Higher Supply Chain Security with Lower Cost:

Lessons from Total Quality Management

Hau L. Lee and Seungjin Whang

Graduate School of Business, Stanford University, Stanford, CA 94305, USA

July 6, 2003

Abstract

Supply chain security has become a major concern to the private and public sector, after the disastrous event of September 11, 2001. Prior to September 11, 2001, supply chain security concerns were related to controlling theft and reducing contraband such as illegal drugs, illegal immigrants, and export of stolen goods. But after September 11, 2001, the threat of terrorist attacks has heightened the need to assure supply chain security. The public is of course concerned with the potential of having weapons of mass destruction embedded in the shipments through the supply chain. In addition, the private sector is concerned with the costs of assuring security, and the potential disruptions associated with real or potential terrorist acts.

Governments and industry have all responded with proposals to create more confidence in supply chain security, while maintaining smooth flows of goods and services in a global supply chain. One of the most effective strategies may be to apply the lessons of successful quality improvement programs. In this paper, we describe how the principles of total quality management can actually be used to design and operate processes to assure supply chain security. The central theme of the quality movement – that higher quality can be attained at lower cost by proper management and operational design – is also applicable in supply chain security. By using the right management approach, new technology, and re-engineered operational processes, we can also achieve higher supply chain security at lower cost. We will demonstrate how this can be done with a quantitative model of a specific case example.

Acknowledgment: The authors would like to thank the inputs from Steve Lambright and Larry Trebesch of Savi Technology in writing this article. The government initiatives are drawn from Lee and Wolfe (2003) and we are grateful to Michael Wolf of North River Consulting Group for sharing his knowledge.

Higher Supply Chain Security with Lower Cost: Lessons from Total Quality Management

Hau L. Lee and Seungjin Whang

Graduate School of Business, Stanford University, Stanford, CA 94305, USA

July 6, 2003

1. Introduction

After September 11, 2001, the security of a supply chain has become a major concern to the public and private sector. In particular, the ocean segment of a supply chain is most vulnerable to security threats. More than 90% of world trade involves containers aboard ships, amounting to about 20 million containers trips annually (Cuneo, 2003). For the US, 17,000 containers arrive at US ports each day. Both the government and industries have begun to examine ways to address the threat of terrorism and the potential of having weapons of mass destruction (WMD) in materials flowing through a supply chain. "Every container destined to enter or pass through the U.S. should be treated as a potential weapon of mass transportation," Rob Quartel, chairman and CEO of Freightdesk Technologies, told the Senate Committee on the Judiciary's Subcommittee on Technology, Terrorism and Government Information on February 26, 2002 (Mottley, 2002). WMD can result in significant loss in human lives, destruction of infrastructure, and erosion of public and business confidence. Ultimately, global trade and prosperity are threatened.

The public sector is of course concerned about the potential of having WMD embedded in the shipments through the supply chain. In addition, the private sector is concerned with the costs of assuring security, and the potential disruptions associated with real or potential terrorist acts. Governments and industry have both responded with proposals to create more confidence in supply chain security, while maintaining smooth flows of goods and services in a global supply chain. Some of these proposals call for increased information exchange among trading partners, ports, shipping companies, and the governments. Some call for heightened inspection and scrutiny of the goods flowing through a supply chain. These measures can add cost, delays, and uncertainties in the supply chain. At the same time, supply chain disruptions resulted from security breaches, can be disastrous. For example, if ports and border crossings were closed for a meaningful time after a major terrorist attack, the economic impact would be devastating. It is not possible to quantify the full direct costs of damages and casualties, recovery measures, congestion, and disruption to business and daily life.

There are indirect costs to a supply chain without security confidence. For example, such a supply chain may be less cost-efficient due to higher freight and insurance rates. Since September 11, 2001, the general liability rates for trucking companies have increased by an average of 32% as carriers renewed their policies in the subsequent year (Hannon, 2002). The cycle time of the supply chain can be handicapped due to longer delays in getting goods through the global supply chain. Companies without security confidence may have to abandon Just-in-Time and lean inventory processes, to safeguard against unexpected security breaches and supply chain disruptions. Some companies may have to expand their supply bases and source from higher cost but local suppliers.

One of the most effective strategies may be to apply the lessons of successful quality improvement programs. In this paper, we describe how the principles of total quality management can be used to design and operate processes to assure supply chain security. The central theme of the quality movement – higher quality can be attained at lower cost by proper management and operational design – is also applicable in supply chain security. By using the right management approach, new technology, and re-engineered operational processes, we can also achieve higher supply chain security at lower cost. We will demonstrate how this can be done with a quantitative model of a specific case example.

In the next section, we outline the key lessons from total quality management and describe how they are applicable to developing supply chain security approaches. Section 3 then describes some examples of the measures and initiatives developed by governments, port operators and technology companies, to use information flows and wireless technologies to help supply chain security. We describe the latest Smart and Secure Tradelane initiative that is in line with the total quality management approach. Section 4 describes some simple quantitative model that we can use to assess the benefits of these measures and initiatives. Section 5 illustrates a hypothetical case study based on an actual manufacturer in the high technology industry with a supply chain that started with manufacturing sites in Malaysia, ending with the distribution center in the US. The quantitative models and the case study are used to illustrate how higher supply chain security can be attained at lower costs. Section 6 concludes with summaries.

