Throughput performance factors in X-ray cargo screening systems

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Overview

As X-ray cargo screening becomes more prominent at ports and border crossings, its impact on container traffic is frequently discussed. This is essentially a question of system throughput, which varies by the type of X-ray system chosen and how it's operated within a port facility.

Screening objectives

X-ray cargo screening has been adopted at ports and border crossings throughout the world because this technology has solved a number of important problems. It first gained prominence for manifest verification, allowing countries to better enforce import tariffs. Authorities also found that the image quality achieved with X-ray screening allowed them to interdict contraband, including drugs, cash, weapons, and other illicit materials. During the last few years, attention has shifted to homeland security concerns, where X-ray screening has become a major tool in prohibiting the smuggling of weapons of mass destruction (WMDs) into countries.

These different objectives often determine which systems are chosen and how they are operated at ports and border crossings. In addition, X-ray capability is often implemented as part of a 'layered' security strategy (Kutz, G. D. & Cooney, J. W. , 2007), frequently supplemented by other technologies and methods, which allows authorities some discretion in how to inspect incoming vehicles. For example, some X-ray screening systems allow scanning at different speeds so that enhanced images can be obtained from a particularly suspicious vehicle or container. Consequently, system throughput performance must be judged in terms of meeting specified objectives, rather than simply comparing average inspection times per vehicle.

X-ray cargo system types

X-ray cargo screening systems are typically available in four basic types (see Table 1).

All four types of X-ray inspection systems can provide good quality images. They differ in how their designers have addressed certain system objectives related to factors such as: intended use, installed location, life-cycle costs, and overall performance. From an operational perspective, these four types can be further divided into stationary and mobile systems. Mobile systems are fully contained in vehicles that can be moved to a location, set up, and ready to scan within about 30 minutes. Advantages of mobile systems include their ability to be operated at temporary locations and rapidly moved from place to place, creating an inspection capability across a large area. They are also smaller and may be less expensive than stationary systems, which typically require a shielded and enclosed operating area.

Stationary systems are available in various configurations. Some have re-locatable mechanisms that can be disassembled and moved to other locations, while others are designed into a permanent structure. Another difference among stationary systems is their shielding configuration. Some systems are heavily shielded near the X-ray source, which minimises the requirement for structure shielding. Others have less source shielding, but require more substantial structure shielding.

TABLE 1: X-RAY CARGO SYSTEM TYPES

Type	Description
Mobile	An X-ray scanning system that is truck mounted and self-contained. It includes a complete data-analysis facility within the scanning vehicle.
Gantry	An X-ray scanning system that moves past a stationary vehicle. These typically operate bi-directionally, improving throughput by scanning in both directions. Some gantry systems can be disassembled and relocated to another site.
Portal	An X-ray scanning system that remains fixed while the vehicle under inspection is driven or towed through the X-ray beam. Some systems may allow drivers to remain in their vehicles. Some systems can be disassembled and relocated to another site.
Fixed	An X-ray scanning system that is optimised to work in a dedicated structure that is not intended to be re-locatable. The X-ray imaging system inside the structure may be designed in either a gantry or portal style.

Stationary X-ray inspection

Figure 1 illustrates the complexity in determining actual throughput performance of an X-ray cargo system. This diagram represents a simplified timeline for scanning a trailer or cargo container using a stationary screening system. It assumes that the truck is driven into a scanning bay and the driver leaves the truck and moves to a secure area while the X-rays are active. Then the driver moves the truck from the scanning bay, completing the cycle. A somewhat different timing diagram for a mobile system will be described later.

Note in Figure 1 that the incoming queue time (segment A) is considered indeterminate because it depends on a number of site-related and logistical variables beyond the scope of this paper.

Thus, the current analysis will start at segment B, where the driver will advance his vehicle into the scan bay, park it, and exit to a secure location. This is typically a room or open area in close proximity to the vehicle. If shielding doors are incorporated into the scanning bay, these doors will close while the driver exits to the secure location. At segment C, the X-ray imaging process begins, which involves the X-ray equipment generating a stream of consecutive X-ray slices beginning at one end of the container and terminating when the complete image is obtained. The

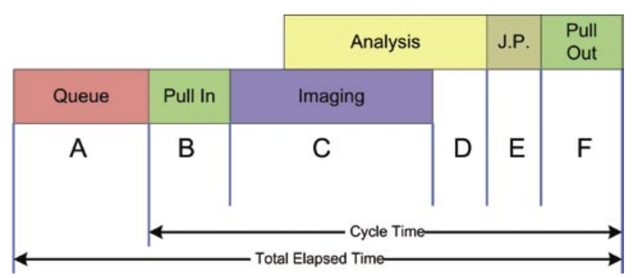

Figure 1. Fixed cargo screening throughput (not to scale).

imaging software works by combining the sequence of vertical 'slices' into a composite image. Each slice is just a few millimetres wide and is sent to the imaging station as it is obtained.

