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Battling counterfeits in a massive market: Designing and evaluating an ID-tag based solution for electronic product monitoring and controlling

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By

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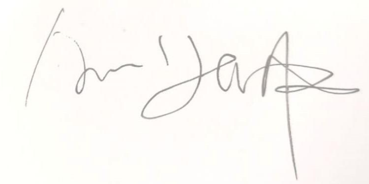
Declaration

I hereby declare that this doctorate dissertation is my original work
and it has been written by me in its entirety.
I have duly acknowledged all the sources of information
which have been used this dissertation.

This doctorate dissertation has also not been submitted for any degree
in any university previously



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Abstract

The problem of counterfeit and shoddy goods in China has been rampant and persistent one. The complexity of the Chinese market makes solving this problem extremely difficult. Three government agencies have tried to combat this problem extensively, from market entrance permission for prior-processing, sampling and inspection for in-processing, and punishment for post-processing. The responsibility division among agencies, however, created the cracks and holes in dealing with the problem. The existing government solution is too slow in response and too sparse in coverage to be effective and efficient. Anti-counterfeit labels and their derivatives are employed for counterfeit identification and prevention. Their effectiveness and coverage, however, are also limited, and the cost and resources required for these techniques have prevented a majority of industries to adopt them.

To address this counterfeit problem, an ID-tag based product tracking solution have been proposed and developed. A unique ID is assigned to each product, a unique and authentic-able ID is assigned to each market participants, and a repository server is used to track all the status changes of the instances. Whenever a market participant processes a product, the market participant is required to report the changes in product status to the repository. Based on the status data of each product, the repository can create an event chain or the life cycle for the product. Using the event chain data, our solution creates a seamless monitoring and controlling system for each product over its entire life cycle in the market. Accountability can be traced to serve as a deterrence mechanism to fight against counterfeits. Our solution is called the Electronic Product Monitoring and Controlling System (EPMCS). For the last 15 years, EPMCS has saw great success in the drug industry. EPMCS has proven itself to be effectively in handling the problematic drugs and efficiently in resolving public crises. The EPMCS success in drug industries inspired many to build and deploy EPMCS like systems in different industries across China and other countries. While applying the EPMCS design to their systems, there are four questions that should be answered: (1) what are the essential elements and rules of the EPMCS design that other EPMCS like systems must follow? (2) Is the EPMCS complete and effective in solving the counterfeit and shoddy product problem? (3) What parameters of EPMCS can be chosen and what are their boundaries while EPMCS like systems are implemented? And (4) What are the worthwhile practices and experience we have gained in our promotion for the EPMCS adoption in drug industry that might shed light on the future EPMCS like system adoptions in other industries?

In this research, the above questions are answered. It has shown that (1) any EPMCS system must have six core elements and eight essential rules; (2) EPMCS is a both complete and effective solution to the counterfeit and shoddy product problem; (3) There are four parameters that can be chosen and adjusted in an EPMCS implementation; (4) The elements of a successful EPMCS adoption include the prototype, effective communication, and accommodation for key stakeholders.

Keywords: Counterfeit, Accountability tracing, EPMCS code, Event chain

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Dedication

This dissertation is dedicated to my parents, Hongda Chen and Yecui Wu, and my family members for their love and support. Without their love and support, I would not be where I am.

Chapter 1 Introduction

1.1 Research Background

The Chinese economy grows at an ever fast speed and in a massive scale. The numbers of market players participated in manufacturing, distribution and retailing accounted over 110 millions (National Market Monitoring and Controlling Agency, 2019a). Most Chinese enterprises are small and mediate enterprises with a life expectancy of less than four years (Ye Qing, 2007). The products manufactured become abundant in variety and quantity. The estimated number of products by type is at more than 40 millions. The largest Chinese E-commerce company has more than one billion product online in 2014 and 48K products sold daily ("Taoba". 2019).

However, counterfeit and shoddy products have been a persistent phenomenon in China ever since the early days of the Chinese reform (Zhang Lizhi, 1994; Wen Zehua & Hou Yanli, 2009). The widespread counterfeit and shoddy products often result in serious public crises that threaten the general public and causes economic damages to legit enterprises and consumers. Under massive government crackdown, the problem of counterfeit and shoddy products remains unsolved. This is evident as the Chinese government repeatedly issues the government directives to call for campaigns to battle counterfeit and shoddy goods from 2010 to 2019 Department of State, 2010, 2011, 2012, 2013, 2014, 2015, 2016,2017, 2018; National Market Monitoring an Controlling Agency, 2019b). It is challenging to eliminate counterfeit and shoddy products because there are strong economical interests from both the supply side and the consumption side (Ma Jianjun, 2005). The fierce competition for profits, among all those small enterprises and , the demand for cheaper goods by consumers are the main reasons that cause the problem of counterfeit and shoddy goods.

To combat this problem, the government takes a pro-active approach by setting up regulations and laws, and creating responding agencies to monitor and control the market circulation[1] of the problematic goods. Three systems are responsible for market entrance permits, product sampling checks, and post-mortem penalties and interventions. These three systems actually fragment the process of the market circulation of product, creating cracks in the product monitoring and controlling. At the same time, the pro-active approach, which requires enormous resources from the government, brings ineffectiveness and inefficiency to government response in product problems. To resolve the ineffectiveness, the government has initiated campaigns to combat counterfeits and their culprits, year after year. Although the problem of counterfeits and shoddy goods is controlled to some extent with government crackdown, it has yet been controlled to a level that is acceptable to the government and public ("Counterfeits and Shoddy Merchandises", 2018). Under heavy pressure, government agencies need more effective ways to monitor and control counterfeit and shoddy products.

As the direct victims of the counterfeit and shoddy goods, the legitimate manufacturers suffer a direct decrease in sale, and damage to their reputations. To

[1] Market circulation is the process in which a product instance is moving from its creation at a manufacturer to its end when a consumer buys it, via a series of intermediates such as distributors.

protect their interests, these manufacturers are forced to invest in anti-counterfeit label technology, hoping that consumers can directly identify whether a product instance[2] is a counterfeit or not based on the anti-counterfeit label printed on the product ("Common Types of Anti-Counterfeit Label Techniques", 2018). Traditional techniques such as anti-counterfeit labels are not working well to suppress the counterfeit and shoddy goods problem. It is well-known that the anti-counterfeit label based strategies cannot solve the problem of counterfeit and shoddy goods. There are two reasons for this. First, an average consumer does not have the knowledge and the ability to identify the authenticity of the product label (e.g., verifying a $100 RMB Chinese bill is legit or not). Second, the anti-counterfeit labels can be replicated through unlawful culprits with certain techniques. Therefore, the manufacturers are also in need of a cheaper and effective solution to the counterfeit problem.

Although the problem of counterfeit and shoddy goods is still a high priority item on the government agenda, However, the drug industry (including manufacturing, distribution and retailing) is seeing some effective control with this issue. Each drug product circulated in the market can be tracked electronically (Chen Xiaoying, 2010). Any problematic drug can be quickly identified and reported. The flow of counterfeit and shoddy drugs and responsible party can be traced accurately and effectively, to that maker and sellers of the problematic drug can be punished by law. Problematic product inventory distribution over China can be instantly determined by the

[2] A product instance is defined as one individual member of a product of certain type. A product is a set of all product instances of the product. Identifying and tracing a counterfeit is meaningful at the level of a product instance since a consumer deals only with a particular instance of the product, and want to know whether this instance is a counterfeit or not.

government, and the product can be recalled in a timely manner. The government which has been handling crises caused by counterfeit drugs quite successfully and in a timely manner, has greatly increased the general public's level of satisfaction.

This exception is made possible by an innovative system, which was proposed and built by the CITIC 21 Century company I found in 2005, then adopted by the Chinese Food and Drug Administration (CFDA) (Chen Xiaoying, 2010)[3]. This system is known as EPMCS, which stands for Electronic Product Monitoring and Controlling System. EPMCS is an ID-tag based product tracking solution. In this solution, each product is assigned with a unique product ID and each market handler[4]is assigned with an authentic-able market handler ID. When a market handler processes a transaction[5] on a product, it reports the information on the change of status (i.e., transaction data or event) to a repository server. The repository server then tracks all state changes of the products and constructs an event chain[6] or a life cycle for each product. Using this event chain data, an ordinary consumer can easily distinguish whether a product instance is a counterfeit or not. At same time, the government is able to track and locate the culprits for counterfeit and shoddy goods, then quickly and accurately carry out the product recall. This system enables the government to execute a seamless product monitoring and controlling process for any products alive

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[3] Originally，I proposed the concept of EPMCS and designed the EPMCS model. However, the EPMCS implementation and market adoption are the work of my led by me at the CITIC 21 Century company. Therefore, whenever I mention "We" in my dissertation, I mean "I and my team".

[4] A market handler is a market participant who processes a product instance during a product instance circulating through the market. The market handler is either a manufacturer, distributor or retailer.

[5] A transaction on a product instance is defined as an operation that a market handler applies to a product instance and the status of the product instance will be changed. The transaction in this research is sold-to and made-by.

[6] An event chain of a product instance is defined as a series of events that causes the state of a product instance to transit to a different state. The event generated transition is cause by the market participants such as a manufacturer, a distributor and a retailer. In this research, the event chain for a product instance is also denoted as the life cycle of the product instance.

in the market[7]. The accountability can be traced efficiently to support the deterrence mechanism for battling counterfeits.

The EPMCS has been implemented in 2005 and CFDA requires that all of the controlled drugs will be covered by EPMCS for monitoring and controlling (Chen Xiaoying, 2010). By 2010, CFDA requires that all drugs, manufacturers，distributors，retailers and medical institutes are incorporated into the EPMCS. Since then, the government has used EPMCS successfully to resolve every crises caused by counterfeit and shoddy drugs or vaccines. During the last 15 years, EPMCS has proven itself to be effectively and efficiently in handling the problematic drugs and related public crises in a timely fashion.

The EPMCS success in the Chinese drug industry inspires many other industries and countries to build and adopt similar systems for themselves. Other government agencies are looking at solutions similar to the EPMCS for their field, such as the Department of Science and Technology (2018), and the Department of commerce(2016). Many companies are also starting to build similar systems like EPMCS to support the market needs (China Tracking Platform (Beijing) Technology Company, 2018).

Our EPMCS is designed and built to accommodate all products across all industries. When applying EPMCS to other industries, there is no need to repeat develop EPMCS like systems. However, our experience has shown that promoting the

7 Market is defined in this paper as the market place in which a product instance flows from its states of being manufactured, distributed and sold to a consumer. When a product instance is produced, it is called the entrance of market for the product instance. When a product instance is sold to a consumer, it is said that the product instance is removed from the market or it is the end of its life cycle. When the product instance is distributed among manufacturers, distributors and retailers, the product instance is still in the market circulation.

adoption of EPMCS takes up the most resource and time. This is because the EPMCS adoption changes the relationship among the key stakeholders and swifts the power and interests among them. This will call for a person or an organization to lead the change and form the consensus for the changes. This task is typically what we can do as an outsider of their industries. Thus, it is inevitable that the new EPMCS systems will be built and deployed time and again for different interest groups.

While applying the EPMCS design to their EPMCS like systems, this dissertation can help to answer the following four questions that EPMCS new comers might have:

1. What are the essential elements and rules of EPMCS? Understanding these core elements and essential rules would help the new EPMCS systems can clearly follow the requirements and conditions for the EPMCS model.
2. Is the EPMCS a complete and effective solution to track products and identify responsible parties? That is, is the EPMCS model cover all products and their market life cycles? With respect to the operations required for product monitoring and controlling, is the EPMCS model is effective?
3. When building a new EPMCS system, what parameters can adjusted to better suit the situation? What kinds of practical trade-offs can be performed in an EPMCS implementation? An answer to these questions will enable EPMCS builders to develop their solution more quickly without repeated analysis?
4. What kind of practices and experience did we gain from pushing our EPMCS adoption in the drug industry? Our practices and experience may be helpful

to those who are promoting their new EPMCS systems into other industries.

1.2 Research objectives

In this research, the primary objective is to answer the above four questions related to understanding, building and deploying EPMCS alternative systems:

1. What are the core elements that are essential for our EPMCS model? What are essential rules that our EPMCS model must follow? The core elements and essential rules constitute the abstract model of EPMCS, which provides all the necessary conditions that any EPMCS must comply with. Otherwise, the EPMCS system will not work correctly. This abstract of EPMCS will help the designers and developers of other new EPMCS systems to ensure that their systems to comply with the essential requirements of an EPMCS.
2. Is the abstract model is complete and effective? The completeness of the abstract model is defined in this research as: (1) any product in market circulation must be covered by the EPMCS and (2) EPMCS must capture all data about the life cycle for any product instances. The effectiveness of the abstract model is measured by its ability to support three functions of product monitoring and controlling: (1) problematic product identification; (2) tracking of responsible parties for the problematic product; and (3) inventory distribution of the problematic goods and the product recall operation. Therefore, if it can be shown that the abstract model of EPMCS is both complete and effective, we can show that any EPMCS that complies

with this abstract model of EPMCS will also be complete and effective.

3. What are the parameters that system builders can adjust for a new EPMCS implementation? What kind of trade-offs can be taken for an actual EPMCS implantation? All implementation related issues of building an EPMCS system are placed into a model that is called an implementation model of EPMCS. This implementation model captures the adjustable parameters and trade offs, helping EPMCS system builders to shortens the development time and eliminates the redundant analyses.
4. Lastly, the practices and lessons learned in our effort are summarized to push the EPMCS for market adoption. The market adoption of EPMCS is very complicated because many key stakeholders are involved and few participants understand it enough to feel comfortable adopting it. As this project lasted more than 15 years, the experiences from our successful project worth further studying.

1.3 Research Methods Used

Four research methods are employed in this research. The first method is to review existing literature to get a scope and complexity of the research problem, along with the causes, existing approaches and their shortcomings as well as areas that have to be addressed for any new solutions.

The second method is divide-and-conquer. our EPMCS solution is divided into one invariant part (the abstract EPMCS model) and one variant part (the implantation

EPMCS model). The abstract EPMCS model is used to determine the core elements and the essential rules that every EPMCS systems must follow. The abstract model is then analyzed and evaluated on its completeness and effectiveness. This ensures that any EPMCS system that satisfies the abstract EPMCS model will be both complete and effective.

The third research method used is the deductive reasoning (Sternberg， 2009； Johnson-Laird, Ruth & Byrne， 1991). The abstract EPMCS model is used to derive a set of basic assumptions. The deductions are then made about the completeness and effectiveness of the abstract EPMCS model. Lastly, a qualitative analysis is employed to summarize the practices used in the EPMCS adoption in the drug industry and experience obtained.

1.4 Dissertation Structure

This thesis is divided into six chapters. Chapter 1 gives an introduction to the research background, objective and methods used. Chapter 2 reviews the literature of the fields and the approaches used in practice. Chapter 3 describes the EPMCS solution in detail. Chapter 4 presents an abstract model of EPMCS. This model describes the core elements and essential rules that define the essence and boundary of the EPMCS model. The completeness and effectiveness of the abstract model is evaluated, although the details of the evaluation are described in Appendix A. The EPMCS is proven to be complete and effective in monitoring and controlling problematic products in market circulation. Chapter 5 evaluates the implementation design of the EPMCS model, especially the design choices of the implementations of new EPMCS systems. Finally, the conclusions of this research will be drawn and the further study extension of EPMCS will be presented in Chapter 6.

Chapter 2 Problem and Literature Review

2.1 Rampant Counterfeit and Shoddy Goods Problem

Counterfeit goods are goods, often of inferior quality, made or solder under another brand name without the brand owner’s authorization from the official brand. The products are disguised as the legitimate product through imitating the appearance or package of a legitimate product without permission. For example, purposely changing the brand name of SAMSUNG to SHAASUIVG to mislead consumers into thinking the counterfeit is a genuine SAMSUNG product. A shoddy product is either an illegitimate product that violates the existing law regulations or its quality is below the national or industrial standards (Beijing Industry and Commerce Agency, 2018). The common characteristics of counterfeit and shoddy goods are poor quality and substandard products.

Counterfeit and shoddy goods circulating in Chinese market has been a rampant and persistent problem for the last 40 years ever since the Chinese market reforms (Zhang Lizhi, 1994; Wen Zehua & Hou Yanli, 2009). It is evident as the government efforts against counterfeit and shoddy goods have been going on year after year to crackdown counterfeit and shoddy goods. From 2010 to 2019, the Chinese government has continuously launched campaigns to combat counterfeit and shoddy goods (Department of State, 2010, 2011, 2012, 2013， 2014， 2015， 2016， 2017, 2018; National Market Monitoring and Controlling Agency, 2019b). The national Day of Fighting against Counterfeiting on March 15 was established for this purpose. On this day, the national TV stations would hold a major TV campaign against counterfeit and shoddy goods selected for the year. In 2018, There were more than 2,334 cases of counterfeit and shoddy products documented with 22 relevant lawsuits in the city of Beijing alone (Beijing Industry and Commerce Agency, 2018). Yet the problem has remained unsolved. There is a need to develop more effective and efficient methods in order to solve this rampant and persistent problem.