2. Lessons from Total Quality Management

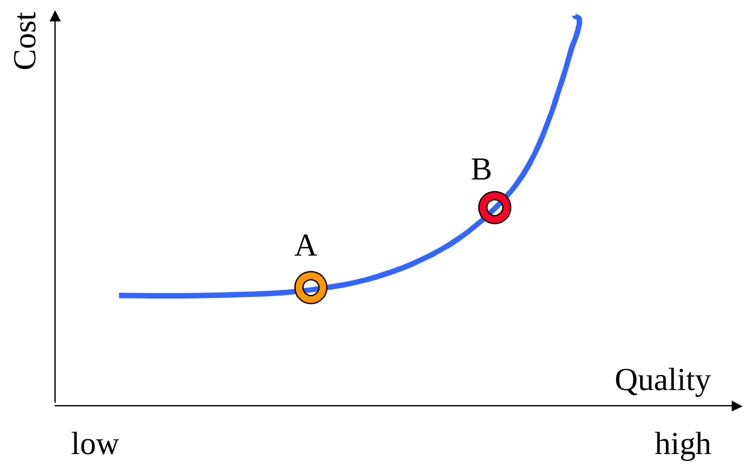
While counter-strategies are being developed by the public and private sectors to enhance supply chain security, we can learn from some lessons based on our experience in Total Quality Management (TQM). There is a rich literature on TQM, and a good reference can be found in the website www.qualityspecialists.com/iso/iso_9000/iso.htm, which also outlines the requirements as documented for ISO 9000 certification. TQM as a management principle has been around for a long time, but widespread industrial adoption and practice in the US occurred in the 70's. The quality movement at that time was a response to the seemingly loss of competitiveness of many US manufacturers in product quality, against their Japanese counterparts. In particular, Japanese automobile manufacturers were gaining significant market shares by their zealous focus on product quality and reliability. Business interest in how the Japanese had mastered quality management techniques and approaches had risen to an all-time high. The "Toyota-system," focusing on lean manufacturing, just-in-time, and superior quality control, was a study subject for business and academics.

The quality movement started with the recognition by industry that defects can be very costly to a company. Failures of the product out in the field, or "external failure costs," that include customer process down time, catastrophic impacts to society, liabilities, product recalls, field repair, goodwill damages, and adverse effects to future sales, can be far greater than the product cost itself. This realization provides the strongest motivation for industry to be engaged in TQM, where all in the organization, suppliers and in some cases, customers, have to be involved to zealously improve quality.

This, of course, bears a striking resemblance to the recognition of the importance of security problems, and the need to engage all stakeholders to drive out security breaches.

In the quality movement, the big message was that quality should not be "inspected" into the product. The naive approach to improving outgoing product quality was increasing final inspection of finished products to screen out non-conformances. Indeed, the popular inspection method used since the 50's was "sampling inspection." A random sample of items was drawn from a production lot, and rules were used to determine if the lot could be accepted or not, based on the outcome of the sampling inspection. One of the all-time gurus in quality management, Edward Deming, had been a major critic of sampling inspection. He found sampling inspection a waste of resources, and advocated either zero or 100% inspection (Deming, 1982). If inspection is the means through which we improve quality, then it is clear that, the higher quality we seek, the more inspection we have to do, and the higher is the cost. As a result, higher quality is possible only through higher cost, as shown in Figure 1, where, in order to get higher quality from A to B, we have to invest more in cost.

Figure 1: Conventional Cost-Quality Tradeoffs



But higher quality does not have to incur higher cost. There were several principles that quality gurus such as Deming, Juran, Taguchi, and Ishikawa have been preaching, and it is worthwhile to list them here, as they are useful in thinking about our responses to the security challenge.

1. Quality assurance by final product inspection is the last resort. Inspection does not improve quality. Screening is expensive, and it is subjected to the usual Type I (labeling a conforming item as non-conforming) and Type II (missing a non-conforming item) errors.

2. In-process control, to assure that the process is functioning in an in-control state, is preferable to final product inspection. A process that is out-of-control will produce many more nonconforming items. Detecting the out-of-control state, identifying the assignable causes (the causes of the out-of-control state), and restoring the process to an in-control state in a timely fashion will always improve quality.

3. Quality assurance requires total organizational focus. Everyone should be aware of the quality problem and each one is trained to be responsible for one's work. Quality is not just the responsibility of the quality control department or quality inspectors, but of everyone's.

