Impact of Unauthorized Distributors on the Supply Chain and Financial Performance of Companies

Youness Eaidgah[1]
(y.eaidgah@hotmail)

Supervisors: Ove Bayard[1], Diganta Das[2], Martin Dresner[3]

[1] *Department of Production Engineering, Schools of Industrial Engineering and Management, Royal Institute of Technology (KTH), Stockholm, Sweden*
[2] *Center for Advanced Life Cycle Engineering (CALCE), University of Maryland, College Park, USA*
[3] *Robert H. Smith Schools of Business, University of Maryland, College Park, USA*

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Abstract

Global supply chains, shorter product life cycles, and technological innovation have made supply chain management a critical issue for firm's success. By improving service and reducing costs, efficient supply chain management brings companies a competitive advantage and helps them to outperform their competitors. Due to tight supply or unfavorable conditions, Original Equipment Manufacturer (OEM) might occasionally find itself in a situation where it is not able or willing to source its required raw material form authorized channel. In this case, OEM options narrow down to waiting until the item become available in authorized channel (backlogging its customer orders), sourcing from unauthorized channel, or cancelling customer orders. Each one of these scenarios causes particular consequences.

Main objective of this study is to clarify the consequences of sourcing form unauthorized distributors on the supply chain performance and its financial performance of OEM. Study is composed of a qualitative phase and a quantitative phase. During each phase, a proper set of supply chain metrics and financial measures are employed to understand the effects of sourcing from unauthorized distributors and counterfeits parts. In both phases, SCOR model is used as a reference for supply chain metrics as well as to understand the supply chain processes.

Based on the study results, there is obviously a trade-off involved in sourcing from unauthorized channel. It may help the OEM in some respects; however, it may pose a risk to the OEM performance at the same time. Particular circumstance of each business is a key factor to determine the effects. Among the factors studied, raw material quality, sourcing volume, and accusation price are the most important ones respectively. The most influential factor is raw material quality and it mostly outweighs the effect of the unauthorized distributors' lower prices. It implies that lower prices should not be the sole incentive to source from unauthorized channel. Concerning all factors is a must. In case that OEM decide to source from unauthorized channel, proper risk mitigation methods should be employed to reduce the risk of receiving low quality articles.

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1 Introduction

In global markets and modern economies, to design, produce, and deliver products and services, companies need to collaborate with other companies such as suppliers, distributors, retailers, and third party service providers. This collaboration forms supply chains. Indeed, supply chain is a set of processes to acquire raw material (tangible or intangible), convert it to finished product (tangible or intangible), and deliver it to final Customer. The main elements of chain are forward material flow, reverse material flow, flow of information, and cash flow with a set of processes to accommodate, facilitate, and adjust the mentioned flows along the chain. Processes are realized by facilities and implemented by different parties along the chain. Flows happen inside the organizations and between organizations. [1][2][3][4]. Supply chain management is a set of polices to govern, adjust, and coordinate forward and reverse flow of material as well as flow of information and cash along the chain. These policies might be integrated and harmonized among different members of the chain or be local to each organization. Main goal of SCM is delivering a higher Customer value through improving service level and reducing costs [5][6][7].

Electronic supply chains are mostly global supply chains. They are usually composed of component producers, distributors that feed original equipment manufacturers (upstream distributors), original equipment manufacturers (OEM), distributors that are fed by OEM (downstream distributors), retailers, and Customers (Figure 1). Component producers are divided to genuine manufacturers and counterfeiters. Upstream distributors, that provide electronic components to OEM (such as chipsets, resistors, boards, and CPU), are also categorized as authorized distributors and unauthorized distributors.

Due to shortage of raw material or unfavorable conditions, now and then, OEM may not be able or willing to source its required articles from unauthorized distributors. In this case, OEM options narrow down to suspending customer orders and waiting until the item become available in authorized channel (backlogging customer orders), sourcing from unauthorized channel, or cancelling customer orders. Each one of the mentioned alternatives has a specific impact on supply chain performance and financial performance of OEM. While sourcing form unauthorized distributors may help the OEM to fulfill its obligations, it puts the OEM under the risk of receiving low quality or counterfeit articles.