2.2 Causes of Counterfeit and Shoddy Goods

A lot of research was done on identifying and analyzing the causes of the counterfeit and shoddy goods issue. In this section, the causes of counterfeit and shoddy goods as well as implications for an effective and efficient solution for this counterfeit problem will be discussed.

2.2.1 Economical Interest-Driven Causes

2.2.1.1 Supply-side Causes

Cao Feiying (2006) identifies the desire for quick and easy profit as the first cause of counterfeit and shoddy goods. During the last 40 years of Chinese economic reform, economic interests become a priority for government, individuals and enterprises. Whoever can get rich fast will be considered a hero, no matter how one does it. Morality and ethics have thus been put aside, and individuals have no fear in making and selling counterfeit and shoddy goods in return for quick money at the expenses of consumers and competitors.

The 40+ million small and micro enterprises with an extremely short life expectancy (less than four years) worsens the situation (National Market Monitoring and Controlling Agency, 2019a; Ye Qing, 2007). Fierce competitions force some businesses to ignore the law and ethics to produce and distribute counterfeit and shoddy goods. Hu (2008) suggests that the low concentration of industries in China also contributes to the problem of counterfeit and shoddy goods from the supply side . Industry leaders of a certain field tend to value their reputations enough not to risk making counterfeits or shoddy goods. The lack of big players in Chinese industries increases the presence of counterfeit and shoddy goods. The short life expectancy of small enterprises encourages the culprits to take the chances with making counterfeit and shoddy goods and escape from the possible consequences.

If a culprit involved in counterfeit and shoddy goods can be traced and identified promptly from the enormous market participants, then legal actions can be applied accordingly and in a timely manner. Accountability tracing would place an effective deterrence on any individuals or enterprises who engages in making counterfeit and shoddy goods. Hence, any effective solution for the counterfeit problem should include an effective accountability tracking mechanism.

2.2.1.2 Consumer-side Causes

The undying demand for cheap goods from the consumer side may be one of the major causes of the widespread and persistent counterfeit and shoddy goods problem, even under heavy and continuous government crackdowns. Xie (2010) finds the consumers sometimes buy counterfeit and shoddy goods knowingly for the reason of saving money. The products involved are typically ordinary items that are seemingly harmless to the consumers' well-being. PPD provides an example of this consumer demand for cheap counterfeit and shoddy goods ("Counterfeits in PDD Reveals a Real China", 2018). Founded in 2015, PPD is a new comer in the Chinese E-commerce industry. It became one of the top e-commerce platforms in three years and went public on NASDAQ in 2018. PDD has accumulated more than 300 million active consumers, whereas Alibaba and Jingdong took more than 15 years to get to the similar position. However, counterfeits and shoddy goods proliferated on PPD. Even though the customers knew that products on PDD are counterfeits, they still chose to shop there, because the merchandises on PDD are significantly cheaper than those on Alibaba's Taobao and Jingdong. Statistically, more than 80% of Chinese families have an average monthly disposable income of less than 3000 RMB per capita; more than 60% of Chinese families have a monthly disposable income of less than 2000 RMB per capita; and the low 20% of Chinese families have a monthly disposable income of mere 500 RMB. Although Chinese people are getting wealthier and wealthier，a lot of people are still under the pressure of limited income and have to chose counterfeit and shoddy goods to make their ends meet. This explains why the close to the 60% of PDD's consumers are from the small and med-size towns.

Xie (2010) also finds that the consumers won't want to buy counterfeit and shoddy goods if those goods are perceived as harmful to their health and well being. Due to the lack of product information and general knowledge, the consumers often misjudge the risk and threats of a counterfeit and shoddy product. Another case is that consumers buy the counterfeit and shoddy goods unknowingly. Xie's research implies that any effective solution to the counterfeit problems should cover two things. Firstly, the solution must cover all of the counterfeit and shoddy products that may affect the health and livelihood of consumers. The solution cannot rely on the appearance of a products and consumer knowledge to identify whether a product is counterfeit or not. Secondly, an effective solution must enable users to identify easily whether a product is counterfeit or not.

2.2.2 Information Asymmetry and Processing Cost

Information asymmetry and processing cost of consumers exacerbate the issue of counterfeit and shoddy goods (Hu, 2008). Typically, consumers do not possess professional knowledge about the product and market, and might end up buying counterfeits unknowingly. Furthermore, consumers would give up on pressing charges against culprits if the cost and time to handle the problematic products are too high.

This implies that any effective solution to the counterfeit problem should support consumers without any special knowledge about the products and tools to easily identify problematic goods. Accountability tracing of the culprits is also a must for a solution to the counterfeit problem to be effective.

2.2.3 Protectionist Local Government

During the Chinese economic reform, the primary goal of all local governments in China was to develop the local economy and annual GDP was the key performance index to evaluate the performance of local government officials. This economy development-oriented measurement brought competition between local governments (Ji, 2001). In order to increase local GDP, local governments have a strong incentive to protect local enterprises in their jurisdictions even if those enterprises make and distribute counterfeit and shoddy goods (Hu, 2008; Xie, 2010). In 2017, a doctor at Guangzhou reported a problematic product of Hongmao, which was manufactured at Inner Mongolia (Li Qingyun, 2018). The local law enforcement flew to Guangzhou (a different jurisdiction) and arrested the doctor in order to protect the local liquid producer. The case was eventually dropped and the doctor was released. The law enforcement also apologized publicly. This local protectionism encouraged the existence of counterfeit products. It is hence that solutions designed to overcome counterfeit and shoddy goods should be a national one and independent of local government jurisdictions.

2.2.4 Lack of Effective Government Interventions

The Chinese law requires that the Chinese government must monitor and control the product and its quality in the market (National Product Quality Law, 2007). Chinese government takes a proactive approach to product monitoring and controlling. It divides product monitoring and controlling into three parts, administrated by different agencies. For the prior event measure, the Chinese government installed a market entrance permission system. One can make or sell a product only when the facilities and products are certified and given a permit to do so. For the in-event measure, the government adopted a sampling and inspection system. Considering the enormous number of product types, product quantity and market handlers, the tasks of sampling and inspection demand massive resources which the government agencies do not have. For the post-event measure, the accountability tracing and punishment system is established. Considering the complexity of the Chinese market, the accountability tracing of culprits using existing enterprise product ledges is extremely difficult, if not impossible. Many enterprises do not even keep a product ledge. The punishments in existing law are too inconsequential to deter or prevent the unlawful activities. In addition, the product monitoring and controlling done by different agencies create the fragments and leaves cracks in the process. These cracks in turn make government interventions ineffective.

Based on the above analysis, an effective solution to the counterfeit problem must support the following two features. The first is to reconnect the fragmented process and create a seamless process of the product monitoring and controlling. The second is to change the focus from pro-active to deterrence in approach. That is, using fast and accurate accountability tracing to deter the unlawful activities of making counterfeit and shoddy products. Modifying existing law to increase the fines and punishment would make deterrence significantly more effective.

2.2.5 Requirements for New Solutions

Based on the above analysis, a set of requirements can be identified for any new solutions if they want to combat counterfeit and shoddy products effectively. Table 2-1 describes these requirements derived from the analysis of causes of counterfeits. In the latter chapters, it will have been shown that the EPMCS solution proposed stratifies these requirements.

Table 2-1 Requirements of New Solution Should Support

Causes of Counterfeits	Requirements for New Solutions
Supply side causes	Every markets handler should be covered.
	Support fast and accurate accountability tracing .
	Amend existing laws to increase punishment deterrence
Consumption side causes	Every products should be covered.
	Identify counterfeits without consumers knowledge and skills.
	Support fast and accurate accountability trace.
Government side causes	Cover the national market , independent of local jurisdictions
	Must be a seamless process of product monitoring and controlling.
	Fast and accurate accountability trace without offline ledges
	Support inventory determination and product recalls
	Amend existing laws to increase punishment deterrence

2.2.6 Solution Evaluation Framework

Based on the cause analysis of the counterfeit problem above, a set of requirements for any future new solution of counterfeit problem are identified. These requirements are regrouped into two categories, the requirements of completeness and requirements of effectiveness. These two sets of requirements can serve as a framework for evaluating any future new solutions to counterfeit problem. In Chapter 4, this framework is utilized to evaluate our solution. This framework consists of two sets of criteria: the completeness and effectiveness of the product monitoring and controlling solution.

2.2.6.1 Completeness

The completeness of an anti-counterfeit solution includes four criteria:

1. Any product in market is covered by the solution. There is no product which is the outside of the coverage of the solution.
2. Any market handlers in market is covered by the solution. There is no market handler who is outside of the coverage of the solution.
3. A seamless process of product monitoring and controlling should be supported.
4. Sufficient data must accumulate in the solution to describe the whole life cycle of any products in market.

2.2.6.2 Effectiveness

The effectiveness of an anti-counterfeit solution has to meet three criteria:

1. Provide easy identification of the problematic products without the need to have special knowledge about the product and technology .
2. Support for fast and accurate accountability tracing without relying on the offline product ledges owned by any market handlers.
3. Support for problematic product inventory distribution and product recall operations(2.2.4).

2.3. Social Cost of Counterfeit and Shoddy Goods

The social cost of counterfeit and shoddy goods is all of the losses caused by a counterfeit or shoddy product. The social cost is classified into two categories: the cost of direct damages and the cost of indirect damages (Zhang Fenlin & Yang Xiao, 2014). The direct damages caused by counterfeit and shoddy goods are those damages that cause sickness, disability, deaths and family difficulties to the victims and their families. The direct damages can either be tangible or intangible. While economic value can be applied to tangible damages, intangible damages are difficult to measure in monetary terms. The indirect damages caused by a counterfeit or shoddy product are those losses suffered by victims other than the consumers and their families. Those can be damages done to the government, competitors, supply chain participants both up and downstream and the society as a whole.

The social cost of counterfeit and shoddy goods in the food and drug industries is particularly high, because counterfeit and shoddy food and drugs can bring serious damages to public health and sometimes produce public catastrophes. For example, a problematic baby formula case in 2008 cost in about 150B RMB in loss (Zhang and Yang, 2014). The company, Three Deer company, produced melamine-polluted baby formula with a high content of counterfeit protein. Close to 300,000 babies were impacted, among which six babies died, 1622 seriously wounded, and 277,428 sicken. The total amount of direct compensation for the sick babies was 1.2B RMB for the sick babies. The direct losses related to impacted families include costs associated with taking care of the sick babies and psychological trauma of families. The total direct social cost is estimated to be at 32.8B RMB. The indirect cost of this scandal include 30.2B RMB of loss of sales on the manufacturers' side, and handling cost of 1.4B RMB on government's side (Zhang and Yang, 2014). After the scandal, 70% Chinese consumers have lost confidence in domestic products and turned to purchase baby formula from oversea at a price of 2-3 times higher than domestic price. This adds another significant indirect cost of more than 70B RMD in loss of sales in the whole domestic industry. Thus, the total cost brought by the the melamine-polluted baby formula instance was as high as 100B RMB. Therefore, controlling counterfeits in the food and drug industries is especially critical in the war against counterfeit and shoddy goods.

2.4 Existing Solutions

2.4.1 Government Solutions

Product monitoring is defined as collecting information for all products and to detecting any product abnormality when products move through the market. Product controlling intervenes the problematic product flow throughout the market and to punishes the culprits. The Chinese government is authorized by law to shoulder the responsibility to monitor and control product circulation in the market (National Product Quality Law, 2007).

The government employs a proactive and intervening approach to product monitoring and controlling. It divides the whole process of product monitoring and controlling into three segments and performs its duties separately. In the following section, the product monitoring and controlling processes are described for prior to product manufacturing, product being circulated in the market, and the post product abnormality detection.

2.4.1.1 Market Entrance Permit System

In this market entrance permit system, any product to enter market for circulation must obtain market entrance permits. Manufacture facilities must pass the respective quality and safety inspection and certification before producing any products. The permit system consists of three subsystems:

1. Production permit system: product manufacture facility must obtain a permit to manufacture before the production begins. This system is to ensure (1) the facility is safe to produce; (2) the products produced meet quality standard. Any facility that does not have a production permit is prohibited from manufacturing.
2. Mandatory product quality inspection system: All producers must inspect their products for quality assurance. A product is not allowed to go on the market if it cannot pass the quality inspection. If the producer does not have the means and facility for product inspection, it must hire a qualified third party to perform the product inspection.
3. Product inspection marker system: Product that passes product inspection must be labeled clearly with a quality inspection marker. For example, QS marker is required for all food products that enter into the market circulation.

It is obvious that this market entrance permit system has a coverage problem. It demands tremendous resources and costs in general to cover the massive facility certification and quality inspection needs. In practice, the government does not have the capability and resource necessary to execute this system to cover all manufacturers and all products in China. The government is only able to enforce the system in a limited amount of industries. The food and drug industries are among the first ones to be covered by the product market entrance permit system, while many industries are still left untouched. This is the reason that the general public often thinks the government has done too little in fighting against counterfeit and shoddy goods (Hu, 2008; Xie , 2010).

The execution of this market entrance permit system is assigned to two government agencies. The Chinese Food and Drug Agency (CFDA) is responsible for pharmaceutical products and medical devices, while the Product Quality Control Agency（PQCA) is responsible for all other general products.

This system takes a preventive approach to the counterfeit problem. It is a heavily loaded task that demand enormous resources and workloads. Instead of rigorously trying to prevent problematic products from entering market like before, accountability tracing and punishment enforcement may deter producers who dare to make or distribute problematic products.

2.4.1.2 Sampling and Inspection System for Product Quality

Entrusted by the National Product Quality Law, the government installed a product monitoring system by sampling and inspecting products in market circulation to determine whether a product is legitimate and meets the product quality standard (National Product Quality Law, 2007). The sampling and inspection results are announced to the public. The government decisions are then sent to the culprits on how problematic products should be processed and what penalties and correct actions they must take.

The sampling and inspection system covers three product categories:

1. All of products that threatens public health, body injuries and damages to private or public properties. Those products include foods, pharmaceuticals, medical devices, pressured vessels, flammable and combustible products.
2. All products that can seriously impact national welfare and the people's livelihood such as pesticides, chemical fertilizers, concrete iron bars and cements and so on.
3. All products reported by consumers, users and organizations as problematic products are detected.

The duty of product sampling and inspection are assigned to two government agencies. The Industrial and Commerce Agency（ICA）is responsible for monitoring products in market circulation, while the sampling and inspection is performed by PQCA. The system is also not as effective as it hopes to be. The frequency of the active sampling by PQCA and ICA is typically too low to be effective due to the massive number of products and their corresponding makers. In addition, passive inspections after the problems have occurred with low report ratio are also ineffective for most products.

This inspection and sampling method is neither complete nor effective. Many products that are not sampled don't go through product monitoring and controlling.

Thus, there are holes in this method. In addition, the accountability tracking is also ineffective, if not impossible. The accountability tracking is based on product handling ledges of each market handlers which are typically offline. There is no uniform product ledge kept by each market handler[8]. As such, to trace the status of a particular product instance is almost an impossible job due to the lack of market handler ledges. Besides, the tracing available ledges also demands too long of a period and gives no answers in time to take controlling actions such as product recalls.

2.4.1.3 Product Quality Accountability and Punishment System

This system consists of three tasks:

(1) Tracing the culprits who are responsible for the problematic products. The accountability solution that traces manually based on product ledges of the market handlers is typically time consuming and ineffective.

(2) Punishing the responsible culprits. There are typically three of punishments: administrative fines, civil penalties and criminal charges.

(3) Executing product control functions, with improvements in facilities or product recall from the market.

The administrative fine is administrated by the ICA, while the civil penalties are handled by the court. If the culprits knowingly manufacture and distribute counterfeit

[8] A market handler is the entity who processes the product instances when these instances move through the market. Typical market handlers are manufacturers, distributors and retailers.

and shoddy goods that lead to serious damages to people health or death, the victims are entitled to demand for an additional punishment in fine on the top of normal civil compensation. This added penalty is known as the punishment penalty, designed to raise the cost of conducting illegal activities. The criminal penalty is decided by the court. It is clear that the accountability or responsibility determination is critical to support an effective product quality punishment system.