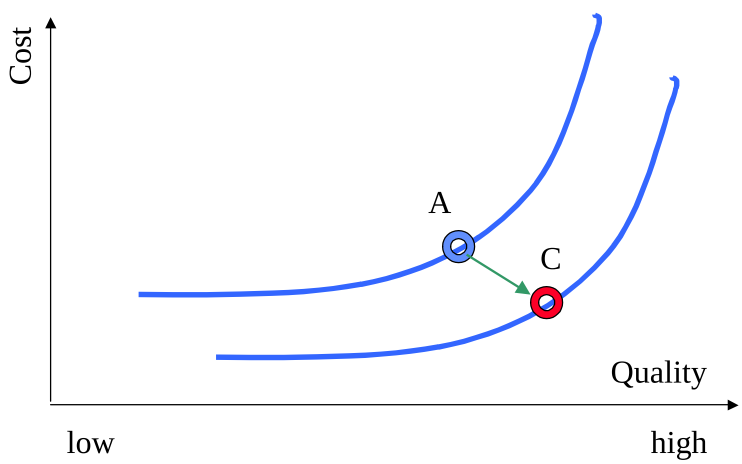
4. Prevention is always the preferred strategy. Hence, installing ways such that nonconforming items cannot be made, or that once something has gone wrong, it could be immediately identified and corrected so that it could never be turned into a defect, would be the goal. The well-known Poka-Yoke system, championed by Shigeo Shingo, is such an approach (Shingo and Robinson, 1990). The Poka-Yoke system involves designing the process such that if some deviations to perfection happen in the production process, they could be identified right away and automatically responded to to prevent defects from occurring.

5. Quality should be designed in. Hence, products are designed so they are less likely to be built with defects. Processes are designed such that the process variation is at a minimum. Indeed, the cornerstone of Motorola's Six Sigma program was to continuously reduce process variability. The well-known Taguchi Method is to use experimental design to enable products to be less subjected to external noises (e.g., see Phadke, 1989).

Over the last decades, the quality movement has evolved from a focus of inspection to a focus of prevention. Prevention emphasizes on education, organizational collaboration, design improvement, process variation reduction, and accountability of the total company. In fact, the notion that such investment would pay off handsomely as the cost of inspection and product failures would be drastically reduced, was the theme of

Crosby's best sellers "Quality is Free," and "Quality Without Tears" (Crosby, 1979 & 1984). Indeed, many companies have found that it was possible to improve quality without increasing costs and jeopardizing productivity. As Figure 2 shows, the right management approach, prevention efforts, and operational improvements can lead to higher quality at lower costs (from point A to point C).

Figure 2: Higher Quality at Lower Cost

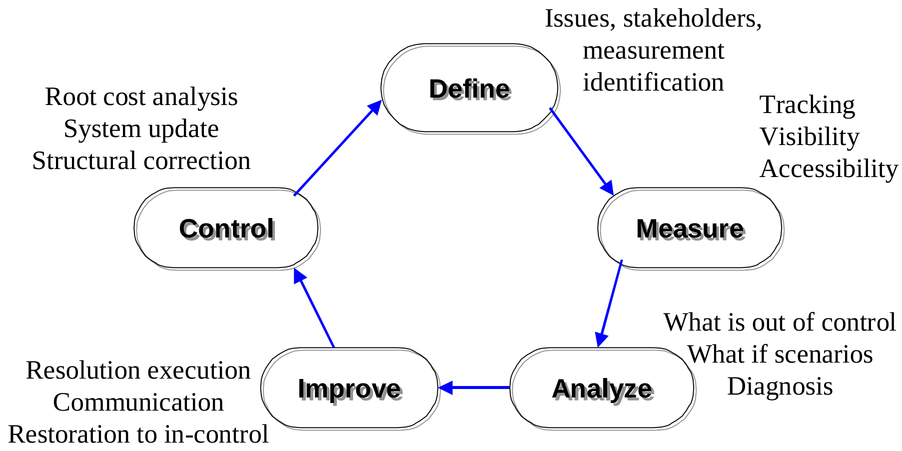


Companies have used the quality movement as a means to direct management and employees' attention to the importance of customer satisfaction, corporate responsibility, and ultimately, operational excellence. Solectron won the prestigious Malcolm Baldrige Quality Award twice based on the company's excruciating attention to quality and customer satisfaction. Motorola's Six Sigma program earned that company a Baldrige Award and considerable recognition. Many other firms, like General Electric, adopted the Six Sigma program as theircore management philosophy.

The security equivalent to final inspections for quality is to rely on inspection of inbound goods at destination ports and border crossings. Some in government have called for heightened inspection of cargoes, containers, and transportation vehicles at ports and border crossings--for example, increasing the inspection rate of containers from today's one-to-two percent to ten percent. In the aftermath of September 11, there were even calls for universal inspection of import containers. Such measures are extremely costly. In addition to the direct labor costs of inspection, which could be passed back to all supply chain partners, there would be indirect costs to the supply chain. The congestion created by increased inspection adds lead time and uncertainties to the supply chain. The service levels for cargo owners and their customers could be adversely affected. Finally, the increased inspection to ten percent is far from giving sufficient confidence and assurance to the supply chain. Disruptions and supply chain security breaches could still be prevalent, and companies will have to increase their safety stocks, use alternative and possibly more expensive supply sources, and add contingency capacities to prepare for such disruptions.

We can reduce the reliance on inspection, the negative effects of remaining inspections, and our vulnerability to overreaction-based increase in future inspections. The key is to apply prevention and process control concepts, as well as the six-sigma approach in the quality movement. The Six-Sigma cycle, originally developed for quality control, is one that we can apply for security management. It has five steps (see Figure 3).