Counterfeiting is an infringement of the legal rights of an owner of intellectual property [8]. A counterfeit component is one whose material, performance, or characteristics are knowingly misrepresented by the vendor, supplier, distributor, or manufacturer [9]. Counterfeiting, as a global problem, has started to impact the high-tech industries. As an example, in the semiconductor market in 2005, the amount of counterfeit parts purchased in that period by and from the U.S. was approximately between $70M and $100M [10]. Even though there is a strong consensus about the negative impact of counterfeits on brand owners, consumers, and involved countries, very little is known about the phenomenon itself, both in practice and theory. Our knowledge about unauthorized distributors, the tactics of counterfeit producers, consumer behavior, mitigation methods, and the impact of the counterfeits on the supply chain and financial performance of companies is limited.

The Main objective of my thesis is to clarify the effects of OEM sourcing decisions on the supply chain performance and its financial performance. While the main focus of this study is on the electronic components and electronic supply chains, the outcome is applicable to other fields as well. The study was conducted in two phases: qualitative phase and quantitative phase. During the quantitative phase, by forming a set of supply chain metrics and financial measures, we proposes a qualitative approach for investigating the effect of unauthorized distributors on both supply chain performance and the financial performance of companies from the original equipment manufacturer perspective. During the qualitative phase, SCOR model is used to develop a discrete event simulation model and its performance measures. Afterward, experiments are conducted through a design of experiment table. We compared the effects of different alternatives to the situation when OEM is entirely sourcing its required raw material form authorized channel.

As sourcing form unauthorized channels is a controversial issue, regarding this study objective, we could not get access to any industry-based data. Even though Center of Advanced Life Cycle Engineering (CALCE) has an established cooperation with some of the biggest electronic OEMs, They were not willing to reveal any particular information in this area. Consequently, qualitative and quantitative phases are tailored to best suit the situation.

Section two, three, four, and five provide the primary information and definitions that are used latter in section six and seven. Section six and seven describe the qualitative and quantitative study respectively.

Section eight describes the overall conclusion of this study. Section six and seven contain their own conclusions which are complementary to the overall conclusion.

2 Electronic Distributors

This section contains a brief description of electronic supply chains, electronic distributors, and the incentives of OEM to source form unauthorized distributors.

2.1 Distribution Channels

Figure 1 illustrates a generic electronic supply chain from the original equipment manufacturer perspective. The main members of the chain are component manufacturers (genuine manufacturers, counterfeiters), upstream distributors, OEM, downstream distributors, retailers, and Customers. Due to specific nature of electronic products, OEM sources a wide range of components from either genuine manufacturers or distributors that distribute those components. These distributors, which are located between OEM and manufacturers, are categorized as authorized distributors (franchised distributors), independent distributors, and brokers. Independent distributors and brokers are referred as unauthorized distributors. Whenever the term distributor is used in this study, it refers to upstream distributors.

Authorized distributors have the permission of genuine manufacturer to distribute their products. They gain this permission after being audited by the manufacturer and hold this permission as long as they comply with the manufacturer's requirements about handling, storage, and shipping procedures. This ensures the quality of the product delivered to the final customer. In turn, genuine manufacturers usually offer warranty only for products acquired through authorized distributors[9][11].

