

Force Protection Joint Experiment (FPJE) Battlefield Anti-Intrusion System (BAIS) Sensors Data Analysis and Filtering Metrics

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ABSTRACT

The FPJE was an experiment to consider the best way to develop and evaluate a system of systems approach to Force Protection. It was sponsored by Physical Security Equipment Action Group (PSEAG) and Joint Program Manager – Guardian (JPM-G), and was managed by the Product Manager - Force Protection Systems (PM-FPS). The experiment was an effort to utilize existing technical solutions from all branches of the military in order to provide more efficient and effective force protection. The FPJE consisted of four separate Integration Assessments (IA), which were intended as opportunities to assess the status of integration, automation and fusion efforts, and the effectiveness of the current configuration and “system” components. The underlying goal of the FPJE was to increase integration, automation, and fusion of the many different sensors and their data to provide enhanced situational awareness and a common operational picture.

One such sensor system is the Battlefield Anti-Intrusion System (BAIS), which is a system of seismic and acoustic unmanned ground sensors. These sensors were originally designed for employment by infantry soldiers at the platoon level to provide early warning of personnel and vehicle intrusion in austere environments. However, when employed around airfields and high traffic areas, the sensitivity of these sensors can cause an excessive number of detections. During the second FPJE-IA all of the BAIS detections and the locations of all Opposing Forces were logged and analyzed to determine the accuracy rate of the sensors. This analysis revealed that with minimal filtering of detections, the number of false positives and false negatives could be reduced substantially to manageable levels while using the sensors within extreme operational acoustic and seismic noise conditions that are beyond the design requirements.

Keywords: JBC2S, MOCU, BAIS, command and control, unattended ground sensor, fusion, force protection

1. BACKGROUND

The Battlefield Anti-Intrusion System (BAIS) consists of a hand held monitor and one or more sensors units. The basic sensor unit has both seismic and acoustic sensors, but other modules including passive infrared, and magnetic sensors are also available. These additional modules provide higher probability of detection and much lower false alarm rates so they are not included in this analysis.

The BAIS theory of operation is based on a sampling of the seismic and acoustic sensors over a rolling 10 second time window. If over that 10 second interval, one or more events was detected that are above the threshold value, then a classification algorithm will be applied and the results reported to the hand held receiver module via RF. The classification algorithm groups events into the following categories: personnel, vehicle, wheeled vehicle, tracked vehicle, or unknown. For the purpose of analysis, it's important to recognize that the events reported to the hand held receiver do not provide a true count of events, but a list of time slices in which one or more events may have occurred.

The purpose of this document is to illustrate the ineffectiveness of the baseline seismic/acoustic BAIS sensors in high traffic areas during the Force Protection Joint Experiment (FPJE) without any filtering and to show how the effectiveness was greatly improved with basic filtering. There are many ways to filter sensor data, and this document only addresses a few of the initial approaches that were used during the FPJE. The intent was to develop a heuristic algorithm based on comparing sensor detections with true data. These sensors only report the result of their own internal

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classification algorithm, precluding the use a more complex mathematical filter that could use the raw amplitude and frequency measurements to further filter out false detections.

2. ANALYSIS TERMINOLOGY

2.1 Baseline

When there is no filtering of the data for a given analysis. The baseline for the analysis of all detection types will differ from the baseline for the analysis of just personnel detections.

2.2 Fusion-Engine

When a sensor creates a detection, it is run through the *fusion-engine* to determine whether to allow the detection to pass through or to ignore it as noise.

2.3 False-Positive

When a sensor creates a detection, or the *fusion-engine* allows a detection to pass through, but there is no known OPFOR (Opposing Force) within a predetermined distance from the sensor. In other words there is a detection but there should not have been. We check the distance of the OPFOR from the sensor for each detection reported by the *fusion-engine*, not just the current detection.

2.4 False-Negative

When there is a known OPFOR within a predetermined distance from a sensor, but that sensor does not create a detection, or the *fusion-engine* does not allow a detection to pass through. In other words there is no detection but there should have been. However there is a special case where the *fusion-engine* does not allow a detection through, but then later utilizes that detection in its decision to allow a detection through. In this case, we claim that the first detection was not a *false-negative*.

2.5 True-Positive

When a sensor creates a detection, or the *fusion-engine* allows a detection to pass through, and there is a known OPFOR within a predetermined distance from the sensor. In other words there is a detection and there should have been.

2.6 True-Negative

When a sensor does not create a detection, or the *fusion-engine* does not allow a detection to pass through, and there was no known OPFOR within a predetermined distance from the sensor. In other words there is no detection and there should not have been.

3. ANALYSIS

3.1 Filters in the *Fusion-Engine*

The *fusion-engine* for the purpose of this analysis is given a detection threshold, a time period in seconds, and a classification. It then searches through previous detections up the given number of seconds prior to the current detection. It counts the number of detections of the given classification that occur on the same sensor in the given time period. If the count is greater than or equal to the given detection threshold, then the *fusion-engine* allows the detection to pass through. Note that the highest time period considered during initial analysis for a classification was 60 seconds.

3.2 Timing Considerations

The BAIS sensor sends detections to the BAIS receiver at most once every ten seconds. It is important to note that while there is a limit of once every ten seconds at the receiver; there is no such limit once the data reaches JBC2S. The results are based on this limiting factor, but because the timestamps are set when JBC2S logs them, there are situations where the process can slow down and two detections can be logged within ten seconds.

3.3 All Detections

There are five different classifications that the sensors give to detections: personnel, vehicle, wheeled vehicle, tracked vehicle, and unknown. This section analyzes the sensors no matter what classification was given. The predetermined distance that is acceptable for detections is 350 meters based on the BAIS manual.