Figure 3: The Six Sigma Cycle



Define: define what is to be measured, what the potential quality problems are, and how they could be identified.

Measure: put in place a measurement system that would track and monitor the appropriate quality performance measures, and provide visibility to and allow easy accessibility to the key stakeholders.

Analyze: perform analysis of possible out-of-control conditions, conduct what-if scenarios to see what could have caused the problems, and do the necessary diagnosis to get to the root cause of the problems.

Improve: respond to identified problems by carrying out decisions, restore the process to an in-control condition, and communicate the decisions and actions to appropriate stakeholders.

Control: eliminate the root cause if possible, reduce process variations, make structural changes to the process so that the chance of the out-of-control condition occurring again would be minimized.

With the new controls in place and a new "in-control" condition defined for the process, we can then repeat the six-sigma cycle continuously.

The six-sigma process emphasizes the awareness, focus, and dedication of everyone in the company to identifying and fixing quality problems. Such a total approach is what we need in addressing the security problem.

3. Measures and Initiatives for Supply Chain Security

In the past year, the governments of the US and its trading partners have instituted some security initiatives that are focused on prevention instead of final inspection. In this section, we describe some examples of these initiatives and show how they parallel the development of the quality movement. There are many sources for more details of such initiatives (see, for example, Aichlmayr, 2002; and McHugh and Damas, 2002).

Governments have been investing in better inspection technologies. For example, besides the standard random sampling inspection, US Customs has begun using data mining techniques to advance information about each shipment and historical data about the shipper and similar shipments, which allows the government to screen and select for inspection the cargos or containers with "higher" risks. To improve the quality of the data that would enable such pre-screening to be more effective, US Customs has instituted an Advanced Manifest Rule (AMR) in February, 2003, which requires detailed cargo data be submitted to US Customs at least 24 hours prior to lifting containers to a

US-bound ship. When fully implemented, containers will only be allowed into the US if detailed contents information has been provided electronically to Customs at least 24 hours before the container is loaded on the ship. The information will be useful to pre-screen questionable containers prior to arrival to US ports and select containers for inspection at ports of entry, using special handheld radiation and explosives detection sensors without opening the container, as well as physical visual inspection of the contents of the container. Besides US ports, the World Customs Organization (WCO), based in Brussels, has also been developing standard sets of customs data elements and guidelines for member countries to enable advanced electronic transmission of such data. It is also developing cooperative arrangements between WCO member countries and industry to increase supply chain security (Gillis, 2002).

In manufacturing, the way to eliminate inspections is to design and build in quality from the start. For supply chain security, the analogy is to design and apply processes that prevent tampering with a container before and during the transportation process. Some of the government initiatives are in this direction.

US Customs has also launched the Container Security Initiative (CSI) and the Customs-Trade Partnership Against Terrorism (C-TPAT) in January and April of 2002, respectively. The C-TPAT program involves multiple countries, and promotes the use of best security practices. Shippers and carriers that certify the use of best security practices are given expedited processing at US ports of entry. Manufacturers, importers, carriers, and third party logistics service providers can all participate by submitting detailed questionnaires and self-appraisals of their supply chain security practices, while Customs would perform periodic audits and verifications of such practices.

Under CSI, the US and some trading partner governments are also pursuing supply chain security by pushing inspections and screening upstream to originating ports. CSI focuses on the twenty ports where most of the US-bound containers originate. The goal is a series of bilateral agreements that would permit exchange of Customs officers and more screening of shipments at the outbound ports. The processes involved in pick and pack, staging of outbound loads, and the final loading, are to be tightly monitored and documented (e.g., the identities of pickers, packers, loaders, checkers, and if any seals are used in the container, etc.).

In addition to source inspection, the quality movement also advocates in-process monitoring, or process control. In the case of supply chain security, we need to put in place a monitor on the shipments while they are in transit. Any tampering of the containers would have to be detected. To do this effectively, we do need to use modern technologies. One promising one is the use of electronic cargo seals. This is an area in which the private sector has also stepped up and work with the public sector towards a better process to assure security. On July 2, 2003, U.S. Senator Patty Murray of the Washington State, Chairman of the US Senate Appropriations Committee's Subcommittee on Transportation, announced the formation of the Smart and Secure Tradelane initiative (SST). Under this initiative, the world's three largest seaport operators – Hutchison-Whampoa Ltd, PSA Corporation Ltd., and P&O Ports – representing over 70% of the world's container traffic, will collaborate to demonstrate and deploy automated tracking detection and security technology for containers entering US ports (see McHugh and Damas, 2002, and Cuneo, 2003, for more details). Hence, containers leaving the participating ports will eventually be equipped with special seals that could be used to track whether the containers have been tampered with during transit. Containers identified can then be sorted out for special inspection. A by-product of such monitoring efforts is theft prevention.

SST is based on solution providers such as Savi Technology, QUALCOMM, Sandler Travis Trade Advisory Services, and Parsons Brinckerhoff. The SST process starts with the identification of personnel, cargo, and transportation information about the container and its contents at the point of origin. This is followed by real-time supply chain security and management information to partners involved in the end-to-end shipment by integrating data from Active-RFID (radio-frequency identification) tags, combined with intrusion detection sensors attached to the containers. The RFID tags are read by stationary and mobile readers at key nodes.

