A systematical approach to improve supply chain: An application of RFID technology on cargo transportation

The MIT Faculty has made this article openly available. Please share how this access benefits you. Your story matters.

<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>As Published</td>
<td><a href="http://dx.doi.org/10.1109/IEEM.2009.5373074">http://dx.doi.org/10.1109/IEEM.2009.5373074</a></td>
</tr>
<tr>
<td>Publisher</td>
<td>Institute of Electrical and Electronics Engineers</td>
</tr>
<tr>
<td>Version</td>
<td>Final published version</td>
</tr>
<tr>
<td>Citable Link</td>
<td><a href="http://hdl.handle.net/1721.1/59406">http://hdl.handle.net/1721.1/59406</a></td>
</tr>
<tr>
<td>Terms of Use</td>
<td>Article is made available in accordance with the publisher’s policy and may be subject to US copyright law. Please refer to the publisher’s site for terms of use.</td>
</tr>
<tr>
<td>Detailed Terms</td>
<td></td>
</tr>
</tbody>
</table>

The MIT Faculty has made this article openly available. Please share how this access benefits you. Your story matters.
A Systematical Approach to Improve Supply Chain: An Application of RFID Technology on Cargo Transportation

C. E. Kao¹, P. C. Hung²

¹System Design and Management Program, Massachusetts Institute of Technology, MA, USA
²Identification and Security Technology Center, Industrial Technology Research Institute, Hsinchu, Taiwan

Abstract — This paper proposes a systematical approach for redesigning a secure and efficient supply chain. A real international trading case of transporting cargos from an offshore bonded warehouse to a domestic one is used to demonstrate. Through supply chain architecture analysis, system boundaries, interfaces, and value related operands are defined. With System Dynamics analysis, feedback and relations of actions to the goals are studied, and potential options are evaluated. Then a prototype of the selected option is implemented to gather further information for future improvement. The two elements, RFID and UCR, applied for improving supply chain, and how they work in the prototype are explained.

Keywords — Supply chain architecture, Supply chain security, Radio frequency identification

I. INTRODUCTION

Supply chain security has become a highlighted issue since Sept. 11th attacks in 2001 making governments realizing vulnerable supply system may ruin in all aspects. With governments’ mandates, supply chain managers are asked to securitize their supply chain systems, and prevent any possible attacks in advance. However pursuing security in current supply chain designs may gain costs, complicate process, low fulfillment efficiency, and hurt profits among the supply chain members. Without external incentives, such as preferential duties or being required by customers, companies are reluctant to improve supply chain security. Supply chain managers are struggling to find the equilibrium among corporate strategy, overall costs, security, as well as operational performances and design the supply chain to meet the needs. Recently, some researches pointed out reviewing fulfillment process can help companies to gain visibility of their supply chain and eliminate un-necessaries. But in practice, we found companies who look forward to increasing security either adopting process-oriented, imposing additional audits and checking-points, or adopting device-oriented, installing RFID or monitoring facilities. Without fundamental revising system design from kernel, system architecture, results in those companies sacrificed cost competitiveness and efficiency for security. Besides, a long supply chain makes defining the boundary of security improvement projects difficult; the impacts and side effects of introducing new technology to existing systems aren’t measurable; security requirements aren’t only derived from corporate strategy, but regulations, trends, and social responsibility. Re-design a secure supply chain needs a systematical approach to deal with uncertainty, complexity to achieve success among multiple goals: security, costs, efficiency and all considered aspects. Hence this research is proposing a systematical approach to design a secure supply chain from architecture, options evaluation, options selection, and prototyping.

II. METHODOLOGY

The definition of supply chain management from Council of Supply Chain Management Professionals (CSCMP) shows components to supply chain planning can be categorized into objects and process. In this article, Object-Process Methodology (OPM) is applied to symbolize supply chain architecture for analysis and redesign. Then System Dynamics analysis is employed in options evaluation and selection. These two are explained in the following.

