ranges in meters.															
EFL (mm)	Pixel IFOV (mrad)	Detection Range (m)				Pixels- on- target- 50%	Recognition Range (m)				Pixels- on- target- 50%	Identification Range (m)			
		NVThermIP- 90%	NVThermIP- 70%	NVThermIP- 50%	NVThermIP- 90%		NVThermIP- 70%	NVThermIP- 50%	NVThermIP- 90%	NVThermIP- 70%		NVThermIP- 90%	NVThermIP- 70%	NVThermIP- 50%	
65	0.26	2594	4188	5974	6244	538	926	1415	1561	418	722	1109	780		
50	0.34	2018	3309	4796	4803	409	707	1086	1201	317	550	848	600		
35	0.49	1390	2323	3433	3362	274	477	737	841	212	370	573	420		
25	0.68	988	1673	2510	2401	192	334	519	600	148	259	403	300		
21	0.81	885	1505	2265	2017	171	298	464	504	132	231	360	252		
19	0.89	807	1375	2077	1825	155	271	422	456	120	210	327	228		
16.75	1.01	718	1227	1860	1609	137	240	374	402	106	186	290	201		
14.25	1.19	615	1055	1605	1369	117	205	320	342	90	159	248	171		
12.8	1.33	539	927	1416	1230	102	179	280	307	79	139	217	154		
12.8	1.33	532	916	1399	1230	101	177	276	307	78	137	214	154		
11	1.55	484	833	1277	1057	91	161	251	264	70	124	194	132		
9	1.89	384	665	1023	865	72	127	199	216	55	98	154	108		
7.5	2.27	343	594	916	720	64	113	177	180	49	87	137	90		
7.5	2.27	329	571	880	720	62	109	170	180	47	84	131	90		
7.65	2.22	377	653	1004	735	71	125	195	184	54	96	150	92		
5.3	3.21	244	425	657	509	46	81	126	127	35	62	97	64		
3.8	4.47	183	320	497	365	34	60	95	91	25	46	73	46		

TABLE A3: PREDICTED RANGES FOR DRS PRODUCTS FOR VEHICLE TARGET, LISTED IN METERS

Analytical Modeling Predictions for Range Capability of DRS Thermal Imaging Products Target is Vehicle. Other Assumptions Apply. (See Text) Ranges in feet.															
EFL (mm)	Pixel IFOV (mrad)	Detection Range (ft)				Pixels- on- target- 50%	Recognition Range (ft)				Pixels- on- target- 50%	Identification Range (ft)			
		NVThermIP- 90%	NVThermIP- 70%	NVThermIP- 50%	NVThermIP- 90%		NVThermIP- 70%	NVThermIP- 50%	NVThermIP- 90%	NVThermIP- 70%		NVThermIP- 90%	NVThermIP- 70%	NVThermIP- 50%	
65	0.26	8510	13740	19600	20485	1765	3038	4642	5121	1371	2369	3638	2561		
50	0.34	6621	10856	15735	15758	1342	2320	3563	3939	1040	1804	2782	1970		
35	0.49	4560	7621	11263	11030	899	1565	2418	2758	696	1214	1880	1379		
25	0.68	3241	5489	8235	7879	630	1096	1703	1970	486	850	1322	985		
21	0.81	2904	4938	7431	6618	561	978	1522	1655	433	758	1181	827		
19	0.89	2648	4511	6814	5988	509	889	1385	1497	394	689	1073	748		
16.75	1.01	2356	4026	6102	5279	449	787	1227	1320	348	610	951	660		
14.25	1.19	2018	3461	5266	4491	384	673	1050	1123	295	522	814	561		
12.8	1.33	1768	3041	4646	4034	335	587	919	1008	259	456	712	504		
12.8	1.33	1745	3005	4590	4034	331	581	906	1008	256	449	702	504		
11	1.55	1588	2733	4190	3467	299	528	823	867	230	407	636	433		
9	1.89	1260	2182	3356	2836	236	417	653	709	180	322	505	355		
7.5	2.27	1125	1949	3005	2364	210	371	581	591	161	285	449	295		
7.5	2.27	1079	1873	2887	2364	203	358	558	591	154	276	430	295		
7.65	2.22	1237	2142	3294	2411	233	410	640	603	177	315	492	301		
5.3	3.21	801	1394	2156	1670	151	266	413	418	115	203	318	209		
3.8	4.47	600	1050	1631	1198	112	197	312	299	82	151	240	150		

TABLE A4: PREDICTED RANGES FOR DRS PRODUCTS FOR VEHICLE TARGET, LISTED IN FEET