In Figure 1 you will see the *baseline* case and the filtering cases where the detection threshold was two and three detections. A threshold of two means that there were two detections in the given time period, and the figure shows the confidence in the detections. There a few points to note in this figure. First, notice that 85.4% of the detections in the *baseline* are *false-positives*, which is quite high. However, with the filtering shown, the number of *false-positives* reduces greatly, exactly how much depending on the filtering variables. Now, notice that there are no *false-negatives* for the *baseline* and yet there are *false-negatives* for the filtered cases. This shows that the while the filters manage to reduce the number of *false-positives* they unfortunately add *false-negatives*.

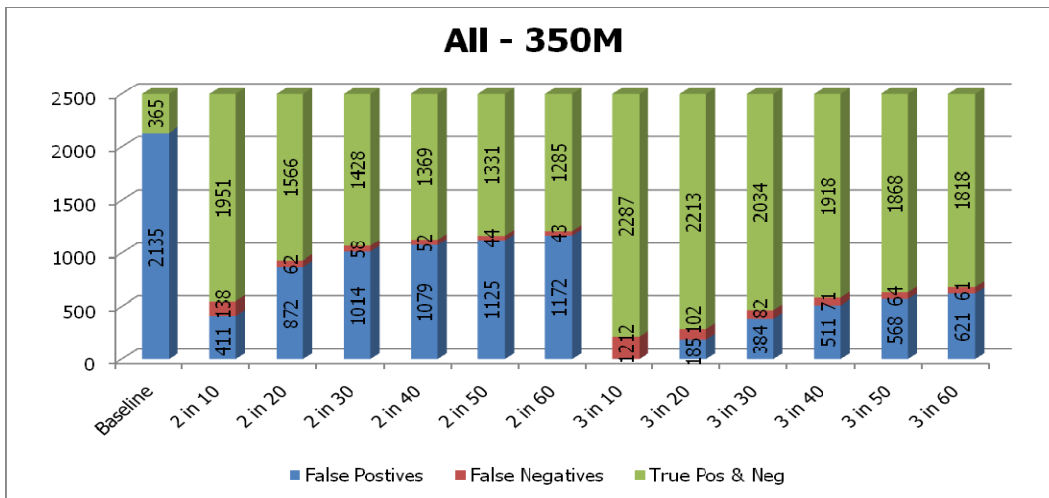


Figure 1: All Detections with Threshold at Two and Three

There are the same interesting features in Figure 2, which shows the *baseline* again and the filtering cases where the detection threshold was four, five, six, and seven. Another feature of the data that becomes apparent in this figure is that there seems to be less data for each scenario as the detection threshold increases. Specifically notice that there is no data for four detections in ten seconds or five in ten or five in 20. These scenarios were not ignored; they were simply not included in the chart because they created a situation where we all detections were ignored, because the scenario never occurred. In other words, there never were four detections in ten seconds, so the scenario gave us useless data.

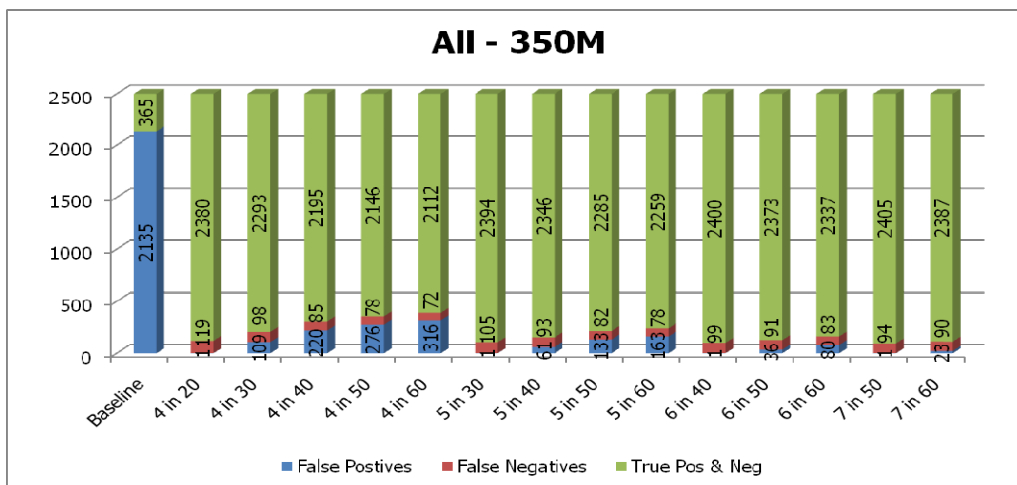


Figure 2: All Detections with Threshold at Four through Seven

The scenario where the detection threshold is two shows that as the time increases for a given scenario, the *false-positives* and the *false-negatives* respond inversely with the *false-positives* increasing and the *false-negatives* decreasing. We will see that this is a common theme throughout the analysis. Without any filtering we have the *baseline* case which is the one extreme of this inverse relationship, with a very high number of *false-positives* and zero *false-negatives*, which is also a theme of the baselines. So for each detection threshold, the goal is to show the other extreme of very low *false-positives* and relatively higher *false-negatives*.

In this next section, there is a chart for detection thresholds two and three. Both charts focus in on the time period that causes the number of *false-positives* to drop close to zero. There is never a detection threshold and time period combination that will have zero *false-positives* on any of these charts. This is because in the cases where there are zero *false-positives*, it is a result of filtering out all detections which by default eliminates all *false-positives*. However, this is not a very good filtering solution, so these cases are not displayed.