2.4.1.4 Shortcomings in Government Solutions

In essence, the government takes a doctrine of active prevention toward the problem of the counterfeit and shoddy goods. It actively and tightly monitors and controls every aspects of the market life of a product，from market entrance permit for prior-processing control, sampling and inspection for in-processing control, and punishment for post-processing control. The following are four shortcomings of the the existing government solution to the counterfeit problem:

1. The segregated product monitoring and controlling as well as the boundaries between agencies create the cracks and holes in the process when a product goes through its life cycle in the market. Product problems caused by these cracks and holes often remain unsolved or significantly postponed.
2. The existing product monitoring and controlling solution demands a lot of manpower and resources, which the government agencies do not have. This often results in delayed responses from the government, and it would be too late to prevent the problem from happening and control the damages. The

ineffectiveness and slow response generate a lot of dissatisfaction.

3. It is very hard for the government to trace and identify culprits who produce counterfeit and shoddy goods, because not every market handlers maintain a product ledge for each product. The lack of the distributive ledges makes it impossible to trace the status of a particular product. Besides, tracing manually through those available ledges demands a very length period of time and does not give answers in time to take controlling measures, such as product recalls. It is necessary to develop an electronically and hopefully automated mechanism to create and maintain a product ledge for each product at each market handler, so that effective tracing of product status and accountability can be realized.
4. The existing system lacks the effective means of market interventions when there are problematic products. The intervention operations should include inventory determination of problematic products and product recall from the market. Efficient government interventions are necessary for the government to handle a public crisis caused by problematic products.

2.4.2 Existing Technology Solutions

This section will described and review the technological solutions used in practice for the problem of counterfeit and shoddy goods.

2.4.2.1 Standard Product Barcode Label

A barcode is an optical, machine-readable representation of data invented in

1952 (“Barcode”, 2018). The barcode is typically printed on a label of an object. The data encoded in the barcode describes something about the object. Soon enough, industry users find that the barcode can be encoded with the data such as product type, product specification, production location and time (Selmeier, 2008). The product type information on the barcode can be used to trace the product instances of a product type along the supply chain to improve the logistic efficiency. The USA Department of Defense adopted the barcode to mark all products sold to the US military. Since then, the barcode has been widely adopted across a variety of industries. The Universal Product Code (UPC) is standardized for the logistics and retailing industry and is especially designed to trace products of a particular type (Weightman, 2015). The Global Standard 1 (GS1) is adopted by ISO as the global standard of product type tracing (“GS1”, 2018).

In 2004, US FDA developed a barcode known as the National Drug Code (NDC) which requires that human drugs must have an NDC containing drug identification (drug type id), medication name, dosage and drug maker name (“Barcode technology in healthcare”, 2018). The purpose of NDC is to reduce the rising medical costs of healthcare by decreasing the high rates of medical (human) errors. A study conducted in 2010 found that NDC usage prevented more than 90,000 serious medical errors each year, cutting the mortality rate by as much as 20% (Poon et al. 2010).

Note that neither UPC nor GS1 nor NDC barcodes are suitable to fight against counterfeit and shoddy goods. Those standard codes are intended to deal with genuine or legitimate products by design. They need only to trace the logistics and supply chain activities of a particular product type, and the barcode that carries the product type information is sufficient to serve the purpose of (genuine) product tracking. The success of UPC, GS1 and NDC is based on the foundation that they deal with only genuine products and not counterfeits. This is true in the case of USA, as the the industry concentration is very high there. There are only a handful of big players who are dominant in each industry. The big players have little incentive to make counterfeits because the consequences are severe and can greatly damage their reputation.

However, the barcode based only on product type, such as UPC, GS1 and NDC, is unable to identify and trace the counterfeit and shoddy goods. By design, all instances of a product have the same product type id, thus, both genuine and counterfeit instances have the same product type id. In this setup, one cannot distinguish the counterfeit instances from the genuine ones based on the information of product type. Therefore, those codes are unalbe to identify and trace product instances.

2.4.2.2 Anti-Counterfeit Label Only

Anti-counterfeit label techniques are based on security printing that deals with the printing of tamper-evident labels to prevent forgery, tampering or counterfeiting ("Common Types of Anti-Counterfeit Label Techniques", 2018). There are more than 20 different anti-counterfeit label techniques, ranging from self-adhesive label, fragile label paper, laser film-based, to security line anti-counterfeiting paper and etc. ("Security printing", 2018). An anti-counterfeit label is designed so that it is difficult, if not impossible, to be reproduced at a low cost. An anti-counterfeit label is typically printed on each product. Although a consumer cannot determine whether a product is genuine or not, by examining the product itself, the consumer can recognize whether the anti-counterfeit label on the product is genuine or not. This way, the consumer can recognize a counterfeit product through examining the anti-counterfeit label.

There are two shortcomings of the anti-counterfeit technologies. First, the anti-counterfeit labels can be reproduced at a reasonable cost as printing technology advances and the associated print costs continuously drops. A reproduced anti-counterfeit label on a counterfeit product can be very deceiving, and a consumer will misjudge the counterfeit product. This defeats the purpose of the anti-counterfeit label. Second, the complex labels are too difficult for a consumer to recognize whether a label is genuine or not, because the consumer does not possess the professional knowledge and appropriate equipment in doing so. Therefore, the new solution to the counterfeit problem must not rely solely on a product label printed on the product. It should employ a system similar to how a bank keeps the true balance for each account based on computer data. A product monitoring and controlling system should keep the product data inside the system to determine genuineness of a product, and the consumer needs only to query the system for product genuineness.

2.4.2.3 Anti-Counterfeit Label Base Query-able Registry

In order to avoid identifying counterfeits based solely on an anti-counterfeit label, a centralized back-end server is to augment to the anti-counterfeit labels to enable consumers to check via the server for product verification. Some hidden information such as serial numbers would be printed on the anti-counterfeit label. The server keeps a list of valid serial numbers for legit product instances. When a consumer buys the product, he rubs away the cover of the anti-counterfeit label and obtains the hidden serial number for this product instance. He then checks via the back-end server to see if the serial number is valid or not. If the answer is yes, then the product instance the consumer bought is the genuine one. The back-end server provides additional security feature on the top of a simple anti-counterfeit label. In fact, the anti-counterfeit label provides a mechanism to prevent tempering of the product label, while the query system gives consumers a convenient means to verify a product's genuineness.

Since only a static data of serial numbers are kept in the server, the query is limited to one per product instance in the system. If the query could support the repeated queries, the system would be cheated with replicated anti-counterfeit labels. The counterfeit instances with reproduced labels with a valid serial number will generate the affirmative responses for consumers with a counterfeit product. This defeats the purpose of the anti-counterfeit measures.

There are two possible improvements on this anti-counterfeit label with the limited query system. Firstly, the backend server is required in this solution and the investment on system building and operation is placed on the manufacturers. Although the cost of modern information technology continues to decrease, the investment required for this approach is still out of reach for a majority of small and micro enterprises. Instead of building and operating its own system, the enterprises may be better off obtaining query services from a public or the third-party platform that builds and operates on a national query server as for all enterprises.

Secondly, there is a need to relax the restriction of allowing for only one query, since the consumer would be confused by the system responses when queryis being processing more than once. In order to enable accurate queries, the status change of a product in the market should be tracked. A query server with the status information related to a product can generate the correct responses for repeated queries. The EPMCS discussed in this dissertation adopts the above two improvements.

2.5 Conclusions

The problems associated with counterfeit and shoddy goods are reviewed and the causes of and costs associated with the problems are further analyzed. The existing solutions used in practice are described and discussed. The following conclusions are drawn:

1. Although a lot of techniques, such anti-counterfeit labels, strict government monitoring and controlling, and constant crackdown by government, are being used, the problem of counterfeit and shoddy products is still rampant.
2. Currently, the government employs a fragmented, proactive and preventive approach in product monitoring and controlling. This approach is neither complete nor effective. The fragmented monitoring and controlling create cracks and holes in the whole process. The proactive and preventive approach demands tremendous resources and manpower which the

government does not have. This prevents the government from effectively doing its job. In addition, the accountability tracing of a problematic product cannot be done effectively because the tracing relies on offline enterprise product ledges and manual processing. This suggests that future product monitoring and controlling can be greatly improved by utilizing modern information technology to create a seamless process, and employing an effective accountability tracing to fight against counterfeits through deterrence.

3. The traditional anti-counterfeit labels are not as effective as expected, because identifying the genuineness of a product is solely dependent on the anti-counterfeit labels which can be reproduced. The anti-counterfeit label based query-able repository is restricted to investment requirement and one query each time. It suggests that identifying the genuineness of a product should not rely on anti-counterfeit labels, but should on product life cycle data collected and maintained by a repository server. In addition, the repository server should be a third party system which covers all products nation-wide, to avoid redundant investment in building and operating such as a system by individual enterprises.
4. Any solution of product monitoring and controlling should be evaluated based with two criteria, the completeness and effectiveness of the solution. The completeness requires that all products and their market life cycle are covered by the solution. Effectiveness refers to supporting the user in

identifying counterfeit product more easily as well as make possible accountability tracing and market interventions of problematic product inventory determination and product recall from market.

Chapter 3 An ID-Tag Based Product Tracking Solution

In order to overcome the deficiencies of the existing solutions, an accountability tracing-based solution is proposed and developed for product monitoring and controlling (Chen Xiaoying, 2010). In this research, the solution is called the electronically product monitoring and controlling (EPMCS). This EPMCS was officially adopted by the CFDA for all drug products and achieved a remarkable success in fighting against counterfeit and shoddy drugs in the drug-related industries. EPMCS was born with the efforts of a team of more than 100 people for more than 15 years. The total investment to build and deploy the EPMCS system exceeded one billion RMB. I am indebted to our team and the people who contributed and sacrificed for EPMCS.

3.1 Design Objectives

To design a solution for product monitoring and controlling, there are four objectives set in my research:

1. Being able to recognize whether a product is a counterfeit or not by depending on only on the product data accumulated inside the system rather than any label on a product.
2. Being able to recognize whether a product is a counterfeit or not without the user having any knowledge about the product and market or

possessing any special equipment.

3. The accountability tracing does not require any market handlers to maintain (paper or electronic) product ledges themselves. Our system should create and maintain electronic product ledges at each market handler automatically inside the system. The effective accountability tracing can be performed electronically based on the ledges in the system.
4. Our system or design must be both complete and effective (see section 2.2.6).

3.2 Design Approach

In order to achieve our design objectives, four key ideas follow to formulate our strategy. The key ideas form the foundation of the EPMCS and they are described as below:

1. Unlike the traditional standard barcodes, a unique ID is assigned to any product instance in the market circulation for product instance identification. This serves two purposes. Firstly, the identifying whether a product is a counterfeit or not, can be performed among all instances of the same product type. Secondly, it enables the EPMCS to collect all transaction events for a product instance, create and maintain the electronic product ledges for each market handler, so that the EPMCS builds the product life cycles for each product instance and traces product movements and accountability of the culprits.

2. Each market handler is assigned a unique ID (i.e. the market handler ID). There are two purposes for the market handler ID. First, EPMCS can trace the product responsible party and find the identity of the culprit. Second, the EPMCS can determine which market handler's product ledge needs to be updated, when the EPMCS repository receives an event report by a market handler.
3. EPMCS employs an event repository on the fly to collect the transaction data on the product, when a market handler processes a transaction that changes the flow of the product in the market. When a market handler performs a transaction on a product, it will report the transaction data to the repository. This repository in tern automatically creates and maintains the product ledges and product life cycle data.
4. The EPMCS uses the data inside the repository to detect product abnormality in product life cycle data to identify the problematic product.The product life cycle data is also used to trace the product flow and the responsible culprits, determine problematic product inventory distribution, and support product recalls.

3.3 Design Description

3.3.1 Product Instance ID (PID)

EPMCS assigns a unique ID for each legitimate product instance in the market circulation. It is also known as the product instance ID or product ID. Legitimate products are all of products that are registered with the EPMCS. Any products that are not registered with EPMCS are considered counterfeit products. In EPMCS, this product ID serves three purposes. First, this product ID enables not only every genuine product to be distinguished from each other, as well as between the genuine products and counterfeits. Second, this ID is tagged to all transaction events of product instance sent to the repository server. Using the product ID, all events related to the product can be used to create or update the product ledge and the history of the product flow. Thus, the accountability of culprits can be traced by EPMCS. Third, the aggregative and distributive ledge of a product can be used to determine product inventory distribution, such as the quantity and locations of the product instances in the market. Thet inventory distribution can then be used to facilitate the product recalls.

Unlike the traditional UPC， GS1 and NDC codes, this EPMCS ID is set at the product instance level, while the standard codes are set at the product type level (Selmeier，2008；“GS1”，2018；“Barcode technology in healthcare”，2018). The standard codes are designed to trace the movements of genuine products for assuming all instances in the product are genuine. They are designed to solve the problem of counterfeit and shoddy product instances, because the counterfeit and the genuine product instances are typically mixed together as the same type of product. EPMCS product ID is needed from eliminating the ambiguity among the product instances.

The product instance ID is printed on a product, every market handler is required to apply for a block of EPMCS product IDs. When a product instance is produced, the manufacturer scans the EPMCS product ID on the product and reports the birth event of the product instance, and the repository will activate the EPMCS ID. In this dissertation, EPMCS considers that the product instance is legitimate to EPMCS. Note that legitimate product does not imply that this product is a legal product. EPMCS legitimate product can be a counterfeit product in EPMCS. Making a counterfeit but EPMCS legitimate product is perfectly alright as long as EPMCS can trace the responsibility of the problematic products to the manufacturer.

3.3.2 Market Handler ID (MID)

A market handler is defined as participants in a product transaction that changes the product flow in the market. There are three types of market handlers. They are manufacturers, distributors and retailers. A manufacturer can perform a transaction by manufacturing a product. A distributor can perform a transaction by distributing a product to another distributor, while a retailer can perform a transaction on a product by selling the product to a consumer.

EPMCS requires a unique, authenticable[9] and non-repudiatable[10] ID for each market handler. The uniqueness of the market handler ID guarantees that EPMCS can determine the identity of the market handler during the accountability tracing. The authentic-ability enables the repository determine the identity who sends the product transaction message to the repository, no matter who it claims to be. This prevents a fake messages being sent to the repository to mix up the product accountability

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[9] Authentic-ability means that the market handler ID can be authenticated by public, no mater the market handler says who it is.

[10] Non-repudiatability means that any messages sent by the market handler cannot be denied by the market handler.

tracing. The non-repudiation of a market handler ensures that the market handler cannot deny its messages once the market handler reports a transaction message to the repository. This guarantees that EPMCS accountability tracing is accurate and reliable. That is, EPMCS ensures that a transaction done and messages sent by a market handler is authentic (others cannot be credited for this action), and the market handler cannot repudiate for what it has done.

3.3.3 Product Transaction Event (PE)

In order to trace the product movements in the market, EPMCS considers only all transactions that alters the product flow in the market. There are three types of such transactions. They are (1) "*being-manufactured*", (2) "*being-sold-to*", and (3) "*being-sold-to-a-consumer*". As a transaction is performed, the product will move to a new direction in the market and transition from the current state to a new state in the life cycle of the product (see Table 3-1).

Table 3-1. Product Transaction and Product Market Movement

Transaction	Life Cycle State		Possession By	
	Current State	New State	Initiator	Receiver
being-manufactured	unborn	enter-market	manufacturer	manufacturer
being-sold-to	in-market	in-market	distributor or manufacturer	distributor or retailer
being-sold-to-consumer	in-market	out-market	retailer	consumer

The new states include (1) the product entrance to market or the start of product life cycle, (2) the product being active in market or the in-market state of the product life cycle), and (3) the product exit from the market or the end of the product life cycle. If EPMCS can capture all the transactions applied to a product in that sequence, the sequence of the transaction can then define the product life cycle in the market. With the life cycle data, EPMCS can trace the product movements in the market and determine the responsibility of market handlers for the product handling.

Each product transaction is involved with two market handlers. One market handler is the initiator of the transaction, another is the receiver of the transaction. The transaction initiator is in possession of the product prior to the transaction, and the transaction receiver is in possession of the product after the transaction. For example, the manufacturer is the initiator of the transaction of *being-manufactured*, while it is also the receiver of the transaction since the product is still in the possession of the manufacturer. In a *being-sold-to* transaction, a market handler sells the product to another market handler. The seller is the initiator of the transaction, while the buyer is the receiver of the transaction. As a result of a transaction, the product moves from the current state to a new state in the product life cycle.

EPMCS uses a transaction event to describe a transaction applied on the product. In this dissertation, the transaction event and the product event are used interexchangeably. EPMCS requires that the market handler that initiates a transaction on a product must report a transaction event to the EPMCS repository server. The event must contain four essential pieces of data, including the transaction type， product ID， the transaction initiator and the transaction receiver. Input of other relevant information about this transaction are optional.