A. Object Process Methodology

Object-Process Methodology (OPM) [1][2][3] is a comprehensive approach, developed by Dr. Doc Dori, to the analysis and development of systems. It explicitly represents objects, processes and their links of a complex system into a single model. In OPM’s view, the world is composed of things, either physical or informational, and a thing is a generalization of an object, which has the potential of stable, unconditional existence for some positive duration, and a process, which is the pattern of transformation applied to one or more objects. An object is exactly in one state at any specific point of time, and the state can be changed through process. The links can exist between pairs of objects to show to structure of a system, or connect entities (objects, processes, and states) to describe the behavior of a system.

B. Options Analysis and Evaluation Approaches

An approach which integrates the concept of System Dynamics analysis and the concept of systems engineering is developed to help options analysis and evaluation. System Dynamics is an approach to understanding the behaviors of systems. It uses feedback loops and nonlinear functions to analyze the relations
between goals and actions. Then computers software is used to simulate a System Dynamics model of the situation being studied to understand how the system changes over time. In the proposed approach, System Dynamics analysis provides not only a holistic view to consider direct/indirect and positive/negative effects, but an evaluation tool for options selection.

Although using computer simulator can dramatically decrease the efforts of prototyping and experimenting, it could still be a burden when multiple control factors have to be dealt with. There are approaches in systems engineering can minimize the number of experiments, such as Taguchi’s Orthogonal Arrays, which can complement System Dynamics in the phase of options analysis and evaluation.

III. ANALYSIS

A scenario of improving an international cargo transportation system is used to demonstrate how architecture analysis using OPM, and options analysis/selection applying Sytem Dynamics work. In the scenario, cargos are shipped from a shipper’s warehouse to a customer’s offshore warehouse. The stakeholders of the whole system includes suppliers, inland transportation operators, customs, carriers, foreign inland transportators, and customers. Each stakeholder has its physical and informational legacy systems.

A. Architecture Analysis

In order to enhance security to the present system, OPM is applied for architecture analysis and system design. The analysis process starts from forms analysis by observing exterior attributes. Then reverse engineering is undertaken by mapping functions to forms. These two bottom-up (from forms to functions) steps can help capture original design knowledge and prevent original concept being infringed. In the next phase, new concepts are converted to functions and added or replaced into legacy systems. Finally forms are revised to deliver adjusted functions.

Fig. 1 shows the object-process diagram of the target transportation system acquired from forms and functions analysis. Information and physical transporting systems are two sub-systems within the whole transportation system and the relations and interactions of those two sub-systems are shown in Fig. 1 as well.

The upper-side of Fig. 1 represents the information systems, which consist of two tires of objects. Warehouse management system (WMS), transportation management system (TMS), and carrier’s system are in the first tire. These systems perform individually, but exist sequencial relations, and any security defects will be carried to all succeeding processes. Customs EDI systems belong to the second tire. They communicate with the first tier systems by specific protocols and usually they don’t generate data but feed by the first tier systems. The figure also shows a standard data format accepted by the Customs affects the information exchangeability.

On the other hand, the downside of Fig. 1 represents the physical movement system. Containers, connected to the majority of the processes in this system, are the value related operands. Proper design to those processes related to containers can enhance entire system performance significantly. Particularly, packing process incurs the longest waiting time and incorrect packing list data will result to destined failure no matter how secure the following tasks are.

The most noticeable points in the object-process diagram are the linkages between information system and physical movement system. The figure shows that a process in the physical movement system not only affect objects in physical and the corresponding objects in informational, but activates the folowing objects in the information segment. For example, “inland transporting” in physical segment feedbacks to “TMS” in informational segment and activates “Carrier’s System”. Hence, the agents, drivers and trucks, of inland transporting processes, play critical roles to connect physical and informational segments, and checking points in the progress of the transporting are needed to support the operations.

With the understanding of the system from OPM analysis, three results are summed up: (1) container is the value related operand of the physical system; (2) well educated drivers, equipped trucks, and more checking points to confirm transportation status and to activate following processes are needed; and (3) a standard data format among information systems can decrease total complexity.