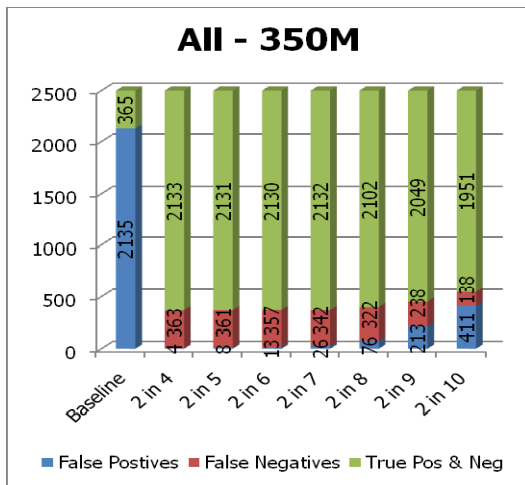


Figure 3: All Detections with Threshold at Two

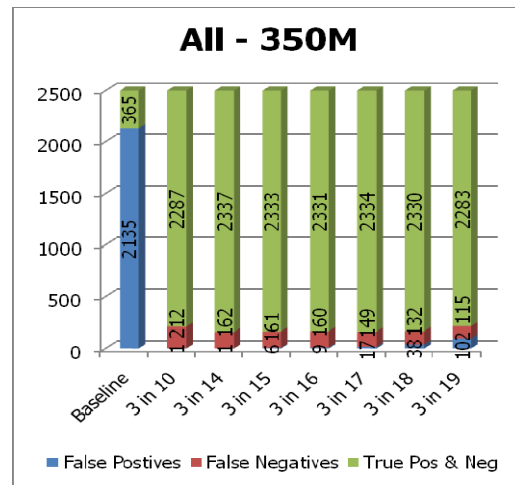


Figure 4: All Detections with Threshold at Three

In some cases like in Figure 4 we jump from ten seconds to 14 seconds along the horizontal axis. This is because there is no change from ten to 14 seconds, so we only show the edges of the time gaps with the same results.

The main thing to notice from these two charts is that the more detections you wait for, the more confidence there is in a *true-positive* or *true-negative*. Also, on both charts, the change from one second to another is only a few *false-positives*, which given a total of 2500 detections, is only a fraction of a percentage in change. Considering the *baseline* is 85.4%, any reduction in *false-positives* below 40% is a substantial improvement.

3.4 Personnel Detections

This section analyzes all detection of classification type personnel. This is a very small subsection of the total detections, with only 186 detections. The predetermined distance that is acceptable for personnel detections is 50 meters based on the BAIS manual.

In Figure 5 you will see the *baseline* case and the filtering cases where the detection threshold was two and three detections. Similar to the section with all classifications, the *baseline* for personnel has a high number of *false-positives* with 77.4%. Again we see that the filtering reduces the number of *false-positives*, but creates some *false-negatives*. In Figure 10 you see the *baseline* repeated and the filtering cases where the detection threshold was four, five, six, and seven.

Figures 7 and 8 are charts for detection thresholds two and three. Both charts focus in on the time period that causes the number of *false-positives* to drop close to zero. The main thing to notice on all the charts in this section is that personnel detections are relatively reliable. Even with a small detection threshold of two, like in Figure 7, the number of *false-positives* is low. As you increase the detection threshold, the *false-positives* remain low and the *false-negatives* decrease.