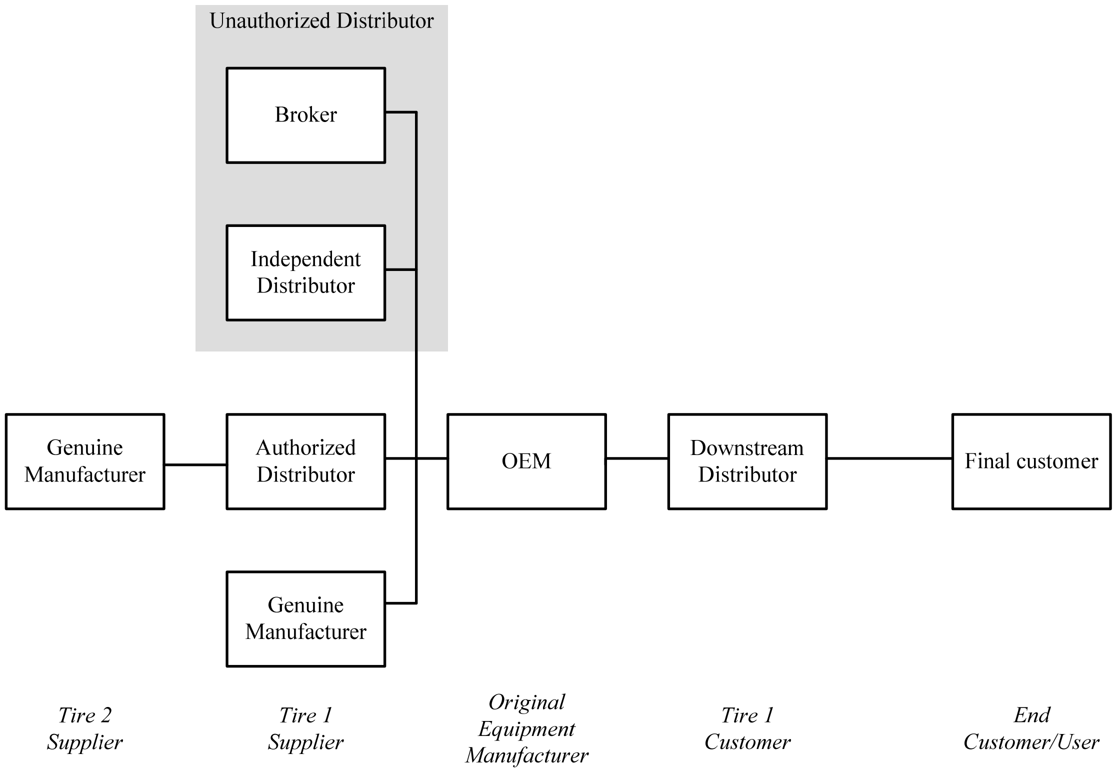

Figure 1: Generic electronic supply chain

Unauthorized distributors do not hold such an agreement with genuine manufacturers. Genuine manufacturers have no supervision over them. They usually do not sell their products to unauthorized distributors[11] and do not offer services for parts purchased from unauthorized distributors[9]. As genuine manufacturers do not sell their products to the unauthorized distributors, unauthorized distributors source their inventory from extra inventory along the chain (forward material flow), counterfeit manufacturers, other unauthorized distributors, reverse material flow, recycled parts, and scraps.

There are two categories of unauthorized distributors, independent distributors and brokers. Independent distributors own a warehouse, keep the inventory, and posses what they trade. However, brokers usually do not hold any inventory and they are not mostly in physical possession of the parts they are trading. Brokers' business model makes them the less reliable source for potential Customers[10][10].

Concerning unauthorized distributor's sources, there is a significant possibility of acquiring either low quality article form their channel or counterfeits. Counterfeit parts almost always enter the supply chain as a result of purchasing form unauthorized distributors. It does not mean that all the articles provided by unauthorized distributors are counterfeits or all unauthorized distributors provide counterfeits and low quality parts. Indeed, there is just a significant probability of flow of counterfeits and low quality articles in their channel, intentionally or unintentionally, particularly in the case of brokers[9]. A case study in semiconductor industry revealed that in almost every case, the supplier of the counterfeit parts was a broker[10][10]. Counterfeiting incidents involving authorized distributors have also occurred, however, extremely rarely[9].