The pilot SST test involved the ports of Singapore, Hong Kong and Seattle. In the last six months, initial results from the initiative have been very encouraging, with key security events and exceptions, such as container tamperings, business processes such as container violations, mis-routes, and delays, promptly reported. SST now has established an open and flexible network infrastructure for commercial use at 15 major ports worldwide and has deployed sensor-related systems to track nearly 1,000 smart containers shipped from Asia and Europe into the United States.

Figure 4: Supply Chain Security and Quality

Quality Movement	*Security Initiatives*
Defects are very costly	Security gaps create big risks
Total quality management	Involvement of all stakeholders
Emphasis on prevention and Poka-Yoke methods	C-TPAT, CSI, sealing, and anti-tamper technologies
Source inspection	CSI and inspection at origin
Process control	Automated chain of custody
Six-Sigma cycle to identify, track and improve	Container tracking and total visibility
Root cause analysis	Profiling system for shipments, shippers, carriers, trade routes
"Quality is free"	Higher supply chain security at lower cost

With the emphasis on prevention, source-inspection and in-process monitoring, we can see how supply chain security can be tightened with lower cost, a lesson that we have learnt from the quality movement. This will restore supply chain confidence while increasing productivity and reducing costs. Figure 4 summarizes the differences and parallels of the quality movement and the current security initiatives.

4. Simple Quantitative Models

Let p be the inspection rate of containers arriving at a destination port. Hence, we can interpret p as the probability that a container load will be inspected by Customs. Given the heightened concerns of terrorism and WMD, it is generally expected that US Customs will increase p from its current level. The immediate effect of this increase is that the direct cost of inspection will increase, and it is expected that this cost will be passed onto shippers and carriers. Besides the direct inspection cost, additional inspection will lead to potential congestion at the destination ports, since inspection resource is limited. The increase in inspection rate may not lead to a corresponding increase in inspection resource. A simple queueing model can be used to quantify the additional waiting time for the increased inspection. The effect of increased inspection to the overall transit time of shipments is therefore: (1) added variability due to the fact that more will now go through the inspection process; (2) added mean lead time with a greater fraction of shipments going through inspection; and (3) additional variability of transit lead time due to the variability of waiting time at the port as the shipment goes through inspection.

The overall lead time, given by the sum of the transit (transportation) lead time and the inspection dwell time (which would be zero if a shipment does not have to go through inspection, but a random variable equal to the total waiting time of the queueing system at the inspection point), will ultimately affect both the pipeline inventory (using Little's Formula) as well as the required safety stock at a distribution center (DC) in the destination country. Suppose that the transit lead time is independent of the inspection dwell time. Let:

x = transit lead time in days, a random variable;

y = inspection dwell time in days, a random variable;

T = total lead time in days.

Then,

$$E(T) = E(x) + pE(y);$$

$$Var(T) = Var(x) + pVar(y) + p(1-p)\left[E(y)\right]^2.$$

Note that $E(y)$ and $Var(y)$ are given by the queueing model that describes the inspection process.

SST has several impacts. First, SST facilitates easy, electronic transmission of the Bill-of-Lading (BOL) information in compliance of the Advanced Manifest Rule. This speeds up the processes that the manufacturer and the shipping lines have to spend to meet the AMR requirement. The immediate result is savings in labor costs and some reduction in the in-transit lead time, which in itself has implications on in-transit inventory and safety stock at the DC. The savings related to this first impact is a function of how much the current process has been automated for the BOL information to be transmitted. For the manufacturer in question, several of the shipping companies handling shipments have already been equipped with automated processes and so the savings is not as large as originally expected.

Second, with the containers equipped with the electronic seals and the processes for source loading and in-transit shipment both tightly monitored, and with the full compliance of the AMR rule electronically, one can reasonably assume that US Customs would not apply the same intensity of inspection. In fact, the idea is that US Customs would make use of such information so that they could focus their efforts on higher risks cargos, and give SST-compliant manufacturers a close-to "Greenlane" treatment.

Third, with a transparent process and early information on the content and transportation needs, and tighter monitoring of the transit process, some of the uncertainties in the transit process can be reduced. This would result in a smaller value of $Var(x)$.

Fourth, SST, together with AMR, allows the manufacturer's DC to have advanced information on whether the shipment will be inspected or not. In other words, part of the uncertainty around the replenishment lead time uncertainty is resolved at the beginning of the lead time. The effect of this is that a lower safety stock can be used by the DC to achieve the same service target. To see this, we develop the safety stock requirements with and without SST.

Let:

μ = mean daily demand of a product;

σ = standard deviation of the daily demand of the product;

R = inter-replenishment time in days for the DC;

k = safety stock factor;

p' = new inspection rate under SST;

$1-\theta$ = percentage reduction of the transit time variance as a result of SST. Hence, the new transit time variance under SST is given by $\theta\, Var(x)$.

