Characterizing Density and Complexity of Imported Cargos

N. Birrer, C. Divin, S. Glenn, H. Martz Jr.

Lawrence Livermore National Laboratory

Introduction:

Approximately 20 million cargo containers are imported into the United States every year. The Department of Homeland Security's Domestic Nuclear Detection Office (DNDO) aims to characterize new and emerging technologies to ensure that imported cargo does not contain radiological or nuclear (Rad/Nuc) threats. Previous DNDO studies have shown that detection performance varies with cargo density and complexity.

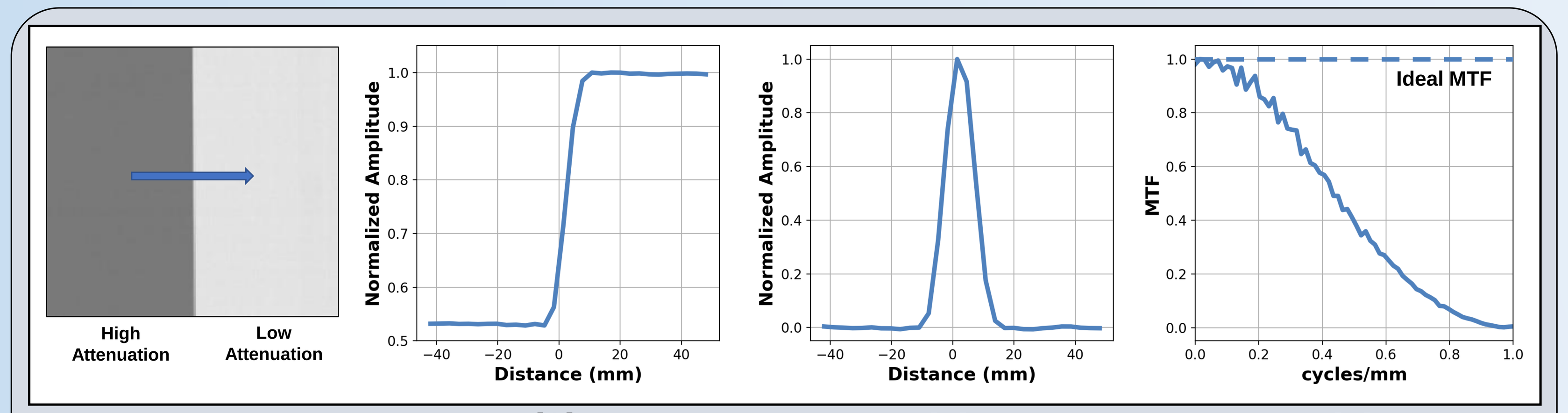
Goals

Our objective was to determine the image quality of two cargo scanning systems and the density and complexity of stream-of-commerce (SOC) cargos. The first used the modulation transfer function, and the second involved development of algorithms to quantify cargo density and complexity, verification against known engineered cargos, and application to SOC cargos.

Image Quality Assessment:

The image quality of two cargo scanning systems was assessed using the modulation transfer function (MTF), a measure of an imaging system's ability to render sharp edges. The MTF is one metric that has shown correlation with human analysis performance (P_D, P_{FA}).

MTF Analysis



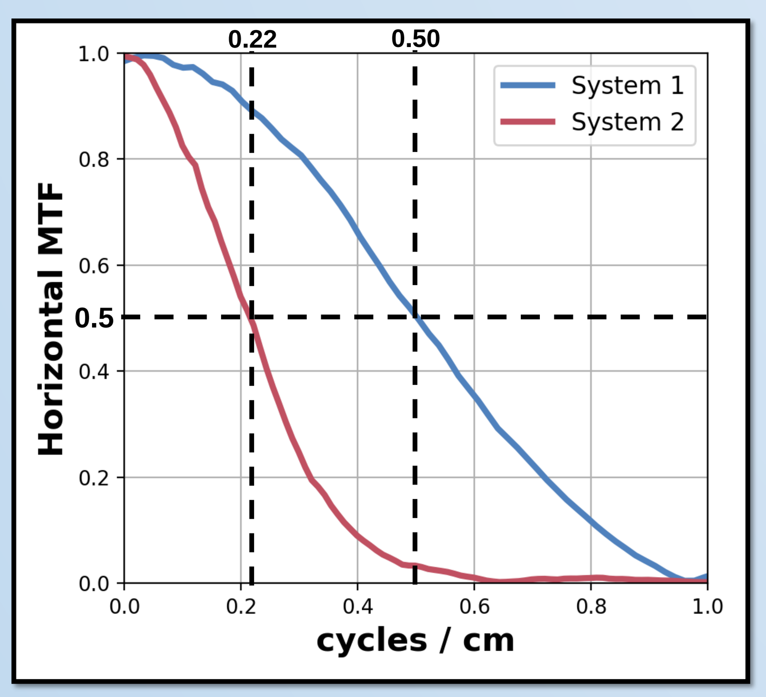
(1) A line segment is chosen across a sharp edge in the image.