Table 3-2 describes the format of an EPMCS event. An event contains an event header and an event data body. The event header has four required fields. For any product event, there are three types of EPMCS transaction events. The event type represents the transaction applied and the resulting state that the product is in. Head event represents the *being-manufactured* transaction, corresponding to the start of its life cycle. Head event is always the first event in the event sequence of product. Tail event represents the transaction of *being-sold-to-a-consumer* and the product state corresponds to the end of its life cycle, because the instance is removed from the market circulation. The tail event is always the ending event for any product instance. The in-market event represents the transaction of *being-sold-to,* corresponding to the state of alive in the product cycle and still in market. It implies that a product from the inventory of the transaction initiator to that of the transaction receiver.

Table 3-2　EPMCS Event Format

Event Data Format				
Event Header Format				Event Data Body
Event Type	EPMCS PID	EPMC Source MID	EPMCS Destination MID	Associated Event Data

EPMCS PID field specifies the product instance involved in the transaction or event. The source MID specifies the market handler who initiates the transaction, while the destination MID specifies the receiver of the transaction. The transaction results in the movement of product inventory from the source market handler to the destination market handler. The event data body contains the transaction specific data.

3.3.4 Product Event Chain

Any two consecutive transactions on a product corresponds to two consecutive transaction events. The destination market handler in the first event is actually the source market handler in the second event. The same market handler is involved in the first transaction as its receiver and in the second transaction as the initiator. That is, any two consecutive events are chained into a two event sequence with the receiver in the first transaction as the initiator in the second transaction. Therefore, all events of a product in its market life can be chained into an event chain that corresponds to the sequence of product transactions applied to the product. A life cycle of a product in the market is defined as the process of the product movements, driven by a series of transactions, from its birth toward its end in the market.

Clearly, this event chain describes the life cycle of the product in the market. The first event is a head event, indicating its start of its market life, as the result of a *being-manufactured* transaction. The second event is an in-market event as the product moves from the manufacturer to a distributor, as the result of a *being-sold-to* transaction, and so on. Finally, the product ends its market life when it gets sold to a consumer, resulting in the *being-sold-to-consumer* transaction. If the last event in an event chain is an in-market event, the product is then still active in the market and the product is in possession by the destination market handler in the last event. Clearly, an event chain of a product represents the life cycle of the product in market. In this dissertation, a event chain is known as the a product life cycle and vice versa. Using the event chain of a product, EPMCS can trace the product flow in the market and the responsibility of the culprits for a problematic product.

Table 3-3 describes the event chain of a product or its life cycle in the market. The first row represents the head event for the product 110134357809. It is manufactured by the market handler AZDELL0293 and is possessed by the manufacturer AZDELL0293. When manufacturer AZDELL0293 sells the product to distributor XFFX430HL3, an in-market event is inserted in the event chain as the second event, and the market handler is in possession of the product. The product moves its life from its birth to being in the market. Retailer ERMKL45671 sells the product to a consumer and generates a tail event. In this instance, the product ends its life and moves out of the market. Table 3-3 describes a life cycle or the event chain of product 110134357809.

Table 3-3 EPMCS Event Examples

Event Type	EPMCS PID	Source EPMC MID	Destination EPMCS MID	Associated Event Data
Head event	110134357809	AZDELL0293	AZDELL0293	Manufacturer AZDELL0293 Location, Time product specs
In-Market	110134357809	AZDELL0293	XFFX430HL3	Manufacturer AZDELL0293 Location, Time Sold to XFFX430HL3
In-Market	110134357809	XFFX430HL3	ERMKL45671	distributor name Location, Time Sold to ERMKL45671
In-Market	110134357809	ERMKL45671	ERMKL45671	Retailer ERMKL45671 Location, Time Sold=to ERMKL45671
Tail event	110134357809	ERMKL45671	ERMKL45671	Retailer ERMKL45671 Location, Time Sold to consumer

An event chain of a product mirrors the life cycle of the product in the market. It accurately describes how a product is made, moved via a series of intermediate distributors, sold finally to a consumer, and purged from the market. Caused by a series of transactions, the process of the product movements from its birth toward its end in the market is called the life cycle of the product in the market.

The event chain or life cycle of a product in Figure 3-1 depicts how the product is moved from one market handler to another through a series of transactions.With this event chain, the product journey in the market can be determined and the responsibility of the related market handlers can be traced and identified. In addition, the possession of the product can be identified and associated inventory can be calculated to support product recalls.

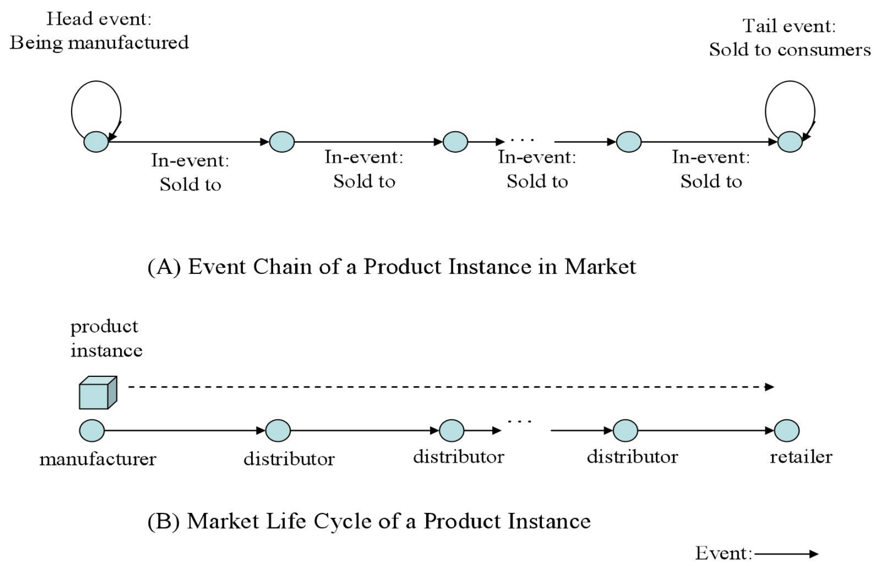

Figure 3-1. Event Chain and Life Cycle

Interestingly, an event chain can be treated as a direct graph[11] mathematically. A vertex is the market handler that initiates a market transaction on a product instance,

[11] A direct graph consists of vertices which are connected by arrow edges. The arrow edges are directed from one vertex to another ("Direct Graph",2017).

while another vertex is the destination market handler of the transaction. The event of the transaction is the arrow edge that connects the two vertices (Figure 3-1 (A)). The head event is the start vertex of the event chain, while the tail event is the end vertex of the event chain. Tracing an event chain is simply translated to visiting vertices of a direct graph, starting from the head event.

3.3.5 Event Report Repository

The event report repository is a core element in EPMCS. During any transaction on a product, the market handler that initiates the transaction must report the product event to the repository. The event report repository then collects all of the product events about every products, constructs an event chain for each product and automatically creates the product ledges for each market handler. Using the event chain, EPMCS can recognize abnormality in product flows, and successfully identify the problematic products by relying solely on the internal EPMCS data and without any product labels. EPMCS design can meet its objective to trace the product flow and responsibility of market handlers based only on the event chain data rather than the product ledges maintained by market handlers. The EPMCS event report repository can calculate the above operations electronically and efficiently.

EPMCS event report repository does not create and store the product ledges directly inside the system. Instead, the ledges are dynamically generated on the fly using the event chain data., when necessary. EPMCS enables that product and responsibility tracing do not rely on the individual offline ledges owned by market handlers. There are three ledges that the EPMCS can calculate. The first ledge is the product flow. The second is the product inventory possessed by a particular market handler, the third is the inventory distribution of a product on the market. Those three ledges assist market managers to determine the inventory distribution of the problematic product so that an effective product recall can be executed effectively and accurately. core element is the national centralized repository employed by EPMCS for reporting, storing and querying of the event data of the product instance in the market..

3.3.6 EPMCS Services

There are six online services supported by EPMCS :

1. Market handler registration: each market handler must be verified and assigned with a valid market handler ID (MID).
2. Product ID allocation: every manufacturer must apply for a block of product IDs prior to the production of the products. The manufacturer will use the allocated product IDs for the products it makes.
3. Query to find out if a product is genuine: a consumer can scan the product label to extract the product ID and use the product ID to query the EPMCS system for determining the genuineness of a product.
4. Problematic product report: a user can report the problematic product when he finds the problem.
5. Product flow and responsibility tracing: a user can determine where the problematic product goes and the accountability can be traced and determined.

6. Inventory distribution determination: a user can determine where the problematic product is located. Once a product recall is decided, the recall can be done accurately and effectively.

3.3.7 EPMCS Operation Process

Figure 3-2 depicts the process of EPMCS. Each product is assigned with an product PID, printed on the product package. Each market handler is assigned with a unique market handler MID. When manufacturer MID_1 produces a product, it scans the PID on the newly made product and reports a head event to the event report repository. EPMCS activates the PID for the product and creates an event chain for the product. There is one head event in the event chain. The head event indicates the birth of the product in the market.

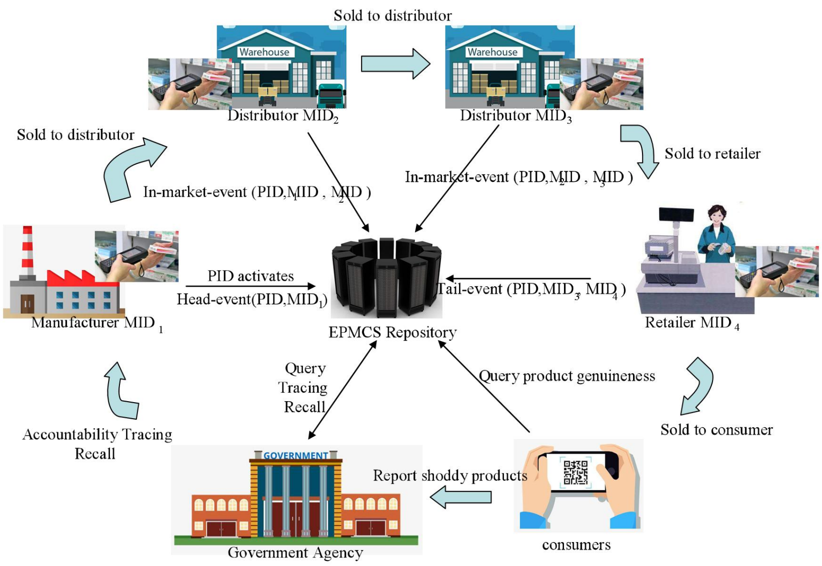

Figure 3-2. EPMCS Process Flow

When the distributor MID_2 buys the product instance from the manufacturer MID_1, the manufacturer MID_1 scans the PID on the shipment of the product to MID_2 and reports an in-market event to the EPMCS repository. The product possession is changed from MID_1 to MID_2. When distributor MID_2 sells the product to distributor MID_3, it scans the PID on the shipment of the product, reports an in-market event to the EPMCS repository, and the product possession is then passed to MID_3. Eventually the retailer MID_4 scans the PID on the product selling to a consumer, and reports a tail-event to the EPMCS repository (the product is sold to a consumer). In this manner, the life cycle of the product instance PID is captured by EPMCS.

A consumer can query easily the EPMCS repository for identifying whether a product is genuine or not, based on the event chain data inside EPMCS system.For example, a product with no PID or redundant PIDs or no head events (the product instance is introduced by a non-manufacturer) are counterfeit or shoddy product. Furthermore, this chain of events can be used by government agencies to trace the accountability for problematic products and execute product recalls. For example, the government can easily obtain the unsold product location and the associated inventories by summing up the quantity of those unsold product instances with their life cycles ended in an in-market event.

3.4 Design Improvements

The EPMCS model has four important improvements over the traditional solutions. First, the EPMCS reconnects the fragmented process of product monitoring and controlling into a seamless process with modern information technology. Second, the EPMCS does not rely on consumer knowledge and skill to recognize problematic products. Identification of the problematic products is solely based on the event chain or product life cycle data inside EPMCS. Third, accountability tracing does not rely on the individual offline product ledges at the market handlers. All product ledges are automatically created and maintained in EPMCS electronically, so that the job can be performed effectively and accurately. Fourth, EPMCS can calculate the inventory distribution of the problematic products so that the product recall can be executed effectively.

3.5 Comparison between EPMCS Blockchain

In recent years, the blockchain–based solutions in building decentralized system that supports transparent, unalterable and distributive ledges became popular ("Blockchains: The great chain of being sure about things", 2016; Morris, 2016). A blockchain is a distributive ledge with a growing list of records or blocks which are linked using cryptography. This distributive and public ledge is maintained without a centralized authority. Based on a constitution of rules, the independent block chain servers can form a consensus that can be trusted.

Interesting enough, our EPMCS proposes and employs techniques that are similar to those used in blockchain technologies. Table 3-4 makes a comparison between our EPMCS and a blockchain.There are two major commonalities for our EPMCS and blockchain. First, the data structure used are both chained data blocks. In EPMCS, an event is data blocks chained by the market handler ID between two consecutive transactions, while a blockchain is data blocks chained by a hash code between two consecutive hash codes. Second, EPMCS uses a public key-based cryptography approach to authenticate the data manipulator (market handler) with a non-repudiation feature. A blockchain also uses a public key-based cryptography technique to authenticate the data manipulator with a property of non-repudiation.

Table 3-4. Comparison between EPMCS and Blockchain

	EPMCS	Blockchain
Similarity	Event chain is a chained data block with market handler ID	A chained data block with a hash code
	Public key cryptography for data manipulator(market handler) authentication, non-repudiation	Public key cryptography for data manipulator authentication and non-repudiation
Difference	Central authority for data keeping	Distributed data keeping
	Trust needed to the authority	Trust by consensus
	Private data, query results only	Data public
	Participation of every market handlers is mandatory	Participation is optional

There are four differences between EPMCS and a block chain. First, EPMCS employs a central authority to control the data inside EPMCS, while a block chain has no central authority and data is controlled by independently operated block chain server. Second, the trust is relied on the EPMCS system, while the trust is formed through a consensus among block chain servers. Third, the data is private to EPMCS. The public can only get the results of their queries, while the data in a block chain is open to public. This transparency of data can also deter the illegitimate operators. Fourth, EPMCS requires that every market handlers must participate in the EPMCS, while a block chain does not require that everyone must to participate. This implies that a block chain implementation must also append the block chain with additional set of rules that forces the participation of every ones. For EPMCS, when there is one market handler who does not follow the EPMCS rules to participate, there will be missing events generated in EPMCS. The product flow will then break and the tracing would fail.

In Chapter 5, the block chain implementation is discussed for the EPMCS event report repository in further details.

Chapter 4 Evaluation of EPMCS Design

In Chapter 3, the EPMCS model is presented and described in detail. In this chapter, the EPMCS model is analyzed and evaluated. The details of the analysis and evaluation are presented in Appendix A for interested partners.

4.1 Analysis Objectives and Strategy

4.1.1 Analysis Objectives

Three objectives are set in this analytical research. First, the core elements of EPMCS is identified to defines the boundary for the EPMCS model. Second, what rules the EPMCS must follow to work correctly is determined. Third, I want to show that the EPMCS is both complete and effective in terms of the EPMCS functionality.

4.1.2 Analysis Strategy

This research analysis employs a strategy of divide and conquer. That is, a complicated problem is divided into two relatively simple but small problems, and the small problems then are analyzed separately. The original EPMCS system is divided into an invariant part and a variant part. This invariant part describes the core elements and essential rules that any EPMCS systems must have. This invariant part is called the abstract model of EPMCS. This abstract model defines the essences of any EPMCS systems. Furthermore, the abstract model is analyzed and evaluated whether the abstract model can support monitoring and controlling products completely and effectively in the market. Any conclusions drawn from the abstract model should hold for any system that meets the requirements of the abstract model. In this way, the repeated analysis and evaluation are eliminated when building a new EPMCS system.

The variant part of the EPMCS model is involved in the parameters and their choices, and the trade-offs made when implementing the abstract EPMCS model. This variant part is called the implementation model of the EPMCS in this research. The discussion and evaluation of the implementation model of EPMCS will be described in Chapter 5.

4.2 Abstract Design of EPMCS

According to the EPMCS design described in Chapter 3, there are six essential elements of the EPMCS model. They are the product, product ID, market handler, event, event chain and the event report repository server. In addition, there are eight key rules that must be met in an EPMCS. Next, the essential rules of the abstract model are discussed in the form of eight assumptions.