Without SST, i.e., under the current process, the safety stock is given by (see, for example, Silver et al., 1998):

$$S_0 = k\sqrt{\mu^2 Var(T) + \sigma^2 E(T+R)}\,.$$

With SST, we have advanced information about the lead time statistics, and so could adjust the safety stock based on the knowledge of whether inspection is needed or not. The resulting expected safety stock is:

$$S_1 = k\left\{p'\sqrt{\mu^2\left[\theta Var(x) + Var(y)\right] + \sigma^2\left[E(x) + E(y) + R\right]} + (1-p')\sqrt{\mu^2 \theta Var(x) + \sigma^2\left[E(x) + R\right]}\right\}$$

We can easily verify that $S_1 \le S_0$. To see this, let:

$$H_1 = \mu^2 Var(y) + \sigma^2 E(y) + H_2, \text{ and}$$

$$H_2 = \mu^2 \theta Var(x) + \sigma^2 [E(x) + R].$$

Then, we can express $S_0 \geq k\sqrt{pH_1 + (1-p)H_2}$, and $S_1 = k\{p'\sqrt{H_1} + (1-p')\sqrt{H_2}\}$. Note that, for any random variable *Z*, $\sqrt{E(Z)} \geq E(\sqrt{Z})$, based on Jensen's inequality. Hence, we have:

$$S_0 \geq k\sqrt{pH_1 + (1-p)H_2} \geq k\left\{p\sqrt{H_1} + (1-p)\sqrt{H_2}\right\} \geq k\left\{p'\sqrt{H_1} + (1-p')\sqrt{H_2}\right\} = S_1.$$

The last inequality above follows from the fact that $p \geq p'$, and $H_1 \geq H_2$.

One of the values of SST is to have the potential of giving advanced lead time information to the manufacturer. Such advanced information, in general, is very powerful. It is more valuable than simply reducing the variance of lead time. We demonstrate this with a simple analysis below. Let *t* be the random variable denoting the exposure time, and μ and σ be the mean and standard deviation of demand per unit time. With advanced knowledge of *t*, it is possible that the manufacturer can dynamically adjust the safety stock at each replenishment instance. Without advanced lead time knowledge, the safety stock requirement is $k\sqrt{\mu^2 Var(t) + \sigma^2 E(t)}$, where *k* is the safety factor. With advanced lead time knowledge, the average safety stock requirement is $k\sigma E(\sqrt{t})$. We can express the safety stock requirement without advanced lead time knowledge as:

$$k\sqrt{\mu^2 Var(t) + \sigma^2 E(t)} = k\sqrt{\mu^2 Var(t) + \sigma^2\left[Var(\sqrt{t}) + \left(E\sqrt{t}\right)^2\right]} \geq k\sigma E(\sqrt{t}).$$

The difference of the two safety stock requirements is greater with higher values of $Var(t)$ and $Var(\sqrt{t})$. With advanced lead time knowledge, we can reduce the safety stock not only from the $\mu^2 Var(t)$ term, but also the $\sigma^2\ Var(\sqrt{t})$ term as well.

Figure 5 summarizes the various cost savings as a result of SST.

Figure 5: Cost Savings Categories of SST

Cost Category	Cost Elements	Comments
BOL Compliance	• Direct labor cost savings • In-transit inventory reduction due to more efficient BOL transmission process	These savings are independent of the amount of inspection carried out at the port of entry, and is a function of how much the current process has already been automated.
Tracking Efficiency	• Reduction in inspection cost • Reduction in pilferage • In-transit inventory reduction due to less inspection	These savings depend on how much reduction of inspection that Customs will give for the Greenlane treatment. Pilferage reduction is due to tighter monitoring of the in-transit process.
Supply Chain Confidence	• Safety stock reduction as a result of reduction in the mean and variance of lead time • Safety stock reduction as a result of transparency of advanced lead time information	These savings depend on how much reduction in the mean and variance of lead time can be achieved by SST. The manufacturer should also have advanced scientific inventory control system in place to take advantage of such improvements.

5. A Hypothetical Case Study of Supply Chain Security

In this section, we use some data from a high tech manufacturer participating in the initial SST pilots, and show how using the right approaches and technologies, we can achieve higher supply chain security actually result in lower costs. The tradelane considered is from Malaysia-Singapore to Seattle.

The current tradelane for this manufacturer is about 4,300 containers per year, with an average value of goods in a Forty Equivalent Unit (FEU) container being about

$300,000. Like many high technology firms, the manufacture's products have short product life cycles. A conservative annual inventory carrying cost rate of 23% is used. The manufacturer has a distribution center (DC) in the US, which operates on a periodic-review replenishment system to ship products from Malaysia to the US, with target inventory levels for the products at the DC. The inter-replenishment time is a week. Currently, the transit time from source to the DC is 30.4 days, with a standard deviation of 6.3. The current DC has a service target of 95%. The manufacturer has put in place a tightly controlled process, so that the number of theft or pilferage incidences has been extremely low, averaging once per year. With tight monitoring under SST, it is quite possible that the pilferage rate could go to near zero.