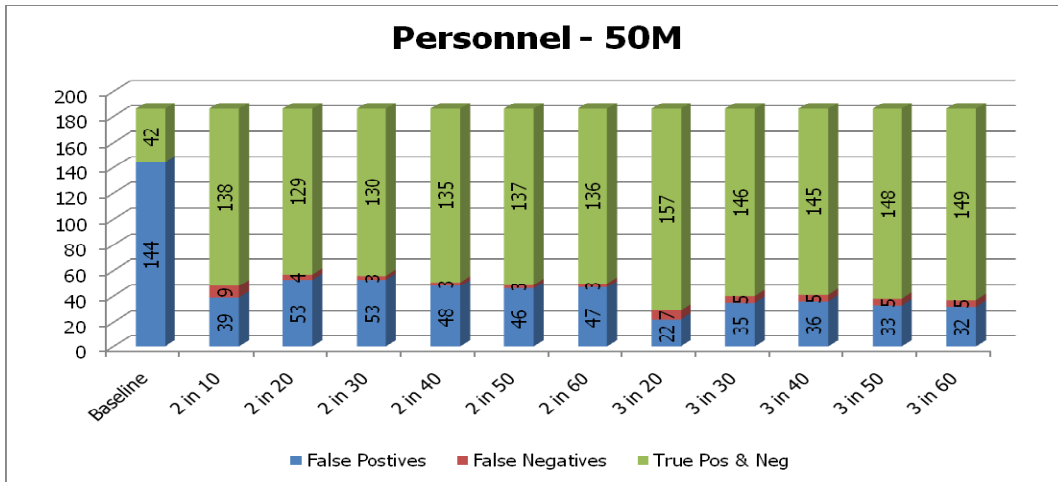


Figure 5: Personnel Detections with Threshold at Two and Three

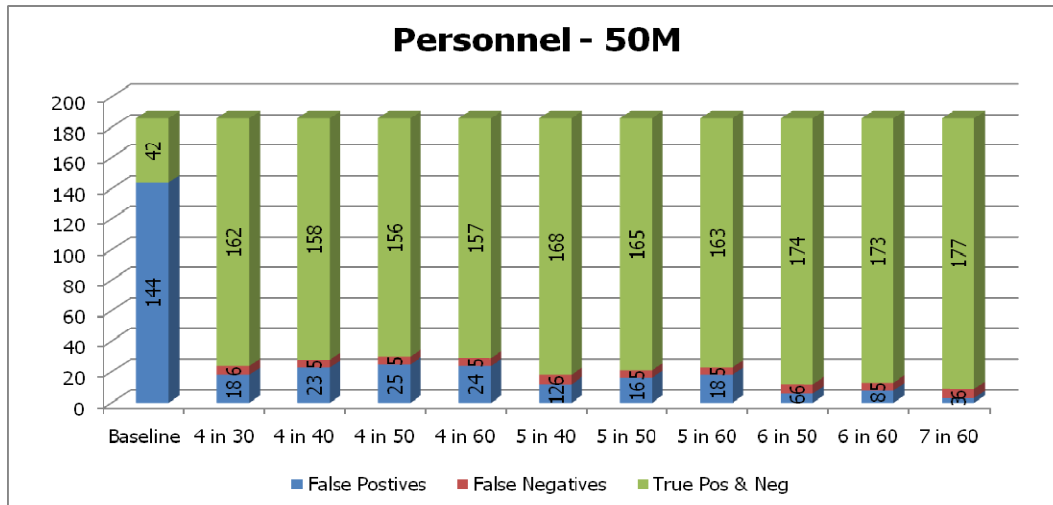


Figure 6: Personnel Detections with Threshold at Four through Seven

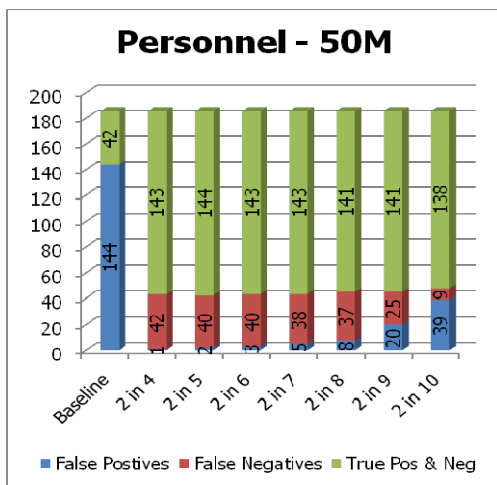


Figure 7: Personnel Detections with Threshold at Two

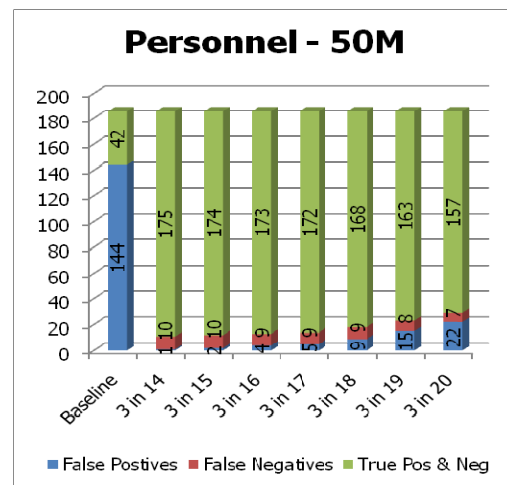


Figure 8: Personnel Detections with Threshold at Three

3.5 Vehicle Detections

This section analyzes all detection of classification type vehicle. This is a fairly large subsection of the total detections, with 1,262 detections. The predetermined distance that is acceptable for vehicle detections is 350 meters based on the BAIS manual.

In Figure 9 you will see the *baseline* case and the filtering cases where the detection threshold was two and three detections. Again, the *baseline* for vehicle has a high number of *false-positives* with 87.7%. Again we see that the filtering reduces the number of *false-positives*, but creates some *false-negatives*. In Figure 10 you see the *baseline* repeated and the filtering cases where the detection threshold was four, five, and six. Unlike for all detections and for personnel detections, the highest detection threshold shown is six. This is because for higher thresholds, the *fusion-engine* would never allow any detections through. For example, let's say the threshold is seven detections. The *fusion-engine* would never let a detection through, because there was never seven detections within the given time periods, the max of which was 60 seconds.