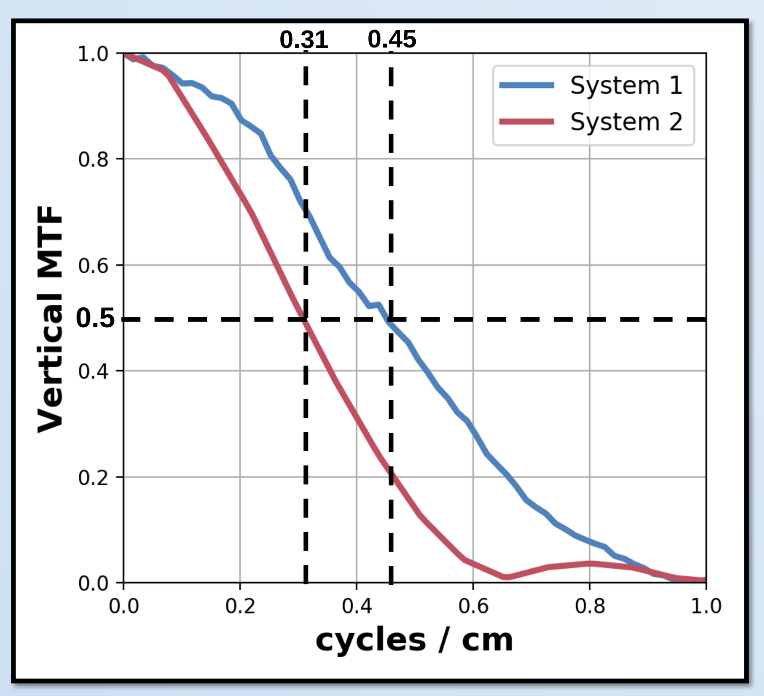
(2) The trace obtained is called the edge response function (ERF).

(3) Numerically differentiating the ERF provides the edge spread function (ESF).

(4) The MTF curve is produced by taking the Fourier transform of the ESF.

MTF data was calculated from vertical and horizontal edges in several images and averaged to produce the final curves. The MTFs obtained correlated with the perceived image quality.