Besides mitigating the risk of counterfeits and enjoying genuine manufacturer warrantees, franchise agreements typically include a number of privileges that protect the user by ensuring product integrity and traceability. Proper handling, storage, and shipping procedures, failure analysis and corrective action support, certificates of conformance, acquisition traceability, and other value-added services are among the benefits that a franchised distributor provides for its customers. Unauthorized distributors, at least as they do not have such an agreement with the manufacturers, have limited means for offering these benefits[9]

2.2 OEM Incentives to Source from Unauthorized Channel

OEMs source from unauthorized distributors due to tight supply, when they cannot source their required articles from authorized channel, or supply constraints, when authorized channel impose unfavorable condition on them [9][11].

Tight supply occurs when the market demand goes beyond the forecasted demand or when products are discontinued (obsolescence) [12][12]. A part becomes obsolete when it is no longer manufactured, either because demand has dropped to low enough levels that it is not practical for manufacturers to continue to make it, or because the materials or technologies necessary to produce it are no longer available[13]. Indeed, obsolescence usually happens when a system has an extended life-cycle. That is, the system life cycle is greater than some of its components[9]. No components typify technology obsolescence more than electronic parts[13][13].

Supply constraints also occur now and then. As an instance, IBM relied on the unauthorized channels in China to get around government regulations requiring the participation of local companies. To forge this partnership, IBM was needed to make large an investment[11].

3 Counterfeit electronic components

Nowadays, counterfeiting is a global problem that accounts for 5–7% of all worldwide trade, amounting to US $350–600 billion. Surprisingly, it is no longer limited to simple products such as bolts, clothing, dolls, stereos, and watches. Counterfeiters have made their way to sophisticated products and high-tech sectors such as semiconductors, advanced electronic systems, pharmaceutical, and automotive industries. This is a market that is growing fast. Indeed, counterfeiting is a problem that has grown over 10,000 percent in the past two decades [10][14].

Customers, genuine manufacturers, brand owners, countries where counterfeiting takes place, and countries where counterfeits are sold, all suffer from this phenomenon [8]. The detection of counterfeit parts usually occurs when there is a product or system failures [10]. In the area of electronic parts, field failures might result in serious risks and safety hazards as well as significant costs and responsibilities for original equipment manufacturer (OEM). Negative effects of counterfeit electronic components, the fast growth of the counterfeit market, and the evolving nature of the phenomenon, make it a critical problem.

3.1. Definition

Webster's Dictionary[15] defines a counterfeit item as "that which is made in imitation of something, with a view to deceive by passing the false for the true". The Agreement on Trade-related Aspects on Intellectual Property Rights (TRIPs) defines a counterfeit item as follows [16]:

a) "'Counterfeit trademark goods' shall mean any goods, including packaging, bearing without authorization a trademark which is identical to the trademark validly registered in respect of such goods, or which cannot be distinguished in its essential aspects from such a trademark, and which thereby infringes the rights of the owner of the trademark in question under the law of the country of importation;

b) 'Pirated copyright goods' shall mean any goods which are copies made without the consent of the right holder or person duly authorized by the right holder in the country of production and which are made directly or indirectly from an article where the making of that copy would have constituted an infringement of a copyright or a related right under the law of the country of importation."

To put it simply, in the field of electronic parts, a counterfeit electronic component is one whose characteristics are knowingly misrepresented by the supplier, which is not the owner of the intellectual property rights, to mislead the customer about the component brand, type, properties, or life cycle characteristics.

Buyers may acquire counterfeit articles either by not being aware of the underlying intellectual property infringement (deceptive counterfeiting) or by knowing full well the illicit nature of the product (non-deceptive counterfeiting) [17].

3.2. Counterfeits' types and manufacturing methods

Counterfeit parts, grouped as used parts or new [9], are produced through re-marking, re-packaging, duplicating, or a combination of these methods. In re-marking, a counterfeiter changes the original label of a genuine product. Changing the label of a product that should be phased out and selling it as a new one is a common practice. In repackaging, the main item is the box. A counterfeiter uses a combination of a genuine product box and illegitimate contents. In duplicating, a counterfeiter illegally manufactures the genuine product, without the original manufacturer's permission, and sells it to customers as a genuine product [18].