B. Merits Definition for Physical System Improvement

Security is the core concept to the system improvement project. Because it is not a solid and
assessable merit, it is difficult to evaluate and select potential improvement options. Moreover, when the governments concern security issues, private sector concerns cost and operational efficiency rather than security. Hence security, cost, and operational efficiency should all be considered at the same time. In the following, the definition of these three indicators and how to assess them are explained.

(a) Security
Visibility is used to assess the degree of security. When a truck is fully equipped and the local status of containers can be monitored real-time, the visibility is set as 1.0. If discrete checking points are used to substitute real-time tracking, an exponential decreasing function, based on environmental factors such as region and transportation type, with input variable “duration” is developed to estimate the degree of visibility. For example, a container at ocean transportation for ten days is more secure than it is at long inland transportation without auditing for ten days. Hence ocean transportation’s degree of visibility decreases for ten days is less than land transportation’s.

(b) Costs
Personnel and equipments costs are both considered. Personnel costs include recruit, education, monthly salary, and other incurred costs, while equipments costs consist of purchase, installation, operation, and maintenance.

(c) Operational Efficiency
The total time required for container status inspection is employed to measure operational efficiency. In order to avoid the affection of external factors, such as schedule and traffic, only the inspecting time is measured. If there are multiple checking points, all of the inspecting time should be summed.

C. Options Selection for Physical System Improvement
There are three control factors: (1) number of checking points, (2) manual or automatic monitor, (3) equipments of trucks and drivers are considered in Taguchi’s Orthogonal Arrays (L4: two level factors). And then a System Dynamics computer simulation is used to outcome a comparison of the results of security, costs, and operational efficiency for further decision making.

### Table I

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Number of checking points</th>
<th>Manual or automatic monitor</th>
<th>Equipping trucks and drivers</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Few</td>
<td>Manual</td>
<td>Yes</td>
</tr>
<tr>
<td>2</td>
<td>Few</td>
<td>Auto</td>
<td>No</td>
</tr>
<tr>
<td>3</td>
<td>More</td>
<td>Manual</td>
<td>Yes</td>
</tr>
<tr>
<td>4</td>
<td>More</td>
<td>Auto</td>
<td>No</td>
</tr>
</tbody>
</table>

Note: Few number of checking points means setting up inspection at the beginning and end of any transportation process; Few number of checking points means adding one extra checking point in the process.

IV. IMPLEMENTATION
The option of few number of checking points with automatic container status checking is selected from previous analysis for physical system improvement. A real pilot project based on RFID technology to achieve automatic inspecting and to activate information system was implemented and tested. On the other hand, regarding the requirement of standard data formats and protocols for data sharing among information systems, Unique Consignment Reference (UCR) was adopted to enhance existing systems. The scope of the pilot system is from the shipping point at the consignor, a bonded warehouse, and via ocean transportation to the receiving point at the consignee.

A. RFID Technology
Radio frequency identification (RFID) has emerged as part of a new form of inter-organizational system that aims to improve the efficiency of supply chain [4]. RFID is not only a data capture technology, but enable computing, integrate systems seamlessly [4], and improve supply chain sustainability [6]. Researches [7][8] show RFID can help supply chain partners improve logistics efficiency, responsiveness, value added service, reduce labor costs, out-of-stock rate, and reduce inventory level. It is unique and contactless, and these features make RFID widely accepted in security applications.

A typical RFID system consists of tags and readers, and application software [9]. Tags, which is memory embedded and has an unique identify code, are categorized into active (with batteries) or passive (without batteries). RFID readers are the devices that collect data from and write data to compatible RFID tags, and pass retrieved data to a server through network and enrich applications, such as inventory control real-time tracking, and business intelligence [10]. To ensure the compatibility of the communication, the tag and reader must work at the same specified working frequency and comply with specific regulations and protocols.
B. Cargo Data Structure-UCR

Unique Consignment Reference (UCR) is a reference number for Customs use and may be required to be reported to Customs at any point during a Customs procedure[11]. The main objective of the UCR is to define a generic mechanism that has sufficient flexibility to cope with the most common scenarios that occur in international trade and to satisfy the need for Customs authorities to facilitate legitimate international trade. Since UCR is used to establish a unique reference to the commercial layer of the transaction between the consignor (customer) and the consignee (supplier) and also has the potential to be shared with the transportation layer and forwarder, it is able to meet the needs of information system improvement, bind information together from initial order, movement, to final delivery, and provide proper information among the supply chain.