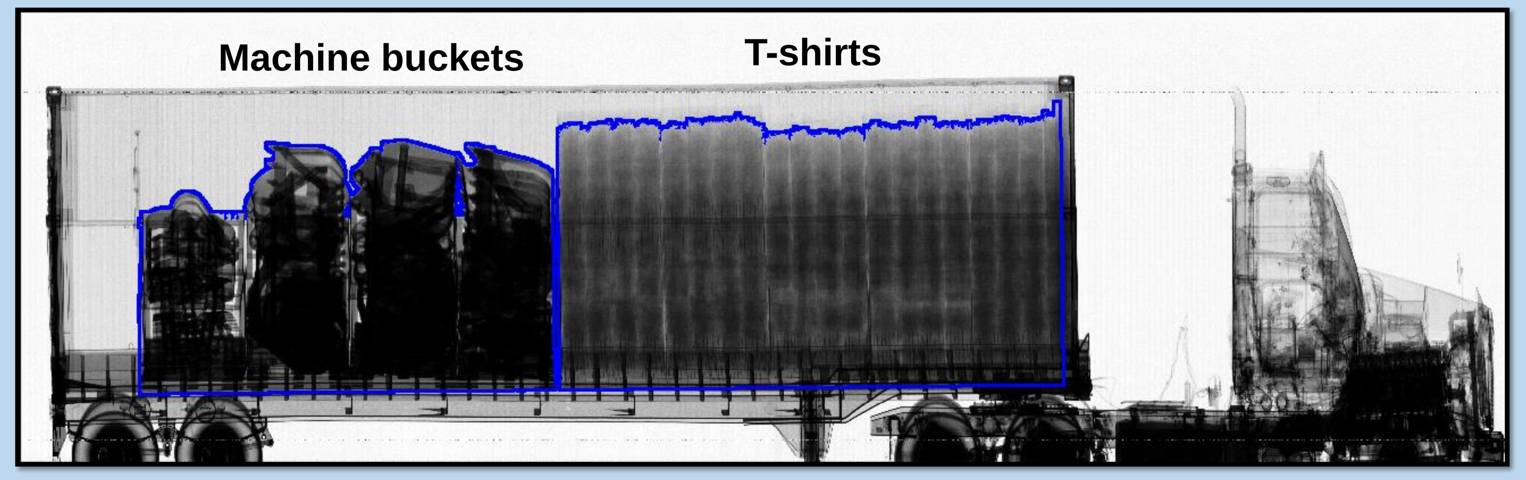


Cargo Density and Complexity Assessment:

Segmentation

To begin the study of density and complexity the images were segmented to isolate the cargo-containing regions. This was done using a threshold algorithm.

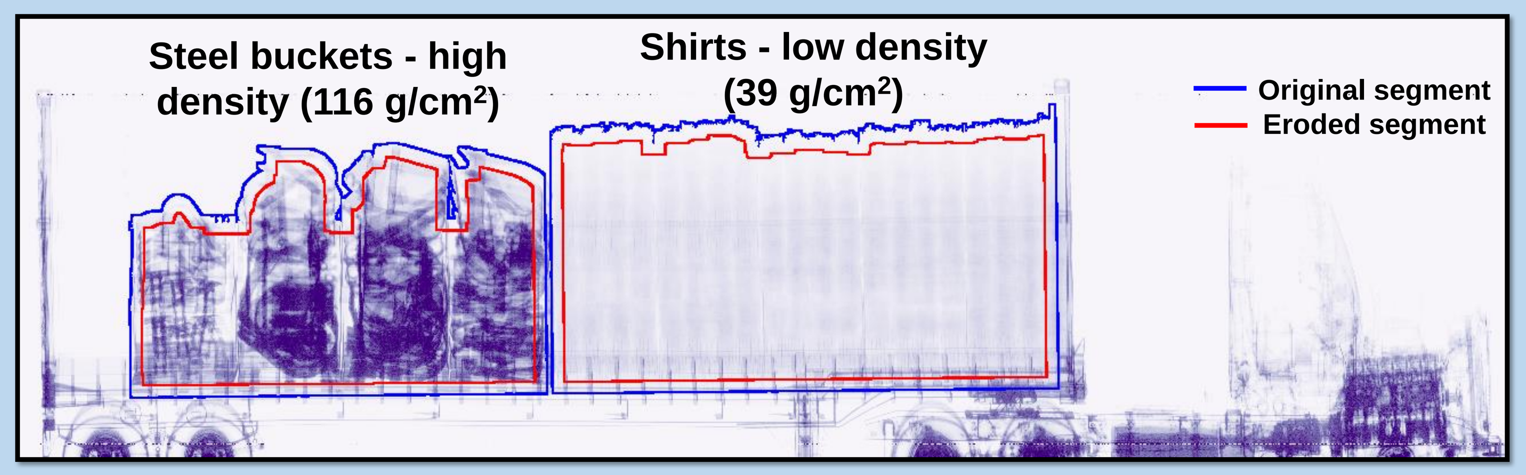
Intensity Image



Density Analysis

The x-ray attenuation (μx) of the cargo was calculated using Beer's Law: $I = I_0 e^{-\mu x}$. Attenuation (μx) was then converted to areal density using a lookup table generated from measurements of calibration samples of known thickness.