The Brookings Institution estimated that, currently, only about 2% of all containers arriving in the US were inspected by the Customs Service, but with tightened security, that number could go up to 10% (Shah, 2002). We used a more conservative estimate in our hypothetical example. Because of the good standing of this manufacturer, the current inspection rate by US Customs on its products is quite low, at 1%. With tightened security concerns, it is quite likely that the inspection rate will go to at least 2%, probably higher. When inspection rate goes up by 100% (from 1% rate to 2%), it is unlikely that the number of inspectors, or the inspection capacity, will be doubled. The US Customs has not budgeted for such an increase. The result is the likely delay for those containers selected for inspection. To get the estimate of the total dwell time, i.e., inspection plus waiting, of containers selected for inspection at the port, we employ standard queueing models as described in the last section. The current inspection capacity and associated service rate can be estimated. For the purpose of analysis, we made the assumption that the inspection capacity will go up by 60% when inspection requirement is doubled. This is an arbitrary assumption, and in fact, it is quite likely that less capacity increase will be in place for inspection. If the latter was the case, then the total dwell time will be even longer.

With increased inspection, the manufacturer will incur a higher inspection cost charged by US Customs.

We assume that US Customs will give Greenlane treatment to SST shipments. We assume that the resultant inspection rate for a manufacturer following the SST initiative would be 0.4% (instead of the expected increase to 2%). Hence, p' = 0.4%.

We assume that the standard deviation of the in-transit lead time is reduced by 10% as a result of higher transparency and tighter monitoring of the transit process, i.e., the value of θ is 0.81.

Figure 6: Inventory Days Reduction

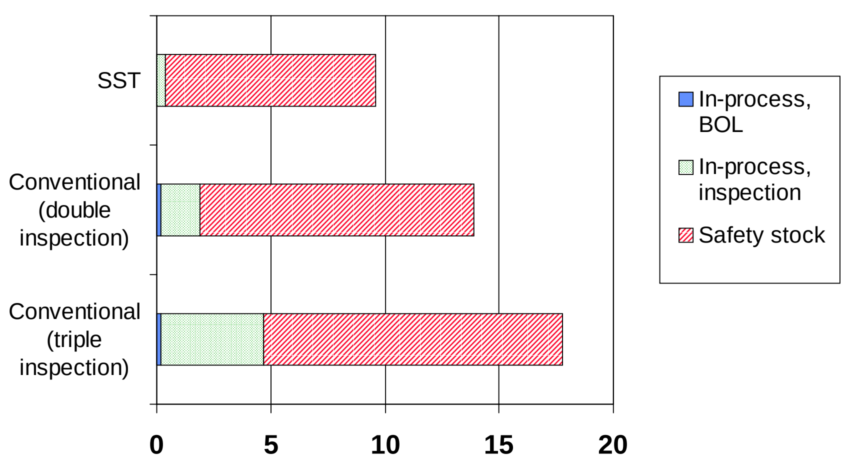


Figure 6 shows the reduction in total inventory as a result of SST. Besides showing the inventory days with the 2% inspection under the conventional process, we also show the result when inspection is increased to 3% under the conventional process. As shown in the figure, SST can help to reduce inventory significantly.

Figure 7: SST Impacts per Container

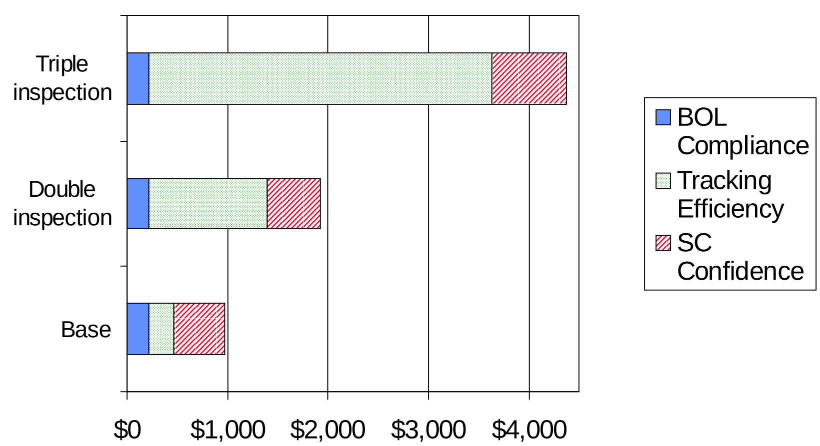
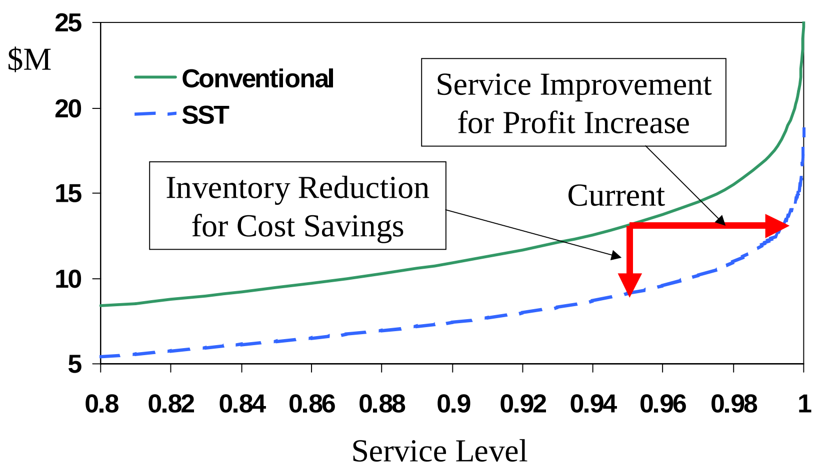