The six core elements and eight essential rules make up the abstract model of EPMCS. Taking no account of individual implementation details, this abstract model gives the requirements that any concrete EPMCS system would need in order to pass as an EPMCS system. Any system that fails to conform to the abstract model would fail to monitor and control products in the market. For instance, CFDA relaxes the mandatory requirement for market handlers to report product events to the repository server, under the pressure from heavy special interest groups such as retail store chain of drugs in 2016 (Gu Ziming, 2016). For instance, the faked aspirin scandal in which 21 provinces were involved broke out in 2019 (2019). The culprits bought the batch of real EPMCS ids from legit manufacturer and disguise the faked aspirins as a legitimate drug, going into market undetected, because event reporting is not required when the manufacturer and its employee sells legit EPMCS ids to the culprits. This scandal indicates that the requirements of the abstract EPMCS model is fundamental. If the requirements are violated, the EPMCS will not function correctly.

4.2.1 Product Instance

The abstract model states that the following eight rules must be satisfied for every products covered in EPMCS.

Rule 4-1: *One transaction can only be initiated to a product instance by only one market handler with a valid market handler ID at one time.*

This rule indicates that a valid market handler can execute one transaction at a time on one product instance. Multiple market handlers cannot transact on the same product instance at the same time.

Rule 4-2: *Each product instance is an atomic unit that cannot be further broken into smaller pieces in the market circulation.*

This rule requires that a valid product instance must be whole and cannot be distributed in smaller packages in its market life. This guarantees that a product instance cannot be sold to different market handlers in one transaction. That is, it assures that no market handler can sell the same instance of a product to different market handlers at the same time. This implies that a transaction performed on a product instance by a market handler cannot generate and report more than one event. This avoids the fork of two events by the same transaction on a product to different market handlers for the same instance of product.

4.2.2 Product Instance ID

This rule specifies the requirement for the product ID.

Rule 4-3: *Each product instance has a unique ID to distinguish itself from any other instances of products.*

This rule states that every product must have a unique ID in EPMCS. This implies that any product instance will only have one and only instance ID. No identical ID can be assigned to two different instances of a product. No instance of a product can have more than one EPMCS ID. When the product instance is produced by a manufacturer, the manufacturer is required to report the head event to the event report repository, and the repository would then verify and activate the product ID in EPMCS. That is, the product made without reporting the event to the repository will not have a valid product ID in EPMCS.

4.2.3 Market Handler ID

Rule 4-4: *Each market handler has a unique ID (MID) to distinguish it from any other market handlers. The sender of any events reported to the EPMCS repository can be authenticated by public and its act cannot be repudiated by the market handler.*

By this rule, all market handlers must follow three rules. First, any market handler would have one and only unique identity ID. There are no other market handler with the same ID. This rule also disallow a market handler who has multiple market handler IDs. This rule ensures that the accountability of the problematic products can be determined accurately. Second, the event report repository can authenticate the sender of an event received. No one can forge an event using the identities of the others. This rule guarantees the faked events sent to the repository can be detected to avoid confusion in the accountability tracing. Third, a market handler cannot deny any events signed with its market handler ID. This rule prevents that the culprits of the problematic products from refusing the result of the accountability tracing. This rule also requires the market handler to be responsible and guarantees that the accountability tracing is creditable.

4.2.4 Event Report Repository

Rule 4-5: *The event report repository must create and maintain a valid event chain for each product instance, when it receives an event from a market handler.*

This rule specifies that all market events must be reported , stored, as well as maintained in the EPMCS repository. With this rule, the EPMCS can construct event chains or aggregate the distributive ledges of product for the market based on the data stored in the EPMCS server. The efficiency in EMPCS will be increased with the help of modern information technology.

4.2.5 Market Event Report Operations

Rule 4-6: *Any event must be reported by the transaction initiator to the event report repository.*

This rule makes it mandatory that any market handler that initiates a transaction on a product is required to report the transaction event to the EPMCS event report repository. This ensures that there are no missing events or transactions in the EPMCS.

EPMCS will capture all events or all transactions of any product.

Rule 4-7: *Any event reporting must be an atomic operation.*

This rule demands the atomicity of event report operations, so that no market handler can send a partial events to the repository. This also implies that the events received by the repository will be in the sequence of event sent or transaction performed. In this manner, the integrity and completeness of event chains can be guaranteed.

Rule 4-8: *Any transaction on a product instance is described by an event in the event chain for the product instance. .*

This rule requires that any event in the event chain of a product to correspond to a transaction applied on the product. It also implies that an event is enough to describe a corresponding transaction.

4.3 Evaluation of Abstract EPMCS Design

According to the criteria described in section 2.2.5, the completeness and effectiveness of the abstract model of EPMCS is evaluated. Any results based on the evaluation of the abstract model will be applicable to other system that meet the requirements of the abstract model.

4.3.1 EPMCS Completeness

The completeness evaluation of the abstract model consists of three concrete criteria. First, all valid products should be covered by the abstract model. There should be no product that is not under the coverage of the abstract model. Second, the abstract model must capture all of the data related to product movements in market, and the abstract model should support all functions needed for monitoring and controlling products in the market. Third, the abstract model should cover not only the whole market but also the entire life cycle of products.

The abstract model obviously meets the first criteria of the completeness. Rule 4-3 states that the product is under coverage of the abstract model, because every products are required to a unique product ID and the ID is reported to and activated by the repository. Therefore, only if the product event chain has shown its complete, will it be shown that the abstract model satisfies the second and third criteria, because the product event chain captures the complete life cycle of the product. In Appendix A, it has been shown that there is one and only event chain for each product instance and the structure of an event chain is complete as it has only one head and one last event, and there is no cracks inside the event chain. Thus, it has been shown that the abstract model of EPMCS is complete.

4.3.2 EPMCS Effectiveness

There are three criteria to evaluate the abstract model of EPMCS to be effective (section 2.2.5). First, the abstract model must have the ability to allow users to recognize whether a product is problematic or not. Second, the abstract model must be able to trace the product movements in market and determine the responsibility of the culprits for the problematic products. Third, the abstract model can determine the inventory distribution of the problematic products and facilitate market intervention such as product recall from the market. In appendix A, the abstract EPMCS model has been evaluated for its effectiveness based on the above three criteria. It has been shown that the abstract model presents four algorithms to calculate the necessary EPMCS operations based only on event chains inside the EPMCS repository. Identifying problematic products can be calculated based on event chain data (see theorem A-2 in Appendix A). The accountability tracing can be performed on the data of event chains (see theorem A-3 in Appendix A). The inventory distribution of the problematic products in the market can be calculated by the algorithm described in theorem A-6 in Appendix A. The product recall operation is determined and executed as prescribed by theorem A-8 in Appendix A. Therefore, it has been shown that the abstract model of EPMCS is effective for product monitoring and controlling management.

4.4. Conclusions

In this chapter, the EPMCS model has been decomposed into an abstract model and an implementation model. The abstract model is used to specify the core elements and essential rules required for an EPMCS model, as well as to defines the essence and boundaries of the EPMCS model. At the same time, the abstract model is evaluated according to the criteria of completeness and effectiveness.

There are two conclusions drawn in this chapter. First, the abstract EPMCS model requires six core elements and eight rules to perform correctly. This abstract model specifies what the core elements any EPMCS must have and what the rules must be observed in order to work correctly. Second, the abstract model is complete and effective with respect to the functionality of product monitoring and controlling. It implies that all products are covered by the abstract model, and all of the data required to support the EPMCS functionality are owned by the abstract model. The identification of the problematic products by consumers and accountability tracing are also effective and accurate. Any system that meets all of the requirements of this abstract model is also complete and effective.

Chapter 5 EPMCS Implementation

The original EPMCS implantation was built in 2005 and it continued to improve for more than 15 year (Chen Xiaoying, 2010). In this research, the original EPMCS is divided into two partitions. This provides a clear division of the invariant model issues and the variant implementation considerations. In the previous chapter, the invariant partition of the EPMCS labeled as the abstract EPMCS model is analyzed. With this abstract model, the required elements and rules are described for any EPMCS system and they set the boundary of the abstract model. Furthermore, it has been showed that the abstract model is a complete and effective solution for product monitoring and controlling.

In this chapter, the issues is considered related to the variant partition of the EPMCS. This partition mainly deals with the issues related to individual EPMCS implementations and adoptions. this variant partition is called an implementation EPMCS model. In this chapter, this implementation model is used as the vehicle for my analysis. In the implementation model, I want to identify the implementation parameters, determine their choice ranges and make trade-offs to balance the cost and performance. In addition, the useful practices and experience gained in the adoption of EPMCS in drug industry will be discussed.

5.1 Trade-off between Cost and System Requirements

During an implementation of EPMCS, the trade-off between cost/time and system requirements must be considered and adjusted to adapt to the application environment. One should not demand absolute compliance with the model requirement, without considering potentially overburdening cost.

The EPMCS requires a unique id for product and market handler. It is well-known that any finite length of id field limits the accuracy of the uniqueness of *EPMCS* ids such as *pid* and *mid*. In theory, the requirement of unique id can be satisfied with a unlimited ID length to ensure no repeats in product ID. However, the unlimited length ID will increase the process cost and overwhelm system performance. The longer the id, the more time it will need to process the id, which will incur more costs. On the contrary, the probability of a repeated product ID will increase if a short and limited length product ID is selected. In reality, a proper length for the product ID needs to be selected properly. A trade-off must be made between the cost and the requirement compliance. The balance should be made that the product ID length is long enough to have the probability of repeated ID under control. In the following sections, the trade-off between the system requirements and process cost from making the implementation decisions on parameter range selection will be analyzed.

5.2 External EPMCS Compliance Environment

5.2.1 Concept

An EPMCS system must comply with the eight rules required in the abstract

EPMCS model, otherwise, the EPMCS system is neither complete nor effective. Except the rule of event chain maintenance by the repository, the EPMCS rules are the requirements for products and market handlers. The event process rule is under the control of the system developers. However, the compliance of the rest seven rules are in the hands of market handlers. There must be a compliance requirement for market handlers to make the EPMCS work. Even if the EPMCS system can be built perfectly to meet the requirements of the abstract model, some market handlers would disobey the EPMCS rules (e.g., no reporting transaction events to the repository). If a market handler did not participate in EPMCS or follow the EPMCS rules, the EPMCS system would fail. The holes and erroneous results are produced, even if the EPMCS implementation is perfectly constructed. In order to force market handlers to comply with the EPMCS rules, there must be an external environment to mandate the compliance of the EPMCS rules. This environment is said the external compliance environment. The compliance environment is used to state the mandatory requirement for the market handlers. That is, the external compliance environment specifies the mandatory level that enforces all market participants to compile with the EPMCS rules during their activities.

Figure 5-1 describes the external compliance environment and its relationship with the EPMCS software system. Both the compliance environment and the EPMCS implementation are crucial for a complete and successful EPMCS system. The external compliance environment is represented in an area of lightly gray region and it exists independently outside the EPMCS system. It provides the compliance requirement for the external environment of the system. The EPMCS system implementation is depicted in the dark shaded area. The compliance with the EPMCS rules inside an EPMCS implementation is done by the system developers. The system developers must ensure that the EPMCS compliance within their implementation. The abstract model provides the criteria for the system compliance with the EPMCS requirements.

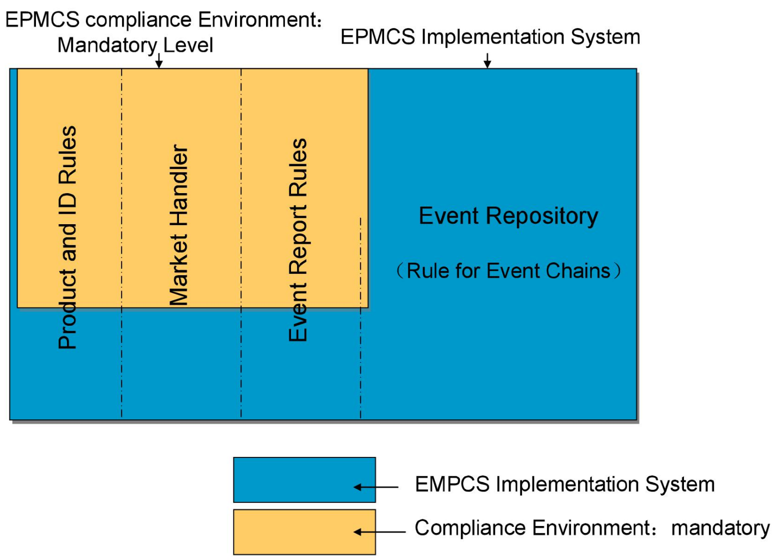

Figure 5-1. EMPCS Compliance Environment & EPMCS System

If a product is not assigned with a unique product ID, the EPMCS model cannot monitor the product flow and thus be identified as a problematic product. If a market handler does not report a transaction event to the repository, the event chain is then broken by missing events, so that the EPMCS will fail in tracing the product flow and responsibility of the culprits. Thus, it is clear that mandatorily satisfaction of the EPMCS essential rues required is the key factor of success for the EPMCS adoption. Not only that the EPMCS system builders need to understand this compliance issue, but also the EPMCS system promoters and adopters must ensure these EPMCS rules to be met and understand clearly the impact of a break down in the external compliance environment.

5.2.2 Mandatory Levels in External Compliance Environment

In the EPMCS compliance environment, the mandatory level decides the strength of compliance requirement. In practice, this mandatory level can be selected, although the EPMCS rules must be satisfied. There are four choices of the mandatory levels. Table 5-1 compares the four choices of the mandatory level. The mandatory strength imposed by the government is the strongest among the four.

The government can mandate universally that every products and market handlers in the market must meet the EPMCS requirements, because the government can make laws and regulations through legislation to make the EPMCS compliance mandatory. All products must be assigned with an EPMCS PID, while all market handlers must own an EMPCS MID. All transactions on a product must be reported to the repository server by involving market handlers. The government can guarantee the EPMCS to cover all products and all market handlers. Any product not covered by the EPMCS is declared as a counterfeit and shoddy product. Any market handler outside the coverage of the EPMCS is considered an invalid market handler and marked as the culprits of counterfeits.

Table 5-1. Mandatory Level in an External EPMCS Compliance Environment

Choice	**Mandatory strength**	Enforcer	**Coverage**	**Effective**	**Adoption difficulty**	Operation cost
1	excellent	government	best	highest	hardest	lowest

2	good	alliance	good	high	hard	low
3	above good	dominant enterprise	better	high	easy	high
4	poor	general enterprise	poor	poor	hard	high

The government mandate would guarantee full coverage of all product instances and all market handlers. All products with valid *pid* are legit and are allowed to the market circulation. All products without a valid *pid* are illegal products and are not allowed to enter into market. All market handlers without a proper mid are illegal handlers and are not allowed into market. The operation cost is the lowest because one EPMCS system can be used for all market handlers in all industries. No one needs to build its own system.

However, adopting an EPMCS system is extremely hard and takes a long time due to fierce resistances from market handlers and encounters with government agencies. The market handlers are worried about tax implication and associated operating cost in event reporting, while the government is afraid of being accused as the monopoly from the public. This actually happened in 2007, when the Chinese government was about to amend the product quality law to make EMPCS mandatory for all products and market handlers in the market. A lobby coalition of special interest groups shot down the legislation under the name of monopoly of EPMCS. After a series of public crises of counterfeit and shoddy products, the EPMCS was finally adopted mandatorily in the drug industry in 2010. It asn't until 2018 that the government included the EPMCS compliance into the product quality law.

At an industry level, the dominant players in an industry can form a coalition and establish "de facto" industry EPMCS mandate for the industry. For example, the Chinese dominant e-commerce company, Alibaba, often faced charges from the government and media that its platform is filled with counterfeit and shoddy products. Alibaba adopted our EPMCS system for the stores doing business on the its Taobao and TMall platforms. As Alibaba grew into a global e-commerce giant, our EPMCS system also expanded into more than 10 countries. The mandate strength and coverage by the industry coalition are weaker than that of the government, because there are still unlawful enterprises that disobey the EPMCS rules. The stronger control by the coalition, the stronger the EPMCS mandates.

At the level of an individual enterprise, the enterprise, such as a major brand operator or manufacture, can use its dominant position to mandate all of its distributors and retailers to comply with the EPMCS rules. Although the coverage of its products can reach to almost 100%, there are still many holes in the because the distributors can ignore the event reporting requirement on purpose to sell counterfeit products among genuine ones outside its channel. In addition, the investment in the EPMCS system is still a burden for the individual enterprise to shoulder on. For example, Maotai counterfeits resulted in serious damage to the brand reputation of Maitai products and company. Maotai utilized its monopoly position to require that all of its distributors and retailers must participate in the EPMCS. It also invested hundreds of millions RMB to build and operate its system. At this level of mandate, one company can solve the problem of counterfeit for its products.