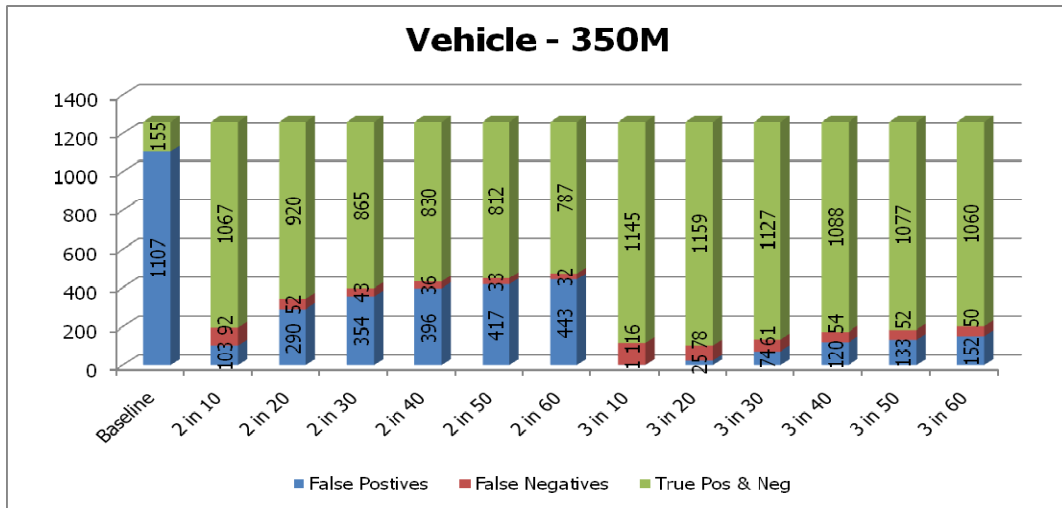


Figure 9: Vehicle Detections with Threshold at Two and Three

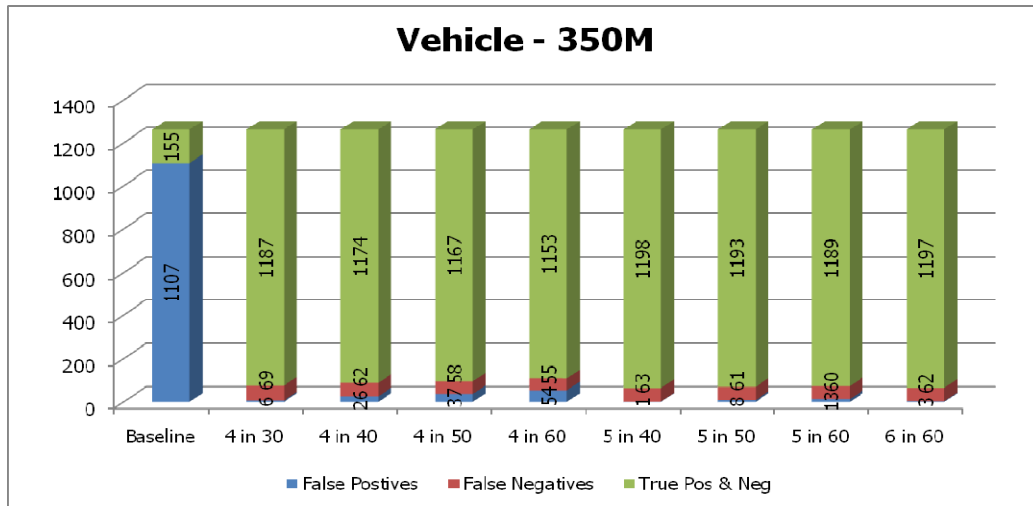


Figure 10: Vehicle Detections with Threshold at Four through Six

Figures 11 and 12 are charts for detection thresholds two and three. Both charts focus in on the time period that causes the number of *false-positives* to drop close to zero. The main thing to notice from these charts is that as you increase the detection threshold, the *false-positives* remain low and the *false-negatives* decrease. Also, as the threshold increase over three, there is not much added confidence.

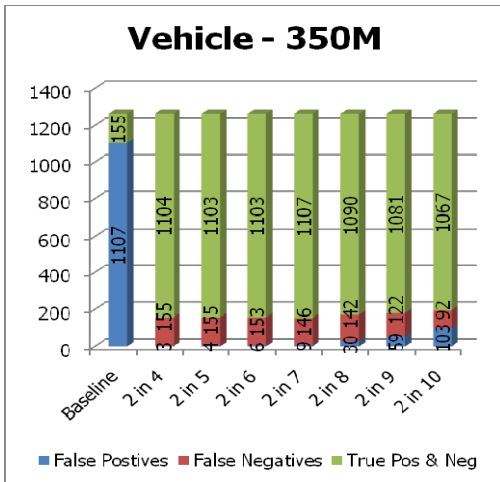


Figure 11: Vehicle Detections with Threshold at Two

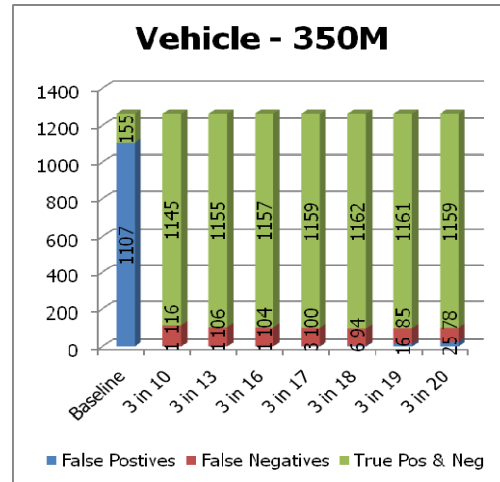


Figure 12: Vehicle Detections with Threshold at Three

3.6 Wheeled Vehicle Detections

This section analyzes all detection of classification type wheeled vehicle. There are 856 detections in this sample of the total detections. The predetermined distance that is acceptable for wheeled vehicle detections is 250 meters based on the BAIS manual.

In Figure 13 you will see the *baseline* case and the filtering cases where the detection threshold was two and three detections. Again, the *baseline* for wheeled vehicle has a high number of *false-positives* with 94.0%. Again we see that the filtering reduces the number of *false-positives*, but creates some *false-negatives*. In Figure 14 you see the *baseline* repeated and the filtering cases where the detection threshold was four, five, six, and seven.

Figures 15 and 16 are charts for detection thresholds two and three. Both charts focus in on the time period that causes the number of *false-positives* to drop close to zero. The main thing to notice from these charts is that, again, as the threshold amount increases above three it has little to no effect on the number of *false-positives*.