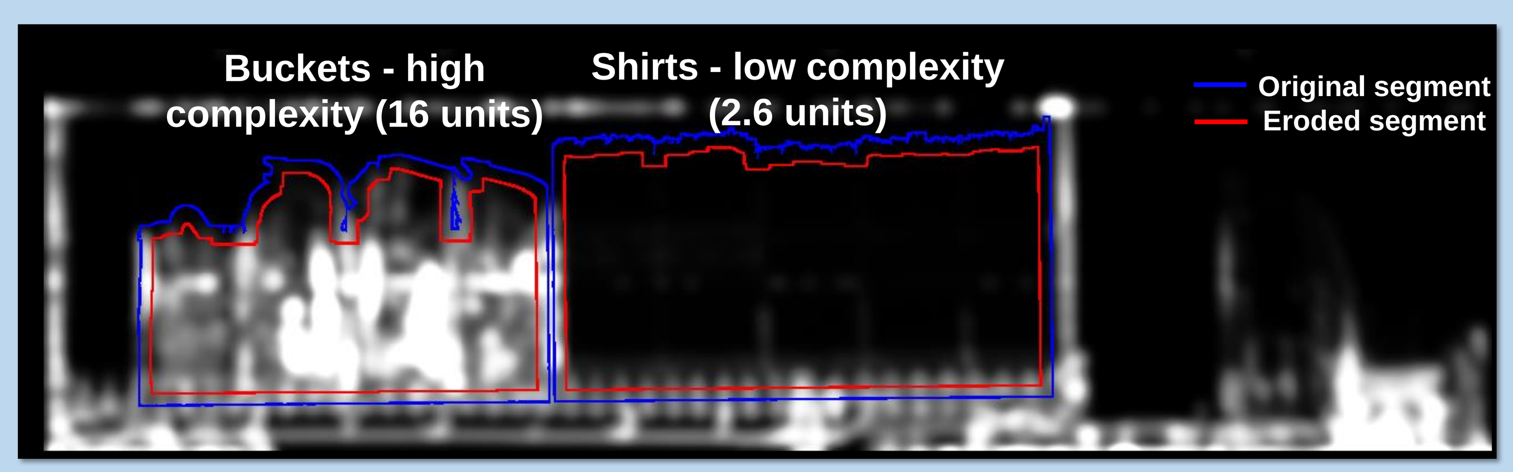
Attenuation (μx) Image



Complexity Analysis

The cargo complexity was calculated with a sliding window technique based on the power spectral density (PSD) calculation shown at upper right. In the resulting images, areas with many fine details appear bright, while relatively homogeneous areas appear dark.

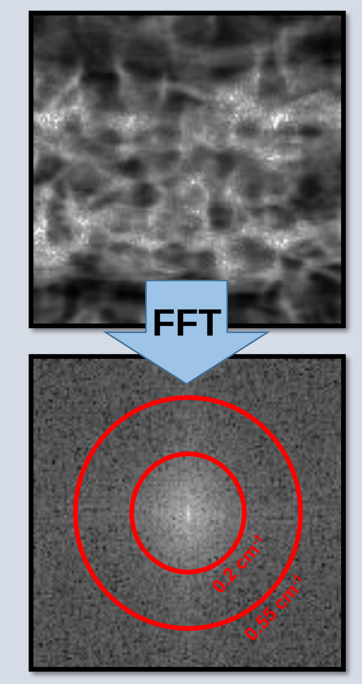
Local Complexity Image



Power Spectral Density Method to Determine Complexity

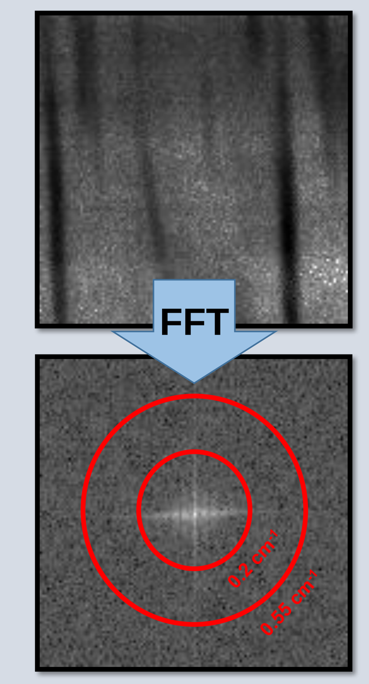
To calculate the complexity of a cargo region, an integrated power spectral density (PSD) technique was used.

- **For each point in the region, a square window was selected.**
- **The 2-dimensional fast Fourier transform (FFT) of the window was then calculated.**
- **The FFT was integrated within an annulus from 0.2 and 0.55 cycles/cm.**
- **The result gave the complexity of the original window.**
- **The sum of the values for each window was the complexity of the region.**



A highly complex cargo generates more bright pixels in the annulus, making the integrated PSD value higher.