However, the enterprise is in a weak position to mandate an EPMCS, when an individual enterprise has major competitors with plentiful substitute products. The coverage of its products and the effectiveness of the system are poor, because there are many market handlers operating outside the system. In addition, there is no one to share the cost of building and operating the system. This is the reason why few enterprises utilize its own system to combat counterfeit and shoddy products.

Note that there is no need to build and operate private system for anyone who wants to fight counterfeit products. Our EPMCS system is a third-party built and operated system. Any industry or individual enterprises wanting to use EPMCS can do so directly without any system investment. However, the external compliance environment has to be installed by these enterprises to ensure the compliance of the EPMCS rules.

5.3 EPMCS Implementation Parameters

The EPMCS implementation model consists of four implementation parameters and their ranges of choices. In the following, these four parameters and their choices will be discussed in details.

5.3.1 Product Instance Determination

The product instance ID or *pid* is printed on its package as the smallest atomic unit of manufacturing and distributing. There is a balance of cost and operation convenience in deciding what is a product instance. If the product package is selected as the smallest unbroken instance of the product, this may generate too much cost associated with too many product labels and scanning needs for EPMCS. For example, there are six pencils in a package of six pencils. If an individual pencil is selected as a product instance, it will require six different labels for the package and each pencil would have a label printed on it. The number of labels and scanning required to process these instances would be excessive and unnecessary. If a box of 24 packages of 6 pencils is treated as an instance of the product, there is only one label will be needed for the box of pencils, and the cost of labels and scanning is rather low. However, the market handling of the box will be difficult since the box has to be distributed and sold as a whole, which is almost impossible. Therefore, the selection of product instance must be a balance between cost and the efficiency of the market operation. The smallest unbroken package, which is typically sold in market as a whole should be picked as the right choice for a product instance.

5.3.2 Product ID Implementation of EPMCS

In implementing an EPMCS, the product instance ID (*pid*) needs to be printed on the package of the product instance and scanned by market handlers to report to the EPMCS repository. When deciding a product ID or *pid* , there are two parameters to be considered. The first is the representation of a *pid*, and the second is the length of *pid*.

The representation of a product ID is either RFID (Bureau，2014), QR code (“QR code features”，2013), or the traditional bar codes (“Barcode”，2018). As technologies advance in future, more choices of the representation of the product ID will emerge. RFID is a radio frequency ID) and is implemented as a silicon chip (Bureau，2014). A

RFID chip is embedded in every product. A special reader device is near the RFID chip and the chip emits the radio waves that carries the information stored in the chip (e.g., the product ID). The RFID reader then extracts the product ID from the radio wave. Compared with other alternatives, the cost of using RFIP is high because every product must carry a high cost chip and every market handler in the market needs to equip a special hardware reader. The application of RFID is restricted by its cost.

The QR Code (QRC) (“QR code features”, 2013) uses a two dimensional scheme to encode product information. QRC is printed on a product so that the encoded information can be extracted by scanning the product label. Today, the smart phones are widely accessible and everyone owns one. Small phones have become the most used QRC scanners, and thus, the cost of using QRC is almost none. The QRC is capable of encoding a large amount of data and can accommodate long stream IDs.

The traditional bar code (“Barcode”, 2018) provides the third representation of a product ID. Traditional bar code uses a group of vertical bars with different widths to encode the product information. Although the information encoded is limited, the scanners are already in place everywhere, so there is almost no investment needed for scanners. UPC (Weightman， 2015), GS1 (“GS1”, 2018) and NDC (“Barcode technology in healthcare”, 2018) are the classic bar codes. The bar code can be printed directly on the packaging of a product, there is almost no extra cost for using a bar-code based product label. The bar code has a limited length of data digits. For example, UPC has only 11 digits for product encoding. This fixed and limited length encoding increases the probability of recycled product IDs.

The second parameter related to the product ID is the length of the product ID. There is a trade-off relationship between the usage cost and system requirement compliance. The longer the product ID , the less likely a product ID will be recycled, the requirement of unique product ID will be complied, but this will be more costly. On the contrary, the shorter the product ID, the more likely a product ID will be recycled and unique requirement violated but this is less costly. For example, if the product ID is four digits long, the product ID will be recycled every 10,000 IDs. This will result in failure of the EPMCS product ID uniqueness. However, the cost to process a 4-digit product ID is very small.

Figure 5-2: EPMCS Bar Code for PID in Chinese Drug Market

15 years ago, the traditional bar code is selected for our EPMCS product ID for three reasons. First, the barcode scanners were already installed in the market everywhere, so the cost and investment to use a bar code is minimal. Second, there is no other low cost method available. QRC is very limited due to the lack of proper scanners. Third, the print cost of a product label is almost zero. Figure 5-2 presents an EPMCS product ID encoding. The product ID coding consists of 20 digits (“EPMCS Bar Code”, 2018). There are 8 digits allocated to each manufacturer for its product ID

with other digits for product type, industry sector, company and encryption against counterfeit *pid*. This 8 digit *pid* implies that the product ID will be recycled every 10^8 product IDs for every manufacturer. That is, there is one in one 100 million chance that a product instance is assigned to a duplicated *pid*. The number of 100 million is a rather huge number for the quantity of products produced by a manufacturer. The risk of being assigned with a duplicated *pid* is practically non-existent. The successful adoption of our EPMCS implementation in the Chinese drug industry has shown that the choice selected is appropriate.

5.3.3 Authentic and Non-Repudiatable Market Handler ID

There are three properties required by EPMCS for a market handler ID (mid). The first is the uniqueness of mid, which is mandatory for us to identify a market handler during the accountability tracing. The second is that the EPMCS repository can use the market handler ID to authenticate the identity of the market handler who sends,. This is to prevent faked events getting sent to the repository under the identity of others, so that the responsibility tracing can produce correct results and the integrity of event chains can be guaranteed. The third is that the market handler ID must support non-repudiatability. That is, any events generated and sent to the repository by a market handler cannot be denied by the market handler, because the market handler ID can prove that the market handler indeed sent this event. This property prevents any one from denying one's action and makes accountability trace reliable.

In order to realize the three properties of *mid*, a pair of private and public keys is adopted, based on the public-key cryptography (Paar & Pelzl, 2009) in our EPMCS implementation. Based on this cryptography, a pair of 64 digit long private and public keys were generated for each market handler, when it registered with the EPMCS. The market handler keeps the private key for itself. The 64-digit public key is used as the market handler ID, and is available to public. The recycle probability of the 64 digit ID is 10^{-64} which is practically zero. This guarantees the uniqueness of the market handler ID.

Anyone who wants to determine if an event is generated and sent by a particular market handler, one can simply decrypt the message with the public key (i.e. the market handler ID). This way, the repository can authenticate the identity of any market handler when it sends an event to the repository. In addition, the repository can use the successfully decrypted event as the proof that the particular market handler has sent the event. In this way, the non-repudiation of any event can be obtained in the EPMCS. Therefore, the public-key encryption based market handler ID satisfies the requirements of uniqueness, authentication and non-repudiation in our EPMCS implementation.

5.3.4 EPMCS Event Report Repository

EPMCS requires an EPMCS event repository to collect events and construct event chains for the products under the EPMCS coverage. Based on the event chains kept in the repository, the repository can trace the product movements (product ledges) and responsibility of the culprits, and it also supports the market interventions such as the product recall. Relying only on its internal data (event chain), the EPMCS can identify problematic products, trace the responsibility of the guilty partners, and intervene the market with product recalls. Therefore, the implementation of the EPMCS repository is the central piece to building a compliant EPMCS system. There are three realizations of building an EPMCS compliant repository: central server, a group of servers, and a block chain one. There are two considerations in evaluating different realizations. The first is the performance of transaction rate, since the repository deals with a high volume of real-time transactions. The second is the availability of the EPMCS services.

5.3.4.1 Centralized Server Implementation

The EPMCS repository can be implemented with a physical centralized server. All market handlers report all transactions to the central server and the server creates and maintains all of the event chains inside the EPMCS. The advantage of the central server is easy to implement because all events received are serialized to make no interventions between events. However, there are two shortcomings in the centralized implementation of the repository. First, the performance of the central server may get stuck due to heavy volume and burst rate of transactions. Its response time can be delayed to make the system unusable. Second, the central server is the single point of failure of the whole system. This will reduce the availability of service. However, the central server implementation is suitable for early prototype of the system, and the system is designed for an environment with moderate transaction rate. For example, the single physical server implementation of EPMCS repository can be used for an enterprise based EPMCS solution.

5.3.4.2 Distributed Logical Centralized Repository

The EPMCS repository server can be implemented by a group of high performance server. This group of server emulates a logical centralized server. This implementation combines the easy maintenance of data integrity by single server and the high performance by a group of distributed server. This implementation is also called the cloud implementation of EPMCS repository.

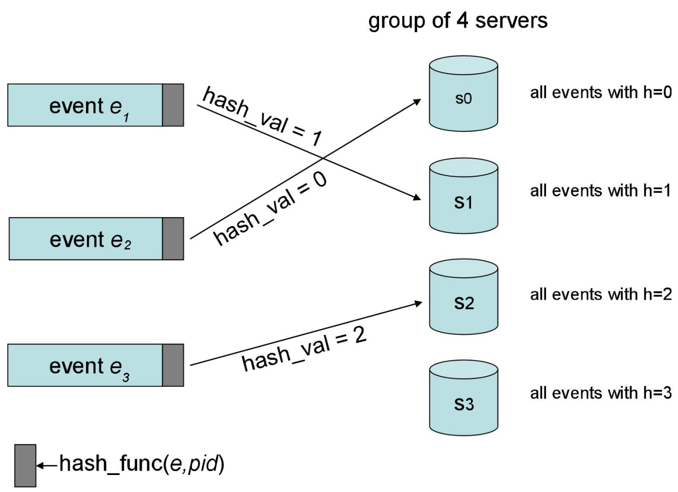

Figure 5-3. Logical Central Server Implementation

This cloud implementation of the logical central repository is possible because all events and event chain related to a particular product instance is independent of any events and event chains of other product instances. Therefore, the processing of a product can be put into one server if it can be guaranteed that all of its events will go to the same server, and the event chain of this product instance can be maintained in the same server. A hash function calculates a hash value for a product ID. The hash value has two properties. First, the hash value is always a fixed range of integers. In the example of Figure 5-3, the hash value is always 0, 1, 2, and 3. This implies that all products and their associated events are partitioned into four partitions. One server is assigned to one partition. Therefore, a group of four servers can be used to emulate the logic repository server. Second, the hash value for a product ID is always calculated to the same value. In Figure 5-2, a hash function is selected with a fixed range of 0-3. Then,a group of four servers can be selected for the event repository. For every transaction a market handler perform on a product, it calculates the hash function on the *pid* of the product and obtains a hash value of 2 for example. The market handler then can dispatch the transaction event to server 2. It is known that any event of product pid will be sent to the server 2 for reporting. This way, all events related to the product pid will always get sent to the same server 2 for processing and the event chain is also maintained in server 2.

It is clear that the transaction load is divided into a group of servers. The cloud implementation can support a high and bursting transaction workload. In addition, the failure of one server will not bring down the whole system. The system performance degrades without affecting the system available time of services.

Our EPMCS implementation for CFDA employs this cloud repository with a group of distributed servers. Our EPMCS system covers about 4500 manufacturers, near 20,000 distributors, 400,000 drugstores and 80,000 medical organizations. Our EPMCS repository can process more than 700,000 transaction per second and support the national drug monitoring and controlling within half seconds. In 2014, our implementation of EMPCS repository with the group of servers becomes the initial core of Alibaba Cloud company with a valuation of more than one trillion RMB today.

5.3.4.3 Block-chain based Repository

In recent years, the block chain–based solutions have become popular in building a decentralized, transparent, immutable and distributive ledge system ("Blockchains: The great chain of being sure about things"， 2015； Morris， 2016). A block chain is a distributive ledge with a growing list of records or blocks which are linked using cryptography. This distributive and public ledge is maintained independently by many block chain servers without a centralized authority. The trust of the system is done by reaching a consensus among individual block chain servers.

In section 3.5, our EPMCS model is compared with the block chain model. The commonality between the two, especially the structures used for event chain and for block chain, makes it possible for us to implement our EPMCS event repository with a block chain technology. In essence, the EPMCS repository constructs and maintains the event chain of a product. There is a perfect match between the EPMCS repository and a block chain, if a block chain is used to construct and maintain an event chain. Therefore, a block chain implementation of the EPMCS repository plus an external compliance environment will result in a blockchain-based EPMCS system.

In Figure 5-4, each data block consists of a previous hash code, time-stamp and document. In the EPMCS implementation, the document is an EPMCS event data. A hash function runs over the data block and produces the previous hash code for the next data block. The block is linked through the hash code into a sequence of block chain data. When a new event data arrives, the block chain servers can travel through the block data from the beginning to the end and calculate the event sequence. If the source *mid* in the event data matches the destination *mid* in the event in the last note, the new event data can form a new block and it gets added to the end block chain. This way, the event data in a block chain correctly produces a valid event chain for a product instance, and the blockchain data can be used to distribute event data ledge for the EPMCS purpose.

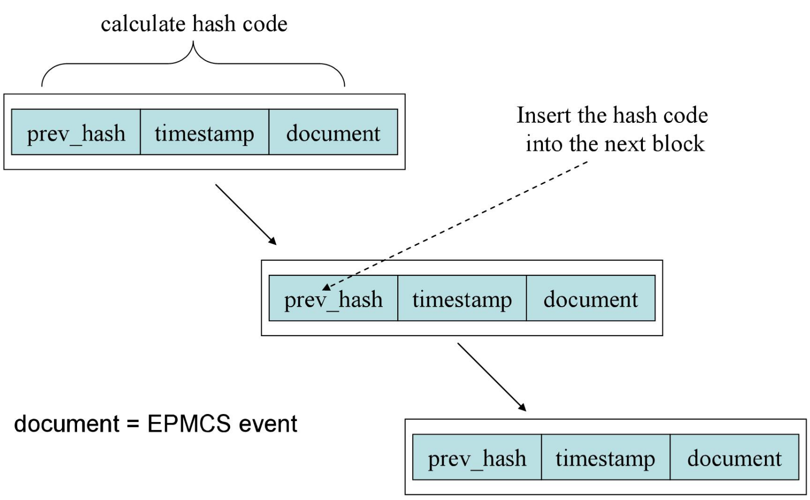

Figure 5-4. Event Chain as a Blockchain

The advantages of the block chain-based repository is that there is no central authority is required for the EPMCS system and this will remove the user suspicious toward the central authority, providing great transparency of data. The core elements and rules specified in the abstract EPMCS design can be described as the constitution of the blockchain repository. There are three different types of block chains: a public chain, alliance chain and a private chain. The public chain is a completely decentralized blockchain that is open to everyone. The private chain is a group of blockchain servers and is open to the owner of the blockchain, but not to public. A private chain is somewhat similar to the cloud implementation with a group of servers. The alliance chain is very similar to that of the private chain. It is open to the alliance but not to the public.

The EPMCS repository based on a public chain supports a transaction processing system that is the decentralized, transparent and public in nature. However, the performance of the block chain solution with current technology is rather limited. The time for a transaction can take as long as a few seconds for a moderate transaction load (Hampton & Nikolai, 2016). EPMCS system generates enormous amount of transactions and demands a fast response time. It seems that more needs to be done in order for the blockchain to become a viable EPMCS solution. However, the block chain solution should remain as an alternative solution as blockchain develops.

5.4 EPMCS Deployment Practice

Although the development of EPMCS is important, market adoption of the EMPCS system is much more critical and time consuming. A suitable external compliance environment must be created and accepted to make the EPMCS adoption successful. There are many overwhelming resistances from the key stakeholders, such as market handlers and the government. To overcome these resistances, we have to persevered for more than 15 years to find effective solutions to address any questions raised from market handlers and the government. Our experience and practices gained are described and hopefully they may be useful to the promoters of new EPMCS systems.

5.4.1 EPMCS Prototype Deployment

Because the EPMCS is so innovative and the boundaries existed, the government agencies found it difficult to see the benefits brought by the EPMCS system, and they often had doubts about the EPMCS. At the same time, the market handlers were worried about the tax threat, which would place a burden on them, and that EMPCS would demand extra work outside of their normal workload.

Therefore, it is crucial to build an EPMCS prototype environment to visualize the problem and solution. Many potential key stakeholders such as the government agencies and market handlers, never saw such a new method that was capable of solving such the complicated problems (many thought it was an impossible task). A prototype system provides an effective means for potential user to see and understand how EPMCS solve the difficult problem of counterfeit and shoddy goods.