The main sources of used counterfeit parts are reverse materials flow and recycling. As an example, a reclamation company in Singapore, Citiraya, had contracts with Intel, AMD, and 3M to retrieve precious metals from scrap parts. Even though Citiraya issued destruct certificates to their customers, instead of reclaiming the parts, they sold them on the broker market [10].

On the other hand, new counterfeit parts might be sourced from counterfeit manufacturers (duplicators), original manufacturer scraps, or extra inventory of genuine products available along the supply chain.

3.3. Extent

The extent of electronic part counterfeiting varies. It starts with a single part, such as a semiconductor, and stretches to complex products and even brands. As an example, in 2006, the Japanese electronics giant NEC uncovered an elaborate chain that was faking NEC's products. Based on the evidence reveled in raids on 18 factories and warehouses in China and Taiwan, counterfeiters had set up a network of more than 50 electronics factories in mainland China, Hong Kong, and Taiwan. Counterfeiters carried NEC business cards, commissioned product research and development in the NEC name, and signed production and supply orders. Using the NEC name, the pirates copied NEC products, and went as far as developing their own range of consumer electronic products, including everything from home entertainment centers to MP3 players. They also coordinated manufacturing and distribution. The actual NEC even received complaints about products that they did not make or provide with warranties[19].

4 SCOR Model

Supply-Chain Operations Reference model (SCOR model) is a product of the Supply-Chain Council (SCC). SCOR model provides "a unique framework that links business process, metrics, best practices and technology into a unified structure to support communication among supply chain partners and to improve the effectiveness of supply chain management and related supply chain improvement activities" [19].

SCOR processes are defined and detailed through four levels of elaboration. At first level, SCOR introduce five primary processes: plan, source, make, deliver, and return (return form Customer and return to supplier). These five primary processes, which are called management processes or SCOR processes, are the basic block that constitute a supply chain (Figure 2). The process Plan contains "processes that balance aggregate demand and supply to develop a course of action which best meet sourcing, production and delivery requirements"[19]. The process source contains "processes that procure goods and services to meet planned or actual demand" [19]. The process make contains "processes that transform product to a finished state to meet planned or actual demand"[19]. The process deliver contains "processes that provide finished goods and services to meet planned or actual" demand, typically including order management, transportation management, and distribution management"[19]. The process return contains "processes associated with returning or receiving returned products for any reason. These processes extend into post-delivery Customer support"[19].

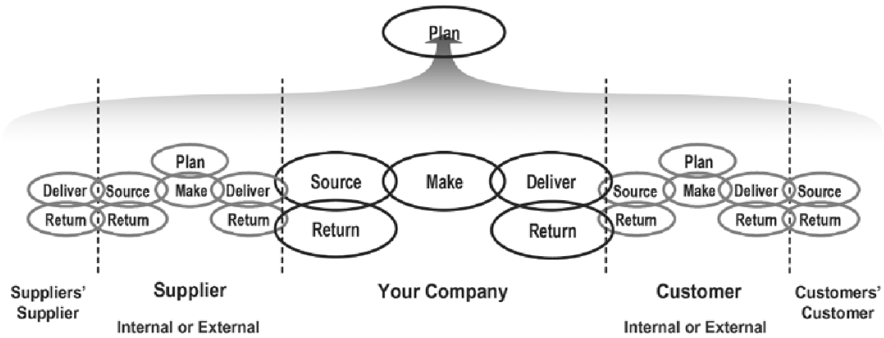

Figure 2: SCOR Management Processes [19]

As Figure 2 illustrates, a combination of SCOR processes forms the internal supply chain of an organization. The combination of organizations forms the extended supply chain. At the boundary of organizations, internal supply chains meet each other and couple together through SCOR primary processes, usually plan, source, deliver, and return.