Integrated PSD value: 0.328

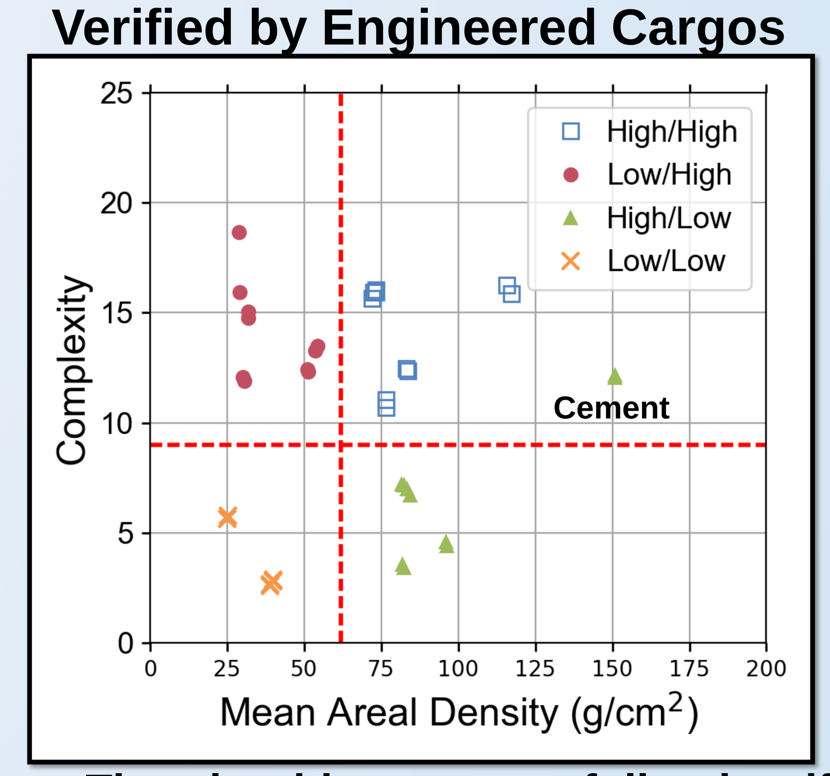


A fairly homogeneous cargo has fewer bright pixels in the integrated region, making the complexity value low.

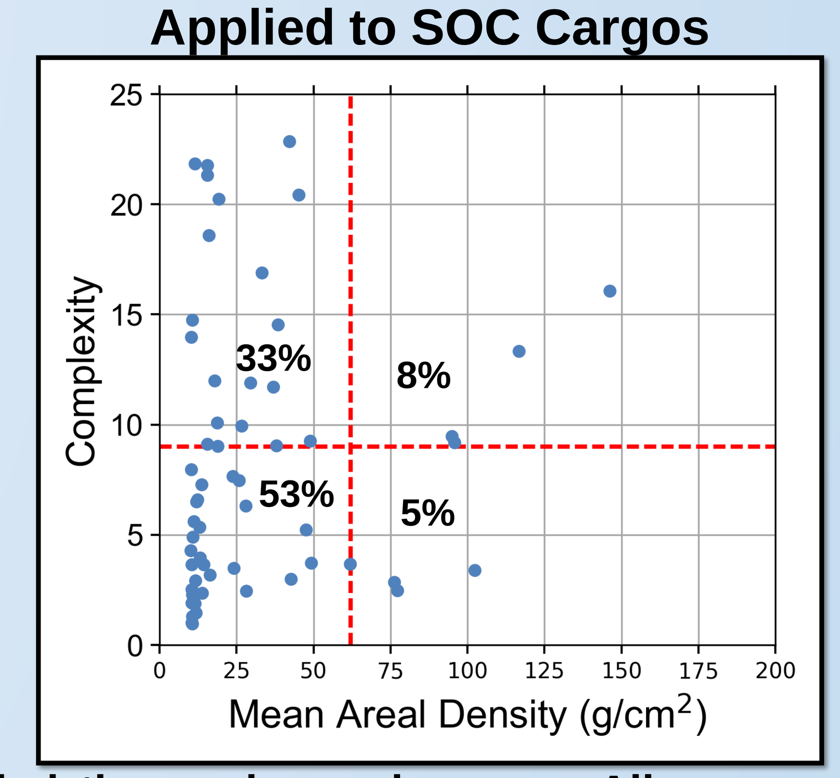
Integrated PSD value: 0.036

Results:

Verified by Engineered Cargos



Applied to SOC Cargos



- **The algorithm successfully classified the engineered cargo. All cargos except cement matched labels assigned by human analysts.**
- **Engineered cement cargo is considered low complexity but the algorithm misclassified it as high complexity. We attributed this to its high areal density of 150 g/cm².**
- **Obtained objective complexity measure for SOC cargo.**
- **53% of SOC cargo was low density, low complexity. Only 13% was high areal density.**

Future Work:

- **This information will be compared against human ability to detect threats in cargos.**
- **Similar analysis performed on other imaging systems will show how these metrics perform across different platforms.**

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