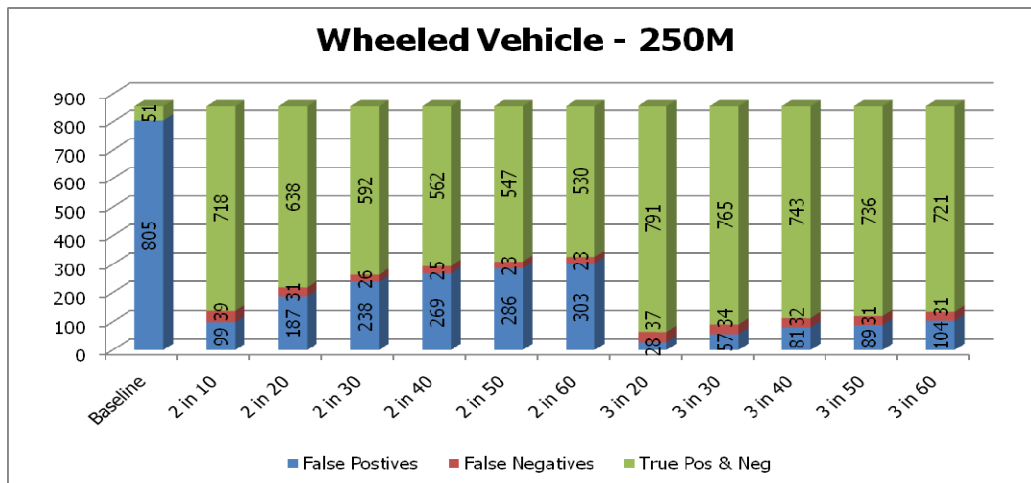


Figure 13: Wheeled Vehicle Detections with Threshold at Two and Three

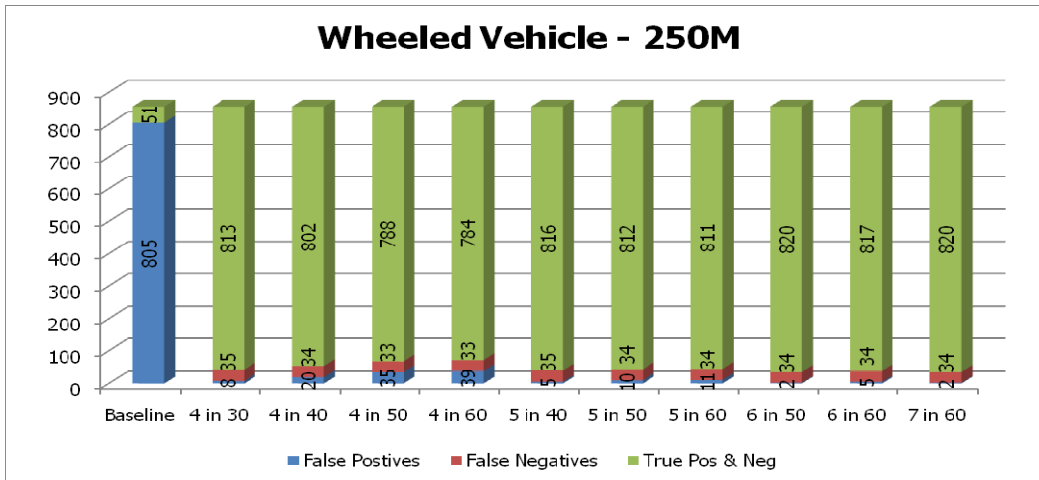


Figure 14: Wheeled Vehicle Detections with Threshold at Four through Seven

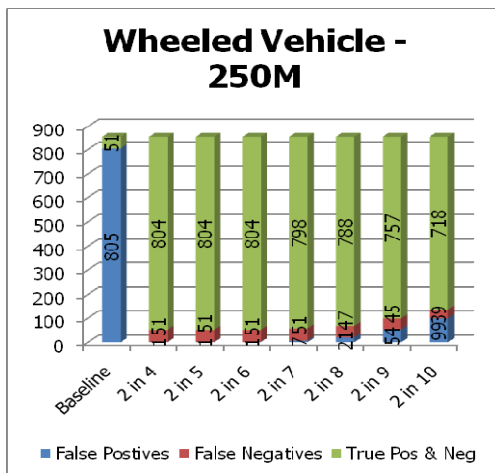


Figure 15: Wheeled Vehicle Detections with Threshold at Two

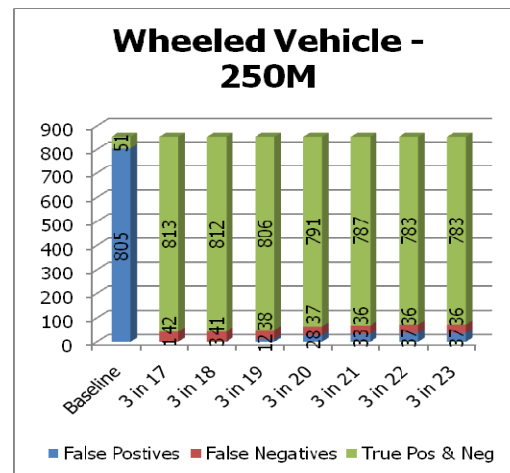


Figure 16: Wheeled Vehicle Detections with Threshold at Three

3.7 Tracked Vehicle Detections

This section analyzes all detection of classification type tracked vehicle. This is an extremely small subsection of the total, with only 13 detections. The predetermined distance that is acceptable for tracked vehicle detections is 350 meters based on the BAIS manual. This low number of detections for tracked vehicles makes sense because the OPFOR was not traveling on tracked vehicles.

In Figure 17 you will see the *baseline* case and the filtering cases where the detection threshold was two, three, and four detections. Despite the extremely low number of detections in this sample, you see the same pattern as seen with other samples. In the *baseline* we see 84.6% *false-positive* rate. Because of the low number of detections in this sample, all we can really note from this chart is that the pattern is consistent even with a small sample.

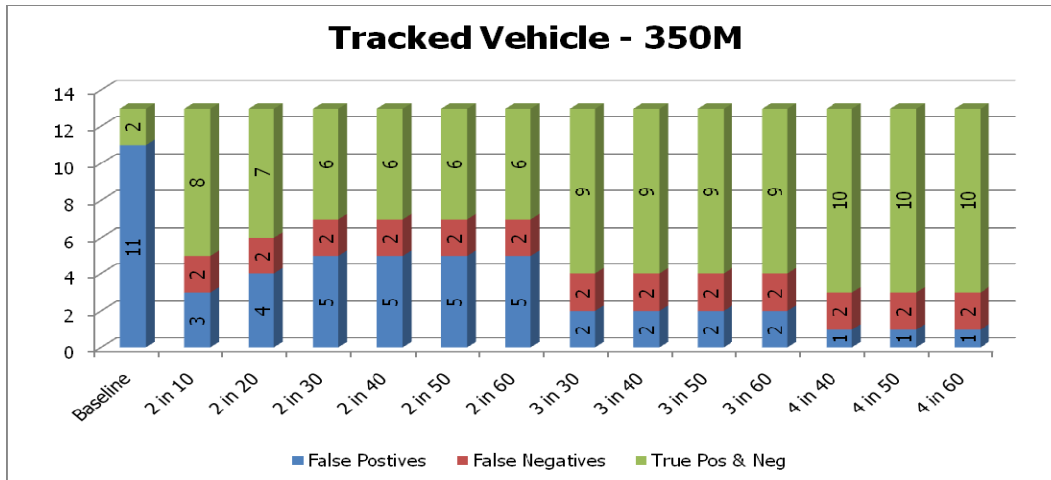


Figure 17: Tracked Vehicle Detections with Threshold at Two through Four

3.8 Unknown Detections

This section analyzes all detection of classification type unknown. This is a small subsection of the total, with only 183 detections. The predetermined distance that is acceptable for unknown detections is 350 meters based on the BAIS manual.