At second level, process categories, the SCOR processes are categorized in two different processes types: planning or execution. Plan process obviously falls in the planning category, while source, make, deliver, and return from the execution category. Execution processes are those that transform or transport the material/product along the chain. On the other words, execution processes model the flow of martial along the chain. Beside these two process types, there is one more process type which is called "enable". Enable covers all processes that "prepare, maintain, or manage information or relationship on which planning and execution processes rely"[19].

The model also distinguish between make to stock (MTS), make to order (MTO), and engineering to order (ETO) supply chain strategies at second level. For example, S1 refers to a "source stocked" product, S2 referees to a "source make to order" product, and S3 refers to a "source engineering to order" product. Make and deliver also follow the same terminology. However, there is an extra deliver configuration: deliver retail product (D4). Plan and Return have different configuration. Plan process contains two different types of processes. Plan Supply Chain (P1) refers to a cross-organizational or a cross functional process that cover the entire supply chain or the entire organization respectively. P1 is aimed at coordinating the supply chain or coordinating the processes inside the organization. On the other hand, each individual execution process (source, make, deliver, return) has its own plan process.

Once a SCOR process is fully categorized at second level, at level three, process element level, each process decomposes to more detailed processes which are called process elements. As an instance, the level three process Make stocked product (M1) consists of the following sub-processes: M1.1 (Schedule

Production Activities), M1.2 (Issue Product), M1.3 (Produce and Test), M1.4 (Package), M1.5 (Stage Product), M1.6 (Release Product to Deliver), and M1.7 (Waste Disposal).

Eventually, at level four, implementation level, each process element decomposes to a set of implementation elements that are also known as activities. Implementation level is the most elaborated level.

Beside the processes, SCOR introduce a number of metrics and couple these metric with the SCOR processes and Process elements. The SCOR metrics are grouped in five categories: reliability, responsiveness, agility, cost, and assets management (Table 1). Reliability, responsiveness, and agility metrics are also referred as Customer facing attributes. Costs and assets metrics are also known as internal facing attributes.

Under each category, which is called attribute, there are three levels of metrics (SCOR metric follow a hieratical structure too). Level one metrics, Strategic metrics, are the highest level metrics. These metrics which are composed of the lower level metrics, level two and three, may cross multiple SCOR processes. In the same way, level two metrics are composed of level three metrics. Level three metrics, which are also called diagnostic metrics, from the most basic blocks of metric system. There are also a set of level three metrics that do not roll up to level one metrics. Furthermore, SCOR introduce a number of best-practices, and some tools for developing the supply chain models. We have utilized some of these tools in this paper.

Table 1: SCOR supply chain performance metrics [19]

Level 1 Strategic Metrics	Performance Attributes				
	Customer-Facing			Internal-Facing	
	Reliability	Responsiveness	Agility	Costs	Assets management
Perfect Order Fulfillment	√				
Order Fulfillment Cycle Time		√			
Upside Supply Chain Flexibility			√		
Upside Supply Chain Adaptability			√		
Downside Supply Chain Adaptability			√		
Supply Chain Management Cost				√	
Cost of Goods Sold				√	
Cash-To-Cash Cycle Time					√
Return on Supply Chain Fixed Assets					√
Return on Working Capital					√

The way that SCOR categorize supply chain processes, its hierarchal approach, and available integrated metrics pose it as a template for supply chain simulation models. The SCOR processes and elements can easily be translated to the simulation blocks. The input and output of SCOR processes and their associated metrics make it easy to detect proper inputs and outputs of the simulation model. Throughout this paper, the SCOR Version 7 is used.

5 Performance measurement

Performance measurement is defined as the process of quantifying the efficiency and effectiveness of actions[21]. Efficiency is defined as the ratio of the effective or useful output to the total input provided to the system. Effectiveness is defined as having an intended or expected output[22].

Performance measurement systems were developed as a means of monitoring the organization status to ensure that an organization pursues strategies that lead to the achievement of overall goals and objectives.