In the early stage of EPMCS project, a sample small grocery store was built in which every items on the shelves were labeled with an EMPCS PID. The visitors were showed how the life cycle is captured in the EPMCS and can be used to track the market movements for any product in the shop. It also demonstrated how a consumer can use EPMCS to distinguish a genuine product from a problematic one. This EPMCS prototype enabled us to reduce the communication cost and time significantly. It helped users to accept the concept of EPMCS. It is found that the prototype is instrumental to win the support of the government and key market handlers.

5.4.2 Government Communications

In order to establish the external compliance environment, the support from the government should be obtained, so a mandate for the EPMCS rules to the market handlers can be enforced. Therefore, communication with the government accounted for a significant part of our efforts. There were many rounds of meetings with different departments and top leadership of the country. The government's concerns mainly include (1) monopoly of the sole centralized EPMCS repository scares the agencies and (2) doubts about the effectiveness of the EPMCS.

The monopoly issue is addressed by donating the EPMCS system to the government and making us as a third-party information technology provider. As for the doubts in EPMCS, successful cases in the market were patiently built and illustrated, so the potential users removed their doubts. At the beginning, CFDA adopted our EPMCS for the controlled drugs as a trial. Through monitoring and controlling the controlled drugs were done electronically instead of traditional paper ledges maintained manually by market handlers, the government was convinced that the EPMCS is more feasible and effective than any other traditional methods. In this project, persistence and endurance of our team was key to our success.

5.4.3 Market Participant Adoptions

The obstacles from the market participants are mainly in two areas. First, market participants think that they have to invest in printing new bar code and automatic scanners at product lines. Second, market participants are afraid of the tax burden. They are worried that the information collected by EPMCS will reveal the real number of products produced, removing possibility of tax evasion. In a typical Chinese factory, it only reports the portion of the products it produced to the tax agency, and another portion of products would evade tax.

To address the first concern, various manufacturers were selected to install the EPMCS for free and let the cost figure answer their doubts. It has been showed that the printing cost of an EPMCS label is less than a half cent. If they print the labels together with the packaging, there is no extra cost for printing the EPMCS bar code.

For the second concern, the actual benefits were used to show how a manufacturer can save in fighting against counterfeits and improve their supply-chain efficiency. For example, Shuanlian Fertilizer Company saved 800,000 RMB by fighting against counterfeits and successfully won two major criminal cases against culprits (Chen Xiaoying, 2010).

5.4.4 Crisis Driven Promotions

During the adoption of EPMCS, it has been found that the public crises are the best driver to push the government into making EPMCS mandatory for the market. Whenever there is a major public crisis arises, the EPMCS system provides a rapid and accurate mechanism for the government to identify the problematic products, trace the guilty partners, and perform product recalls. In the process, the government realizes the power our EPMCS possesses and it was eventually willing to adopt the EPMCS.

From 2005 to 2008, the adoption of EPMCMS is very slow, even though EPMCS has been successful in covering all controlled drugs for three years. No one at the CFDA wants to take the next step to cover all drugs. In 2008, a scandal of the melamine-polluted baby formula broke out, the public was raged, and the Chinese primmer quickly made decision to adopt a full EPMCS coverage of all drugs in three years. In 2010, more than 4500 pharmaceutical companies adopted the EMPCS. By 2012, all basic drugs, all distributors and partial retailers were covered by EPMCS. In 2016, CFDA relaxed the mandatory requirement on using EPMCS under the pressure of large drugstores. In 2018, the scandal of Changchun Vaccine broke out and more than 400,000 children were impacted. In 2019, the faked aspirins spread into 21 provinces (2019). These two scandals led to the direct amendment of the existing Drug Management Law, and the mandatory compliance requirement was written into the national law.

5.5 EPMCS Deployment Status

In 2005, the Chinese Food and Drug Administration (CFDA) adopted the EPMCS for trial runs to cover controlled drugs. In 2008, CFDA mandatorily adopted EPMCS for drugs industry. In 2010, EPMCS has covered all manufacturers. In 2012, all basic drugs, all distributors, partial drugstores and medical institutes were covered by the EPMCS. In 2016, CFDA relaxed the requirement of mandatory compliance. In 2018, more than 650,000 shoddy vaccines were distributed nationally and more than 400,000 children were affected. In 2019, fakes aspirins were distributed into 21 provinces. China amended its drug law and made the EPMCS mandatory for the whole drug industry.

Today, the EPMCS has become a standard in the drug industry and it continues to grow. Alibaba extends the area served by EPMCS into consumer products globally. The EPMCS is a market successful story and a legendary case on how the modern information technology can be used to address a complicated problem such as counterfeit drugs.

Chapter 6 Conclusions and Suggestions

6.1 Summery

In this paper, the research background, the causes and the existing solutions are discussed for the problem of the counterfeit and shoddy products. Based on the literature research, the essential elements and rules are determined, for any new solution must have. A framework of criteria is proposed to evaluate any new solutions. Furthermore, our model of the electronically product monitoring and controlling system (EPMCS) is described.

In order to analyze and evaluate the EPMCS model, the EPMCS model is divided into two parts. The invariant part is defined as the abstract EPMCS model, while the variant part is known as the implementation EPMCS model. The abstract model is used to specify the core elements and rules required for EPMCS, while the implementation EPMCS model is used to guide the system building. The abstract model is evaluated for its completeness and effectiveness. Finally, the practices and experience gained in our EPMCS promotion are described and hopefully they can enlighten for the promoters of new EPMCS systems.

6.2 Conclusions

In this research, the following conclusions can be drawn:

1. The abstract EPMCS model has six core elements and eight rules that must

be met for any new EPMCS systems to work correctly. These core elements and rules also specify the boundaries and processes used in the EPMCS system.

2. To evaluate the abstract model, it is showed that the abstract model is complete and effective. Any system that satisfies the abstract model will thus also be complete and effective. Specifically, every products and market handlers are covered by the abstract model. The abstract model captures all transactions that can change the product movements in market and the corresponding product life cycle in the market. With these life cycle data, it is showed how the abstract model supports effectively the identification of a problematic product, including accountability and product tracing, as well as market interventions such as product recall.
3. To ensure the successful adoption of any EPMCS systems, an external compliance environment has to be constructed. A set of mandatory requirements are needed to enforce the EPMCS rules among the market handlers. The government mandates are most effective.
4. There are four parameters that can be adjusted in an EPMCS implementation, including product packaging, product id selection, market handler id selection and repository alternatives. The choices and their ranges are considered for adjusting these parameters, and the trade-offs that can be performed.
5. To promote an EPMCS solution, it found that that the practices of a

successful EPMCS adoption include the prototype, effective communication, and accommodation for key stakeholders. Our experience showed that the public crises should be utilized to drive the EPMCS adoption. The visual prototype of the EPMCS is effective in communicating with the key stakeholders. Lastly, the persistence and endurance of team efforts are critical for EPMCS to be successful.

6.3 Suggestions for Future Research

6.3.1 Expanding EPMCS to Product Self-Market

The Internet and artificial intelligence technologies are fundamentally changing the landscape of every aspects of any industry. Traditional companies have transformed to break the traditional boundaries between companies and industries. Everything is going on Internet. Not just that operations and business have gone online, every aspects of business are interconnected with Internet. The traditional stores are going online and starting to turn into an automated and intelligent stores that (“Man-less Stores”, 2018). It is the new retailing that the traditional offline shops are going online (Du and Jiang, 2017). It is China manufacturing 2025 that the manufacturing is going online (“Department of State Issues 《China Manufacturing 2025》, 2015). In the following, I will consider how the EPMCS product ID can be extended to bring products online so that they can sell themselves.

6.3.1.1 Everything is on Internet (Internet of Things or IOT)

Mobile Internet provides universal and low-cost connectivity to everything on the world. This also means the boundaries between industries have been broken through. Traditional enterprises once organized around these boundaries and must now reorganize around these new boundary-less environment, to create unprecedented values for consumers. For example, the manufacturers of the past depend on other business organizations to distribute and sell their products. Today, they can interact with consumers directly by the QR code printed on the product package. When a consumer sees a product he likes and wants, he can scan the QR code with his smart phone; the display of the product will jump onto his phone and interact with him. In this interaction, the consumer can directly buy the product by one click from the phone. This linkage of every product onto Internet via a QR code scanning enables that every product to promote itself and sell itself. Products going online changes the way how a product can be promoted and sold. This self-promotion and self-distribution is known as produce self marketing.

6.3.1.2 Customer is on Internet Always

In 2018, China became the largest consumer market in the world (Sohu,2018). As the older generations of people born in the 50’s and 60’s gradually withdraw from the market, the young generations of consumes who are born in 80’s and 90’s became the mainstream customers. Their behaviors and demands will reshape the landscape of the product providers.

Traditional companies are centered around themselves and are waiting for consumers to go to them. However, today's young consumers are raised in a relatively rich environment and as the center of their families due to one child policy. They are used to having everything go to them (Long, 2013). The phenomenon growth in home delivery business shows this trend. When a consumer sees a product he like, he should not have to go to any place to acquire this item. Instead he can directly purchase this item by scanning the QR code on the product.

6.3.1.3 Product Self Marketing

Product self marketing is an innovative and new model of marketing. It allows the product to promote and market itself. In order to make a product self marketing, one needs to create the electronic content about this product on the Internet, and link the product content with a QR code. When a consumer sees a product and wants it, he can scan the QR code and associated product contents will be activated on the consumer phone via Internet. The electronic contents include three pieces of information: product information, story of the product brand and the sale button that allows the consumer to make a purchase right a way.

Figure 6-1 depicts a case of product self marketing. The package box of a pair of shoe is printed with QR code. When a consumer sees and wants this pair of shoe, he can scan the code to activate the electronic content of product. There is a green button the consumer can press to purchase the pair of shoe.

Figure 6-1: Product Self Marketing

The product self marketing will actually turn the whole world into a largest automatic store. The home serves as an automatic grocery store that a consumer visits most frequently. This new model of marketing a product may have a serious impact on most existing e-commerce platforms and real world stores.

6.3.1.4 EPMCS Extension to Product Self Marketing

Since the EPMCS is already assigning an ID (bar code) to each instance of a product, the EPMCS can be extended to support product self marketing if a QR code is used to replace the EPMCS barcode, and electronic contents of that product are associated with the QR code. A customer can scan the QR code on the product and buy the product when he sees a product he likes. In this way, the EPMCS will support for both problematic product detection and product self marketing. The EPMCS will be extended into a powerful marketing channel. The adoption of EPMCS should be welcomed by manufacturers, since the sale of their products is always a key value for any business. This extension of EPMCS should be a valuable research for further pursue.

6.3.2 Expanding EPMCS for Oversea Adoption

The problem of counterfeit and shoddy goods is quite universal, as it exists in both developed and underdeveloped countries (more so in underdeveloped countries). The EPMCS adoption in those regions is both urgent and beneficial. As China leads the way to push economic development through the Belt & Road Initiative, the EPMCS should also play a part. There are many worthwhile issues that deserve further research in order to successfully push EPMCS overseas and the experience we gained in China may shed some light on others.

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Appendix A. Evaluation of Abstract Model

In order to evaluate the abstract model of EPMCS, I want to start my analysis from the only the eight essential rules of the abstract model and show the abstract model is complete as well as effective. I rephrase the eight essential rules as the eight fundamental assumptions of my evaluation.

A.1 Definitions

Before going into detailed analysis, the terms used are defined in this chapter.

A.1.1 Product Instance

In EPMCS, a product instance is defined as the product instance with a unique product ID in a product category. A product instance is made by a market handler with a valid market handler ID. A product consists of all product instances with the same characteristics and made in the same batch. The product instance is the object that EPMCS is designed to deal with. Under the circumstance of different meanings, we often use a product in the place of a product instance, and vice versa.

A.1.2 Market Handler

A market handler is defined in EPMCS as a market entity that initiates transactions on a product that changes the direction of product movements in market. Every market handler is assigned a unique market handler ID by EPMCS. There are three transactions defined in EPMCS. They are *being-manufactured*, *being-sold-to* a distributor and *being-sold-to-a-consumer*. Corresponding to the three EPMCS transactions, there are three types of market handlers, including manufacturers, distributors and retailers. A manufacturer produces a product, which is when the product starts its market life. A distributor sells the product to another distributor or retailer, and the possession of the product gets changed from one distributor to another. When a retailer sells the product to a consumer, the product is removed from the market and the product reaches the end of its market life.

However, there are two other types of market participants that are not considered market handlers in EPMCS. They are the government and consumers. No matter what a consumer does to the product purchased, the product will remain out of the market. Normally the government monitors and regulates the market activities, it rarely manipulates and alters the life cycle of products directly. For example, the accountability and product flow tracing will not be changed due to government participation. Although the government may affect the movements in a very special manner in a product recalls, the impacted products are all ending their market life. Therefore, the government is not considered as a market handler that initiates product transactions.

A.1.3 Product Event

A market event in EPMCS is defined as the information related to a transaction on a product referring to the product movement in its market life. EPMCS considers only three transaction events as a result of market handlers' transactions on the product instance. The first EPMCS event is caused by a manufacturer when it produces the product (the birth of the product instance). This event is called the head event and describes the start of the product's life cycle. The second type of event is the in-market event. This event is *being-sold-to,* in which a distributor sells the product to another distributor or retailer. This event is an intermediate event in the product life cycle. The last type of event is the tail event. As the result of a transaction of *being-sold-to-a-consumer,* this event describes a retailer selling the product it owns to a consumer. This event represents a remove of the product from market circulation or the product reaches its end of market life.

In this paper, an event is denoted as $e_i(pid, mid_i, mid_{i+1}, d_i)$, where *i* is the *i-th* event in the product life cycle, *pid* is the product ID, mid_i is the source market handler or the current market handler, mid_{i+1} is the destination market handler that will gain the possession of the product as the result of the transaction, and d_i is the event data associated with the processing action by mid_i. Sometimes, e_i is used to denote $e_i(pid, mid_i, mid_{i+1}, d_i)$ for simplicity. When *i*= 0, event e_0 is the head event.

A.1.4 Event Chain of Product

For any two consecutive transaction events applied on a product, a link occurs between these two events. The receiver of the first transaction (i.e., destination market handler in the first event) is the same market handler as the initiator of the second transaction (i.e., the source market handler in the second event). In this scenario, the linkage between two consecutive events will chain the events of a product into a series of events that are mirrored to the sequence of transactions on the product, in the order of the transaction occurrences.

In EPMCS, an event chain of a product is defined as the events are chained into a sequence of events, corresponding to the sequence of the transactions performed on the product. The event chain describes the life cycle of a product in the market. That is, it describes how a product enters into the market, moves from one market handler to another, and finally exits the market. The event chain of a product is the core of EPMCS.

Let's $e_i(pid, mid_i, mid_{i+1}, d_i)$ and $e_{i+1}(pid, mid_{i+1}, mid_{i+2}, d_{i+1})$ be any two consecutive events in an event chain. In the first event $e_i(pid, mid_i, mid_{i+1}, d_i)$, the market handler mid_{i+1} is the same handler mid_{i+1} in the second event, $e_{i+1}(pid, mid_{i+1}, mid_{i+2}, d_{i+1})$. Therefore, the market handler has linked the two events.

In this research, the term of life cycle and that of event chain are used interchangeably. An event chain or life cycle of a product is denoted as C_{pid} = { e_0 , e_1 ,..., e_N }, where pid is the product ID, e_0 is the first event for the product instance, e_1 is the second event and so on. e_N is the last event in the event chain at present. The last event is either a tail event or an in-market event. In the case of a tail event, the market life of a product ends, while an in-market event marks that the product is still active in the market and is in the possession of a market handler.

A.2 Essential Rules or Basic Assumptions

My analysis of the abstract model is based on the eight essential rules. I want to show that the abstract model can be analyzed and evaluated based on only these eight essential rules. That is, the deductions of the abstract model can be reasoned from these eight assumptions if the eight essential rules are treated as eight assumptions respectively. In the following, I will restate the eight essential rules in the form of eight assumptions.

Assumption A-1: *One transaction can only be initiated to a product instance by only one market handler with a valid market handler ID at one time.*

This assumption indicates that a valid market handler can execute one transaction at a time on one product instance. Multiple market handlers cannot transact on the same product instance at the same time.

Assumption A-2: *Each product instance is an atomic unit that cannot be further broken into smaller pieces in the market circulation.*

This assumption requires that a valid product instance must be whole and cannot be distributed in smaller packages in its market life. This guarantees that a product instance cannot be sold to different market handlers in one transaction. That is, it assures that no market handler can sell the same instance of a product to different market handlers at the same time. This implies that a transaction performed on a product instance by a market handler cannot generate and report more than one event. This avoids the fork of two events by the same transaction on a product to different market handlers for the same instance of product.