In Figure 18 you will see the *baseline* case and the filtering cases where the detection threshold was two, three, four, and five detections. Again, the *baseline* for unknown has a high number of *false-positives* with 84.2%. Again we see that the filtering reduces the number of *false-positives*, but creates some *false-negatives*.

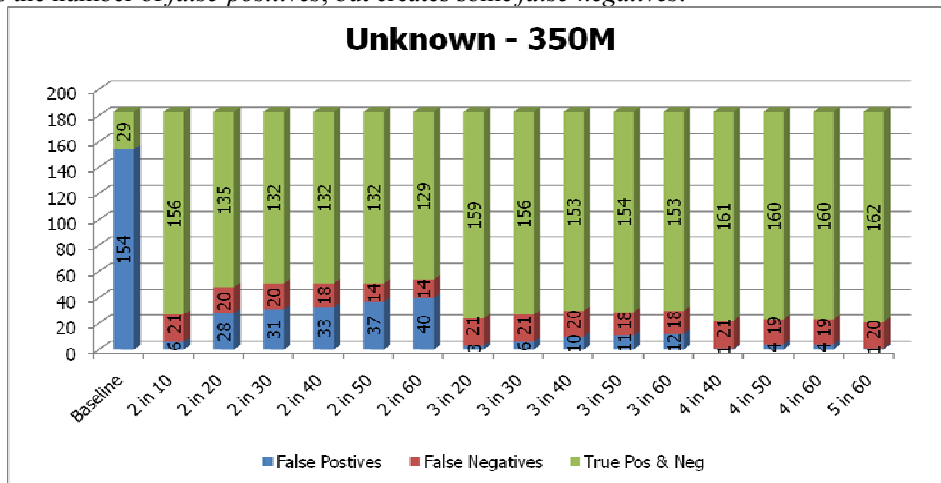


Figure 18: Unknown Detections with Threshold at Two through Five

Figures 19 and 20 are charts for detection thresholds two and three. Both charts focus in on the time period that causes the number of *false-positives* to drop close to zero. The main thing to notice from these charts is that for the higher thresholds, a relatively small change in acceptable time has little to no effect on the number of *false-positives*. Also, after a threshold of three, there is not much improvement in results.

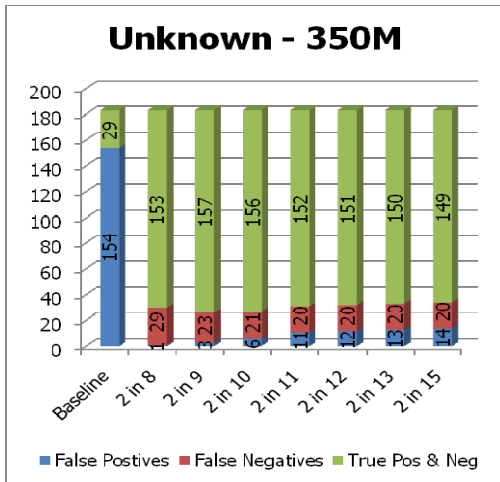


Figure 19: Unknown Detections with Threshold at Two

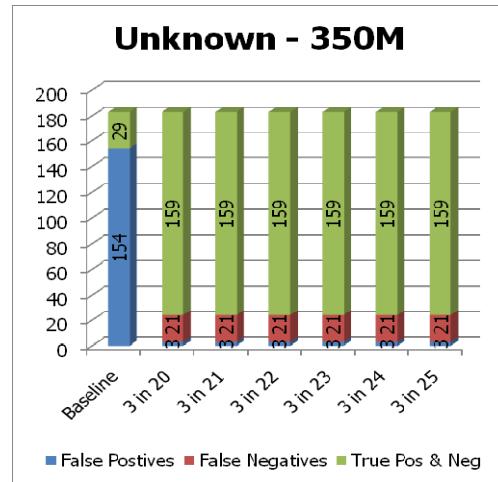


Figure 20: Unknown Detections with Threshold at Three

3.9 All Vehicle Detections

This section analyzes all detections of classification types, including vehicle, wheeled vehicle, and tracked vehicle. This is a large subsection of the total, with 2,131 detections. The predetermined distance that is acceptable for all vehicle detections is 350 meters based on the BAIS manual.

In Figure 21 you will see the *baseline* case and the filtering cases where the detection threshold was two and three detections. Again, the *baseline* for all vehicles has a high number of *false-positives* with 88.5%. Again we see that the filtering reduces the number of *false-positives*, but creates some *false-negatives*. In Figure 22 you see the *baseline* repeated and the filtering cases where the detection threshold was four, five, six, and seven.

Figures 23 and 24 are charts for detection thresholds two and three. Both charts focus in on the time period that causes the number of *false-positives* to drop close to zero. The main thing to notice from these charts is the same as for the previous section for Unknown Detections. For the higher thresholds, a relatively small change in acceptable time has little to no effect on the number of *false-positives*. Also, after a threshold of three, there is not much improvement in results.