In UCR framework, logistics units can be divided from moving vehicle (truck, aircraft, ship, train) to individual item into five layers [12], and each layer can be identified by its correspond RFID tags. In this research, RFID are tagged on ocean containers (e-seal), pallets and boxes which are used in the supply chain (as depicted in Fig. 2).

C. Pilot Test

In this pilot test, RFID tags, ultra-high frequency (UHF) tags, are applied on boxes, pallets and containers. A supporting system to match these three sorts of unit was developed and the matching process is invoked by the packing process in the physical system.

Two types of RFID readers, mobile and fixed, were used in the pilot test. Mobile RFID readers, with wireless communication ability to send data to bankend systems through the wireless network, are used at the consignor’s packing/unpacking field to update the reations between boxes and pallets, and pallets and containers to WMS. On the other hand, fixed RFID readers were placed at the access gates, such as receiving/shipping point at a bonded warehouse, container yard, and the receiving point at consignee’s warehouse, to record the combination data set of driver, truck, and containers, and update them to information systems, and trigure subsequent systems. These fixed readers are used at the It can send data to the bankend system through the internet.

D. System Modules

In order to well integrate physical and information systems, there are three new modules: picking and packing information collecting/sharing module, container inspection module and UCR code generating module, introduced.

(a) Picking and packing information collecting module

This module is designed to gather all good’s exit/entry events at warehouse to help the supply chain managers to track and manage goods movements. The module also maintains the relations between containers and pallets, and pallets and goods automatically. When a stuffed container leaves the warehouse, a detail list of the good, contrainer ID and its UCRs can be generated for Customs authority without delaying and further efforts. In addition, in the container consignee side warehouse, the detail package list can be aquired for checking and updating to warehouse management system using container ID and UCR. This module also provides a protocol for inventory managers to understand their real time and accurate status of inventory for applications, such as picking/packing errors prevention, or new inventory models, such as VMI (vendor management inventory).

(b) Container Inspection module

Each container in the pilot run was sealed with RFID embeded e-seal. When a container was detected by fixed RFID readers deployed at gates, the status of e-seal incorporates with UCR code were retrived and uploaded. This model not only helps add checking points without hiring more staffs, but decrease total inspecting time.

(c) UCR code generating module

The module centralizes the UCR codes for the shipping in the pilot project. Although each comapny can define their UCR code following some specific rules, UCR code should be unique and with the same format definition in a corporation.

The pilot project followed EPC network architecture to design and develop the system (as shown in Fig. 3) to improving secutiry while multiple goals (security, efficiency and cost), and legacy systems are considered. At each control point, there are one EPCIS and one ALE installed to store and collect detected tags data and related events. There is also an Event Registry Server for authorized organizations to query the belonging historical events and relevant box/pallet/container to a specific RFID tag.
V. CONCLUSION

This paper proposed a systemmatical approach comprising architecture analysis and options selection to design a secure international trading system. Then a pilot project adopted RFID technology and UCR framework to implement the design, and provided feedback for further improvement. Through architecture analysis, the system boundary, the legacy systems, and the key components are identified, and such identifying can prevent device-oriented or process oriented improvements. On the other hand, adopting System Dynamics in options selection help consider multiple purposes and positive/negative feedback in advance. Although the total process spent more time than typical projects, such analysis has given clear information for future improvements.

Regarding the learnts from the demonstration, RFID works well as an enabler and cause physical flow communicating with information flow. Such communication might consume considerable workforce but still difficult to avoid input errors. Standard data format, such as UCR, strengthens the impacts of RFID by removing barriers of data sharing. With comprehensive design and proper technology, the win-win among cost, efficiency, and security (or the win-win between public and private sector) is achievable.

ACKNOWLEDGMENT

This research needs to thank the support from Ministry of Economic Association, and also appreciate the cooperation of ASE Group and T-Shine International Logistics in Taiwan.

REFERENCES