This assumption specifies the requirement for the product ID.

Assumption A-3: *Each product instance has a unique ID to distinguish itself* *from any other instances of products.*

This assumption states that every product must have a unique ID in EPMCS. This implies that any product instance will only have one and only instance ID. No identical ID can be assigned to two different instances of a product. No instance of a product can have more than one EPMCS ID. When the product instance is produced by a manufacturer, the manufacturer is required to report the head event to the event report repository, and the repository would then verify and activate the product ID in EPMCS. That is, the product made without reporting the event to the repository will not have a valid product ID in EPMCS.

Assumption A-4: *Each market handler has a unique ID (MID) to distinguish it from any other market handlers. The sender of any events reported to the EPMCS repository can be authenticated by public and its act cannot be repudiated by the market handler.*

By this assumption, all market handlers must follow three rules. First, any market handler would have one and only unique identity ID. There are no other market handler with the same ID. This rule also disallow a market handler who has multiple market handler IDs. This rule ensures that the accountability of the problematic products can be determined accurately. Second, the event report repository can authenticate the sender of an event received. No one can forge an event using the identities of the others. This rule guarantees the faked events sent to the repository can be detected to avoid confusion in the accountability tracing. Third, a market handler cannot deny any events signed with its market handler ID. This rule prevents that the culprits of the problematic products from refusing the result of the accountability tracing. This rule also requires the market handler to be responsible and guarantees that the accountability tracing is creditable.

Assumption A-5: *The event report repository must create and maintain a valid event chain for each product instance, when it receives an event from a market handler.*

This assumption specifies that all market events must be reported , stored, as well as maintained in the EPMCS repository. With this rule, the EPMCS can construct event chains or aggregate the distributive ledges of product for the market based on the data stored in the EPMCS server. The efficiency in EMPCS will be increased with the help of modern information technology.

Assumption A-6: *Any event must be reported by the transaction initiator to the event report repository.*

This assumption makes it mandatory that any market handler that initiates a transaction on a product is required to report the transaction event to the EPMCS event report repository. This ensures that there are no missing events or transactions in the EPMCS. EPMCS will capture all events or all transactions of any product.

Assumption A-7: *Any event reporting must be an atomic operation.*

This assumption demands the atomicity of event report operations, so that no market handler can send a partial events to the repository. This also implies that the events received by the repository will be in the sequence of event sent or transaction performed. In this manner, the integrity and completeness of event chains can be guaranteed.

Assumption A-8: *Any transaction on a product instance is described by an event in the event chain for the product instance. .*

This assumption requires that any event in the event chain of a product to correspond to a transaction applied on the product. It also implies that an event is enough to describe a corresponding transaction.

A.3 Evaluation of Abstract EPMCS Design

According to the criteria described in section 2.2.5, the completeness and effectiveness of the abstract model of EPMCS is evaluated. Any results based on the evaluation of the abstract model will be applicable to other system that meet the requirements of the abstract model.

A.3.1 EPMCS Completeness

The completeness evaluation of the abstract model consists of three concrete criteria. First, all valid products should be covered by the abstract model. There should be no product that is not under the coverage of the abstract model. Second, the abstract model must capture all of the data related to product movements in market, and the abstract model should support all functions needed for monitoring and controlling products in the market. Third, the abstract model should cover not only the whole market but also the entire life cycle of products.

The abstract model obviously meets the first criteria of the completeness. Assumption A-3 states that the product is under coverage of the abstract model, because every products are required to a unique product ID and the ID is reported to and activated by the repository. Therefore, only if the product event chain has shown its complete, will it be shown that the abstract model satisfies the second and third criteria, because the product event chain captures the complete life cycle of the product.

First, let me draw two lemmas about the structure of an event chain.

Lemma A-1: *There is one and only head event for any valid event chains.*

Proof: Let me prove this lemma by contradiction. Consider the following two situations. There is no head event in the event chain, there are more than two head events in an event chain.

Case 1: Assume that there is no head event in the event chain for a product. By definition of the head event, it is generated by a manufacturer and reported to the repository. The missing head event means that there is no manufacturer producing the product and no the repository receiving the event. However, there exists the event chain for the product. According to Assumptions A-1, A-6 and A-8, it is impossible, because there is no head event and the product ID is not activated by the repository. There would not exist the event chain for the product. This contradictory proves the lemma.

Case 2: Assume there are more than two head events in the event chain of a product. If the head events are generated by different manufacturers, this implies that two manufacturers can assign the same PID for two different instances of the product (assumptions A-1 and A-2). This is contradictory. If the head events are generated by the same manufacturer, these head events will be the redundant events corresponding to the same transaction of *being-manufactured*. According to assumption A-8, this is impossible.

Therefore, it has been proved that for any event chains, there is one and only head event in the event chain. *QED*.

This lemma is intuitive because a product is born and died once in its market life. Similarly, the following conclusion can be drawn.

Lemma A-2: *There is one and only the last event at the end of an event chain for a product.*

Proof: Let me prove this lemma by contradiction. Consider the following two situations.

Case 1: Assume that there is no last event in the event chain. Therefore, the event chain is empty. But this contradicts with lemma A-1 since an event chain has to have at least an event (the head event).

Case 2: Assume that there is more than two last events in the even chain. This is impossible because a product instance is an atomic unit that cannot be distributed to different market handlers (assumptions A-1 and A-2). Otherwise the product is sold to different market handlers or consumers.).

Therefore, it has been proved that for any event chain, there is one and only last event in the event chain.

QED.

This lemma has shown that the last event in an event chain represents the current product state of its market life. The product state is either active in market or its life in the market has ended, the last event in an event chain is either a head event, or an in-market event or a tail event. Both the head event and the in-market event indicate that the product is still active in market. The tail event implies that the product has been sold to a consumer and its life cycle is completed.

Theorem A-1: *There exists one and only event chain for each product instance in EPMCS.*

Proof: Let's prove that there is an event chain for a product by contradiction. Assume there is no event chains corresponding to a product instance.

According to assumption A-3, the product must be assigned an activated product ID as the result of *being-manufactured* by a market handler. This market handler must report the transaction event to the repository. Thus, the product must have an event chain in the repository. This contradicts our assumption and, therefore, the theorem holds.

In the following, it has been showed that there is a sore event chain for each product in the market by induction. Suppose there exist two event chains for a product. I need to show that one event chain must be a part of another event chain, and the two event chains overlap. Let $e_0e_1e_2...e_n$ and $e_ie_{i+1}...e_{i+m}$ denote the two event chains.

Consider the case of i=0. e_0 is the head event of event chain, $e_0e_1e_2...e_n$ and e_i the head event, $e_ie_{i+1}...e_{i+m}$. According to lemma A-1, it is known that the two head events must be the same event (i.e., $e_0 = e_i$).

Now assume that the first k events in two event chains are the same ($e_0, e_{1,}...e_k = e_ie_{i+1}...e_{i+k}$, $k \le n$ and $k \le m$). Now consider the case of k+1. If $e_{k+1} = e_{i+k+1}$, that indicates that the first k+1 events in the two event chains are the same, $e_0e_1...e_ke_{k+1} = e_ie_{i+1}...e_{i+k}e_{i+k+1}$. Therefore, the case of k+1 holds true. If $e_{k+1} \neq e_{i+k+1}$, the source market handler in e_k generates two distinctive events to two different destination market handlers. By assumptions A-2 and A-7, this is impossible. Therefore, $e_{k+1} \le e_{i+k+1}$ cannot be true and $e_{k+1} = e_{i+k+1}$ holds. Thus, it has showed that the first k+1 events in the two event chains are the same. By induction, it has been proved that the short event chain of the two event chain actually overlaps with the first part of the long event chain. Therefore, it has been proved that there exists one and only event chain for each product.

QED.

The following direct conclusions can be drawn from theorem A-1 as below.

Lemma A-3: *There is no event that is not linked to the event chain for any product.*

Lemma A-4: *Every event for a product is included in the event chain for the product. That is, the event chain of a product captures all events of the life cycle of the product.*

Lemma A-5: *There are no cracks in the event chain so that the event chain is broken into the separate fragments of event sequences.*

Lemmas A-1 shows that there is neither separate nor unreachable event from any event chain for a product, while Lemma A-3 states that there are no cracks and fragments in any event chain. An event chain is structurally complete.

Lemma A-1 shows that there is one and only traversing path if an event chain is considered as a direct graph. The traversal path starts from the head event (the birth of the product instance) and ends at its removal from the market (tail event) or an unsold state at a market handler (still in market). This ensures that the product movements in market can be traced and the responsibility of each market handlers along the traversing path can be determined. In the next section, it will be showed that all functions needed for EPMCS can be supported by the event chains. In other words, the EPMCS captures all data and mechanisms needed to support all of the EPMCS functions via event chains of products. Therefore, the abstract model of EPMCS is complete.

A.3.2 EPMCS Effectiveness

There are three criteria to evaluate the abstract model of EPMCS to be effective (section 2.2.5). First, the abstract model must have the ability to allow users to recognize whether a product is problematic or not. Second, the abstract model must sbe able to trace the product movements in market and determine the responsibility of the culprits for the problematic products. Third, the abstract model can determine the inventory distribution of the problematic products and facilitate market intervention such as product recall from the market. In the following, the abstract EPMCS model will be evaluated for its effectiveness based on the above three criteria.

A.3.2.1 Problematic Product Recognition

Theorem A-2: *A consumer can scan the product ID on the product label and query the event report repository to determine whether a product is problematic or not.*

Proof: Let me prove this theorem in three situations.

case 1: the product does not have a product ID. According to the EPMCS rules (assumption A-3), this product is not a valid product, so the product is identified as a counterfeit or shoddy product.

Case 2: A consumer scans the product ID on the product label and the repository finds no event chain to match with the product ID. This implies that the product is not activated by the repository and there is no valid manufacturer produces the product. The product is determined as a counterfeit or shoddy product.

Case 3: A consumer scans the product ID on the product and there is an event chain associated with this product ID. If the location of purchase does not match with the location of the market handler in last event in the event chain. This product is considered as a counterfeit or shoddy product. If the locations above are the same and the last event is the tail event, the product is considered as a valid product. Whether a valid product is genuine or not rests on the shoulder of the manufacturer of the product. The responsibility of the manufacturer can be traced to deter it from making counterfeits. Otherwise, the product is recognized as a problematic product.

QED.

Theorems A-2 shows that the abstract model can support the effective and accurate identification of problematic products. As for the EPMCS valid products, the accountability tracing can identify the manufacturer of the product and place the responsibility of the genuineness of the product to the manufacturer. In addition, the process of the evaluation also presents the algorithm of problematic product identification.

A.3.2.2 Accountability Tracing

The accountability tracing of the culprits in the problematic products is a necessary capability for an EPMCS system. It has two impacts. First, it can locate the guilty partners of the problematic products and legal actions can be pursued. Second, the responsibility tracing serves as a deterrence to the culprits if they dare to make counterfeit products. In the following, the ability of the abstract model will be evaluated to trace the responsibility.

Theorem A-3: *In the abstract model of EPMCS, the responsibility of the culprits who make counterfeits can be determined in the following manner. If a product is problematic, the source market handler in the head event of the event chain is the guilty partner to manufacture the problematic product. The source market handlers in each in-market event of the event chain are the guilty partners who sell the problematic product.*

Proof: Consider the event chain for the product as a direct graph. Traversing the event chain is equivalent to visiting every events in the event chain, starting from the head event. If a problematic product is identified, the culprits who is responsible for the problematic product can be traced based on its event chain.

The culprits can be determined by the following algorithm. Starting with the header event, visit every events along the event chain. The source market handler in the head event is the guilty party who made the problematic products., while the other source market handlers in the rest of all other events in the event chain are guilty partners who sell the problematic products.

QED.

Theorem A-3 describes an effective algorithm for accountability tracing, since the algorithm only depends on the internal data of the abstract model of EPMCS. It can be implemented electronically in the repository.

Theorem A-4: *If the problematic product does not have an event chain in the abstract model, the market handler that is selling this product is the guilty partner that introduces problematic products into the market and sells them on the market.*

Proof: If there is no event chain for the product and the market handler sells the product, according to theorem A-2. the product would be identified as a problematic product, and the market handler is the guilty partner for introducing the problematic product into the market.

QED.

Theorem A-3 describes that the abstract model can effectively and accurately trace the responsibility of the culprits, when there is an event chain in the abstract model for the product. Theorem A-3 shows that the accountability tracing when there is no event chain associated with the product.

A.3.3 Market Intervention Operation

An effective system must support inventory determination of the problematic products for each market handler, the inventory distribution over the market, and total inventory on the market. The inventory distribution of a product is the inventories of the market handlers (the inventory locations and quantities for individual market handlers). Once the inventory distribution of problematic products is determined, product recalls can be executed effectively and accurately.

A.3.3.1 Inventory Determination

Based on the abstract model, a product ledge can be calculated for each market handler who own the product in inventory (including the product movement direction and quantity). In this section, the algorithms are presented to determine effectively the inventory of the problematic products.

T**heorem A-5**: The *Inventory at a market handler mid is calculated as below.*

$$Q_{p,mid} = \sum_{\substack{\text{all pid in p} \\ \text{pid, mid in last(e)} \\ \text{event}_{\text{last}} \neq event_{tail}}} 1 \quad ,$$

where mid is the source market handler who ends in the last event in the event chain for pid and he last event is not a tail event.

Proof: By theorem A-1, it is known that each product has a corresponding event chain for this product. The product is presently possessed by the source market handler in the last event of the event chain. All events but the last event in the event chain describe the history of the product movements in the market and the market handlers in these events no longer possess the product at present. If the last event is a tail event, the product has exited the market. All event chains with a tail event can be excluded for this calculation.

In order to calculate the inventory at the market handler, I will first find all product instances and their *pids* in the product category *p*. For each *pid*, its event chain is obtained. If the last event is a tail event, the event chain is excluded for further consideration. Otherwise, all event chains are determined so that the destination market handler in the last event is *mid*. Because each event chain corresponds to one instance of the product, the inventory is the quantity of one. Therefore, the inventory at a market handler, $Q_{p,mid}$, is the sum of the number of the event chains that satisfy the above conditions and obtain the inventory at the market handler *mid*.

QED.

This theorem calculates the inventory of problematic products owned by a market handler. If the inventory can be calculated for every market handler that owns the problematic product, the inventory distribution of the problematic products over the market can be easily determined .

Theorem A-6: The *Inventory distribution of product p over the market is calculated as below.*

$$D_p = \bigcup_{i=1}^{m} \{Q_{p,mid_i}\} = \{Q_{p,mid_1},\ Q_{p,mid_2},\ldots,Q_{p,mid_m}\},$$

where Q_{p,mid_i} *is the inventory at the market handler mid, and i is the i-th market handler that possesses the inventory of the product p, and i = 1, 2, ..., m.*

Proof: Using theorem A-5, the inventory owned by market handler mid_i, D_{p,mid_i}, can be calculated , for product *p* (*i=1,2,...,m*) , and the inventory distribution can be determined with a set of D_{p,mid_1}, D_{p,mid_2}, ..., D_{p,mid_m}. This set of inventory is thus the inventory distribution of product p over the market.

QED.

With an inventory distribution, the inventory quantities in the inventory distribution can be added together to obtain the total inventory of the product p in the market.

Theorem A-7: *The total inventory of a product in the market is calculated as below:*

$$Q_p = \sum_{i=1}^{m} Q_{p,mid_i} ,$$

where Q_{p,mid_i} is the inventory that the market handler mid_i possesses, i is the i-th market handler that owns product p.

A.3.3.2 Product Recall Operation

According to theorem A-6, the inventory distribution of the problematic product can be calculated effectively based on the event chain data. Once the government decides to issue a product recall from the market, all market handlers that are involved in the inventory distribution can be notified to pull the specified product off the shelf. In this manner, the product recall can be executed effectively and accurately.

Theorem A-8: *A product recall can be supported effectively by the following algorithm: (1) calculate the inventory distribution of product p by using theorem A-6; (2) for each market handler involved in the inventory distribution, notify it to pull off the shelf the product* *and associate quantity.*

Therefore, it has been showed that the abstract model is both complete and effective. Thus, any system that also meets the requirements of the abstract model of EPMCS will also be complete and effective.

A.4 Conclusions

In this appendix, it has been shown that the abstract model of EPMCS is complete as well as effective with respect to the functionality of product monitoring and controlling. It implies that all products are covered by the abstract model, and all of the data required to support the EPMCS functionality are owned by the abstract model. The identification of the problematic products by consumers and accountability tracing are also effective and accurate. Any system that meets all of the requirements of this abstract model is also complete and effective.