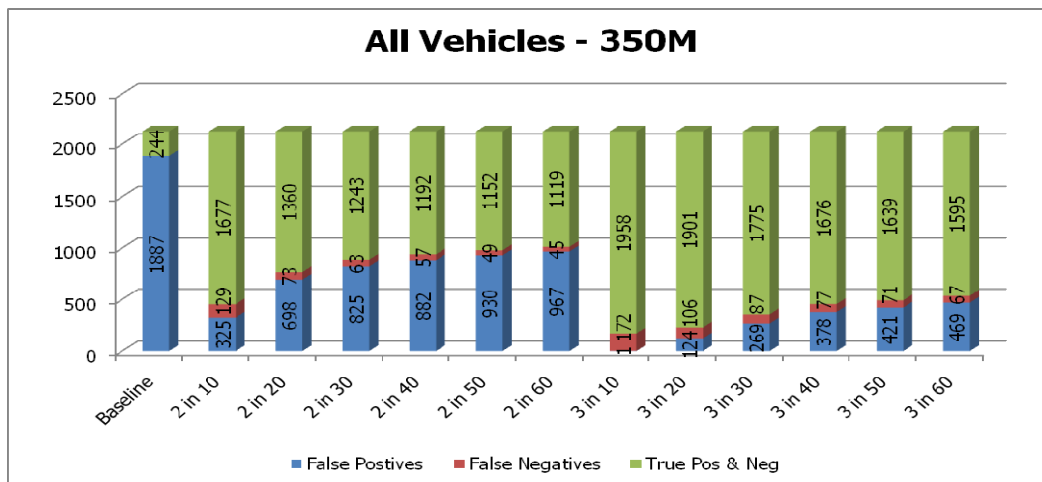


Figure 21: All Vehicle Detections with Threshold at Two and Three

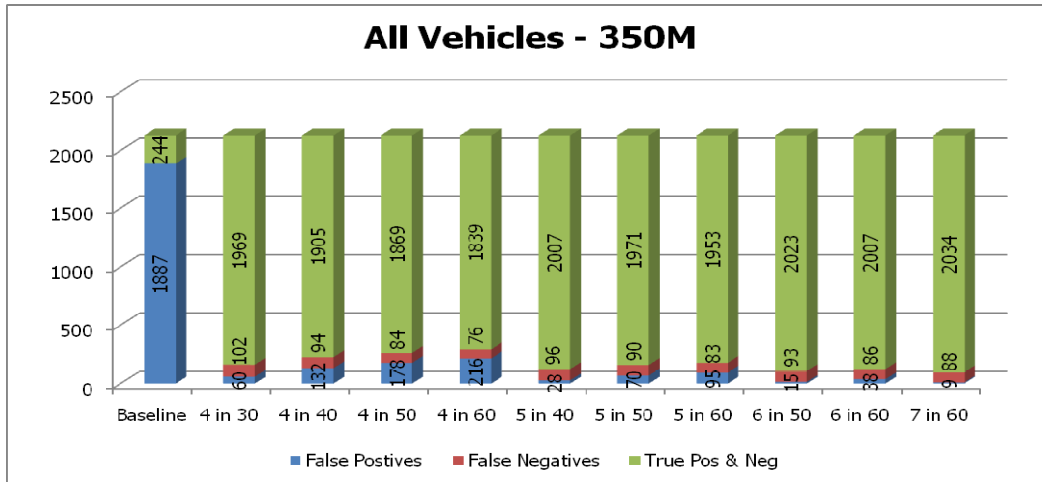


Figure 22: All Vehicle Detections with Threshold at Four through Seven

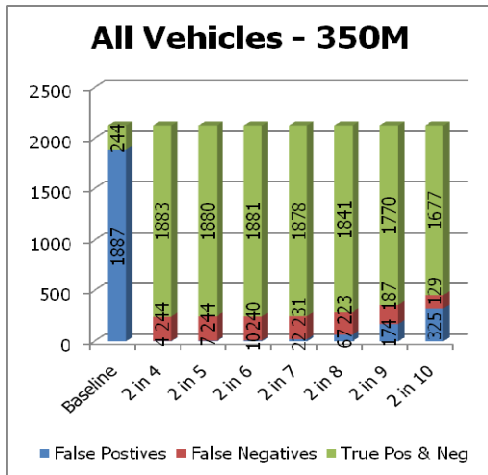


Figure 23: All Vehicle Detections with Threshold at Two

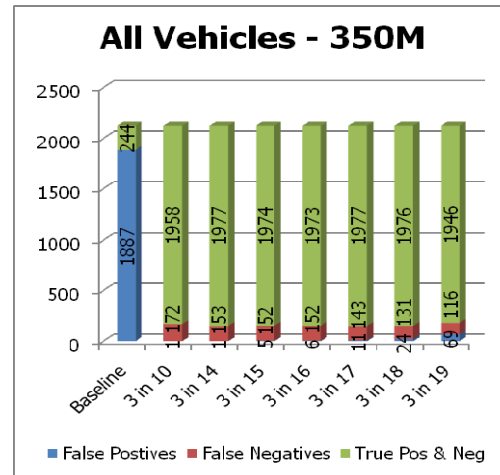


Figure 24: All Vehicle Detections with Threshold at Three

4. CONCLUSION

This analysis shows that for all cases, the *baseline* has a very high number of *false-positives*, and that utilizing a filter will reduce the *false-positives* substantially while creating some *false-negatives*. However, it is quite apparent that the use of a filter greatly increases the ratio of true results to false, which causes the sensor information to be much more reliable and useful. The best filtering methods are those which maximize the ratio of true results to false. It is clear from the graphs shown that requiring many detections in a small amount of time provides the best true/false ratio. However, expecting too many detections in too small of a time will degrade results due to limitations of the BAIS system. A proper balance is required.

The results of this analysis make intuitive sense because any real targets, personnel or vehicles, cannot make it through the coverage area of the BAIS, as much as 350 meters in diameter depending on soil conditions, during a single 10 second time window, thereby increasing the likelihood of multiple detections on a single incursion. It is also reasonable to think that the detecting sensors would continue alarming at the maximum rate as the threat in the area persisted. Filtering out these single detection events removes much of the noise in the system from such sources as aircraft, distant highway traffic, inclement weather, and other transient sounds.

The data used for this analysis is not perfect, though it's obvious that a truly perfect scenario does not exist in real life. However, some environmental factors definitely did come into play, which could not be accounted for in the collected data. These factors included: traffic on the nearby highway, traffic from site personnel, and traffic from the unmanned vehicles also being used in the experiment. Despite these interferences, this analysis should be considered a first step in properly filtering BAIS sensor detections, when deployed in high traffic areas.

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