Figure 7 shows the cost savings per container of SST over the conventional process. Several scenarios are considered in this figure. First, we show that there is a very modest cost savings if Customs continued with the inspection level of today, i.e., 1% inspection rate. Second, we show that there is about $2,000 savings per container if Customs increased the inspection level of non-SST cargoes to 2%. Third, we show that the savings can go to $4,000 per container if Customs raised the inspection level of non-SST cargoes to 3%. These cost savings far exceed the costs of implementing the electronic seals, the readers, and the other infrastructure investments.

Finally, Figure 8 shows the inventory cost and service level tradeoff curves under the conventional process and under SST. With SST, the manufacturer could improve its service level from 95% to 98% with the same inventory costs, which could result in potential increases in profits due to less stockouts. Alternatively, SST can enable the manufacturer to reduce its inventory costs to achieve the same level of service. In other words, supply chain security can achieved with lower costs. The value from service level improvement is much more difficult to quantify. It depends on the rate in which customers may switch to another product when the manufacturer is stocked out, the margins associated with the accessories or consumables, and the possibility that the customers may switch to a competitive product in the future. In the case of high tech products, the margins of accessories or consumables can be huge. We used very conservative estimates of these rates in coming up with the value of service level improvements.

Figure 8: Improving Service and Inventory



5. Summary and Conclusions

The quality movement has offered us sound lessons that can be very powerful to address supply chain security concerns. Instead of final, end-product inspection, the quality movement emphasizes prevention, total quality management, source inspection, process control, and a continuous improvement cycle. These are all ingredients for successful and effective ways to manage and mitigate the risks of supply chain security.

We applaud the efforts that are underway to instill quality processes, to inspect products and containers at the points of origin, to use technology to automate the chain of custody, to monitor the process closely during the transportation journey, and to create transparency and visibility across the supply chain. Informational, rather then physical, activities form the core of security measures.

The SST initiative has shown great promise to assure supply chain security. The initiative has now migrated into its second phase with the objectives of adding 20 additional tradelanes, developing fully sensor-equipped "smart containers." SST is also extending the development of smart containers, ranging from the placement of intrusion-detection systems on existing containers to embedding sensors into the containers at the time they are manufactured. In addition, Phase 2 will build onto the platform more layers of security, including a grid of sensor technologies for detecting environmental changes inside containers, automated surveillance cameras, biometric identification, and satellite tracking for in-transit visibility. These developments could enable even tighter process control of the supply chain from end to end.

The emphasis on *process* control, rather than *output* control, has another advantage of capitalizing on the emerging advancements of new RFID technoliges. As more products come out the production line embedded with RFID tags, the cost of tighter process control is lowered. Needless to say, technologies do not offer security free, and are even double-edged, potentially also serving terrorists to violate public security. Only continuous improvement and constant alerts on technologies would assure supply chain security.

In the end, having the right strategies and preparedness in place, we can make great strides toward supply chain security at lower costs.

References

Aichlmayr, M., “Mission Critical: Closing Security Gaps,” *Transportation & Distribution*, 28-32, May 2002.

Crosby, P.B., *Quality is Free*, McGraw-Hill Book Company, New York, 1979.

Crosby, P.B., *Quality Without Tears*, McGraw-Hill Book Company, New York, 1984.

Cuneo, E.C., “Safe at Sea,” *Information Week*, April 7, 2003.

Deming, E., *Out of the Crisis*, MIT Center for Advanced Engineering Study, 1982.

Gillis, C., “Customs Agencies Turn Attention to Exports,” *American Shipper*, 10-13, August 2002.

Hannon, D., “Chemical Carriers See Tighter Security, Costlier Insurance,” *Purchasing*, 37-38, April 4, 2002.

Lee, H.L. and M. Wolfe, “Supply Chain Security Without Tears,” *Supply Chain Management Review*, Vol. 7, No. 1, 12-20, Jan/Feb 2003.

McHugh, M. and P. Damas, “Mega-Port Groups Back Security Pilot,” American Shipper, 14-18, *American Shipper*, September 2002.

Mottley, R., “Terminal Troubles – Container Terminal Operators Worry About Cost and Extent of Security Procedures,” *American Shipper*, 24-28, May 2002.

Phadke, M.S., *Quality Engineering Using Robust Design*, Prentice Hall, Englewood Cliffs, New Jersey, 1989.

Shah, J.B., “Initiatives Look to Safeguard Trade,” *Electronic Buyers News*, May 6, 2002.

Shingo, S. and A. Robinson, *Modern Approaches to Manufacturing Improvement: The Shingo System*, Productivity Press, 1990.

Silver, E., D. Pyke and R. Peterson, *Inventory Management and Production Planning & Scheduling*, Third Edition, John Wiley & Sons, 1998.