In some systems, the partial image is available to inspection officers in real time. This allows some analysis work to begin while the scanning is still in progress, as illustrated by the overlap of imaging and analysis in Figure 1. However, a more robust analysis, assisted by software tools, is usually performed on the entire image once it is complete (indicated by segment D). This can involve software algorithms and manual operations, or a combination of both. Segment E is defined as the 'judgment processing' phase, during which the operator makes a pass/fail determination, communicates with the other inspection officers, and closes the scan file. Finally, Segment F indicates the time required for the driver to re-enter the scan bay and move his vehicle to a point which makes the scan bay available for the next inspection.

It should be noted that some portal systems may be designed to allow drivers to remain in their trucks during an X-ray scan. This would reduce some of the time required at segments B and E, perhaps saving several seconds. However, this benefit could be reduced if the inspection process is delayed briefly for an authority to interview or request information from a driver; a process that could otherwise occur during the scanning period.

Table 2 provides some general time estimates for the segments described in Figure 1.

The cycle time is primarily driven by the analysis time allocated for segment D, which follows completion of the scan. For security reasons, there is little public data available on how much average time authorities use in performing this type of analysis. However, the total time may be reduced because of supporting and complementary technologies that provide additional intelligence about the container under inspection. For example, in the U.S., the CBP (Customs and Border Protection) has implemented the Automated Targeting System (ATS) to provide authorities additional information, enhancing their ability to inspect containers (Caldwell, 2007).

TABLE 2: TIME ESTIMATES IN SECONDS FOR A STATIONARY SYSTEM. *INSPECTION TIMES ULTIMATELY DEPEND ON MANY FACTORS AND CAN BE SHORTER OR LONGER THAN INDICATED

	Lower Estimate*	Higher Estimate*
Queue (A)	Indeterminate	
Pull In (B)	30	45
Imaging & Analysis (C)	75	90
Additional Analysis (D)	20	60
Judgment Processing (E)	15	30
Pull Out (F)	25	35
Cycle Time (B through F)	165 (21.8 scans/hr rate)	260 (13.8 scans/hr rate)

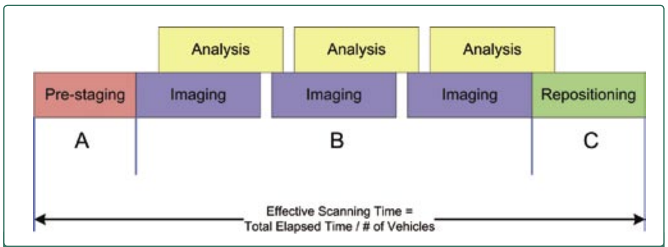

Figure 2. Mobile cargo screening throughput (not to scale).

Mobile 'truck-based' X-ray inspection

A number of manufacturers offer mobile X-ray screening vehicles capable of inspecting cargo containers and full-size trucks. From an X-ray imaging perspective, these can offer essentially the same image quality and operate at speeds comparable to fixed inspection facilities. Their mobility makes them ideal for smaller ports that may need to share X-ray capabilities or for larger ports that are geographically dispersed.

While mobile systems can be operated in a single vehicle inspection mode that emulates fixed sites, they also can inspect a row of pre-staged vehicles. In the first mode, a single vehicle can be driven to a starting point in a designated inspection lane. Then the driver departs to a secure area while the scan is in process. Upon completion of the scan and subsequent analysis, the driver can return to his vehicle and proceed. Because mobile systems are driven past the vehicle under inspection, there is additional time required to return to a starting point before the next vehicle can be inspected.

The second mode operation is more efficient. For this mode, shown in Figure 2, a row of vehicles is pre-staged (three in this example) in a designated scanning lane. (Segment A indicates the time required to pre-stage all the vehicles to be screened.)

All of the drivers depart their vehicles and wait in a safe area while the inspection truck moves down the row imaging each vehicle (Figure 2 – Segment B). This sequential process allows analysis of the earlier vehicles to occur simultaneously with the scanning of the later ones. In this way, much of the individual vehicle dwell time is reduced. When the imaging is completed, the scanning vehicle can be repositioned (Figure 2 – Segment C) to repeat the process. Alternatively, it may be possible to pre-stage a second row of vehicles and then reposition the scanning truck to the second scanning lane. Operating with dual or multiple scanning lanes could eliminate a significant portion of the pre-staging time shown in Segment A. For either scenario, the effective scanning time can be measured by dividing the total elapsed time by the number of vehicles scanned. This is roughly equivalent to the cycle time shown in Figure 1 for a fixed system and does not include any required queuing time exclusive of the pre-staging process. The "per-container" imaging and analysis time estimate for mobile systems is roughly similar to the estimates for fixed systems shown in Table 2.

Summary

With the advent of the U.S. SAFE PORT Act, requiring 100 per cent scanning of U.S. bound cargo containers by 2012 (Caldwell, 2007), port operators have a vested interest in choosing X-ray inspection systems that operate most effectively in their own environments. This paper introduced some of the key parameters that impact system effectiveness in terms of throughput performance for various system types. It also emphasised the importance of considering inspection objectives in determining throughput effectiveness. Because this technology is evolving rapidly, interested parties should contact manufacturers directly for more specific throughput estimates that apply to specific systems.

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ABOUT THE COMPANY

Varian Medical Systems, Inc., Security & Inspection Products, is the market leader for industrial CT systems, high energy X-ray linear accelerators, and matching detector arrays.

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