In this sense, performance measurement is central to the issue of organizational control[23]. On the other hand, besides monitoring and comparing with the internal criteria, performance measures have been widely used to benchmark against competitors and to explore a firm's weaknesses, strengths, opportunities, and threats. Nowadays, performance measurement systems are utilized to:

1. Provide information for decision-making processes. This ensures that decisions are rooted in facts and not emotions, faith, or a mere understanding.
2. Help businesses understand their processes better.
3. Provide information through benchmarking.
4. Assist managers in identifying success/failure and to measure the improvements.
5. Guide behavioral and emotional issues within the business. That is, a performance measurement system, by providing information about management perspectives, defines the priorities and reforms the communication between staffs[24].

Akin to other performance measures, supply chain metrics provide information that assist managers to monitor, control, benchmark, and improve their supply chain performance, locally and globally. A proper set of these metrics can reflect the effect of different supply chain policies [24]. A wide range of metrics have been developed by scholars, institutions, and companies to measure different aspects of supply chain performance.

Financial performance illustrates the ability of a company to utilize its assets to generate profit, improve shareholder value, and enhance growth. The usual starting point for any assessment of financial performance and valuation of a firm is the financial statement of that firm, which is composed of three distinct reports: balance sheet, income statement, and statement of cash flow[25]. Financial ratios, which use numerical values taken from financial statements, are useful indicators of a firm's financial performance. Provided that they are interpreted correctly, financial ratios reveal important information about the company's performance that might remain hidden without them. There are different categories of these ratios, such as profitability, liquidity, debt, and efficiency. The most important components that form the nominator and denominator of these ratios are asset level (balance sheet), inflow of cash to the company (statement of cash flow), outflow of cash from the company (statement of cash flow), sales revenue (income statement), cost of goods sold (income statement), and sales, general, and administrative costs (income statement) [25].

6 Qualitative phase

During this phase, by forming a set of supply chain metrics and financial measures, we proposes a qualitative approach for investigating the effect of unauthorized distributors on both supply chain performance and the financial performance of companies from the original equipment manufacturer perspective.

6.1. Methodology

The study initiated with a review of the literature in the field of performance measurement, supply chain performance measures, financial performance, counterfeits, illicit markets, and unauthorized distributors. Afterward, a small set of supply chain metrics and financial measures were formed in order to investigate the effect of sourcing from unauthorized distributors and counterfeits. The main criteria to pick the metrics were:

1. Each set of metrics should have enough power to represent its domain. That is, supply chain measures should be able to represent supply chain policies up to an acceptable extent. In the same way, a selected set of financial measures should have enough power to reflect financial performance.
2. A supply chain measure would be selected with regard to counterfeits and sourcing from unauthorized distributors. We try to pick the measures that represent the effects of counterfeits on supply chain performance.
3. Financial measures would be selected with regard to supply chain measures, counterfeit, and sourcing from unauthorized distributors.

The SCOR model, due to its standardized framework, provides a useful set of supply chain metrics. Regarding the components of each metric, we investigated the effects of sourcing from unauthorized distributors and the presence of counterfeits in the supply chain. Finally, the interaction between supply chain metrics and financial measures were examined.

6.2. Forming sets of performance measures

Level one SCOR metrics (Table 1) can be divided into two categories: cost and non-cost metrics. Non-cost metrics include:

- Perfect order fulfillment
- Order fulfillment cycle time
- Upside supply chain flexibility
- Upside supply chain adaptability
- Downside supply chain adaptability.

Cost metrics include:

- Supply chain management cost
- Cost of goods sold
- Cash-to-cash cycle time
- Return on supply chain fixed assets
- Return on working capital.

We want to study the effect of sourcing from unauthorized distributors and counterfeits on the supply chain non-cost performance measure and, consequently, the effect of supply chain non-cost measures on the financial performance (cost measures). Out of the available non-cost metrics and regarding our interest, the following metrics have been selected: perfect order fulfillment, order fulfillment cycle time, and capacity utilization. All metrics, except capacity utilization, are level one metrics. Also, supply chain management cost is included in this set because it measures the cost associated with SCOR processes (plan, source, make, deliver, return). These metrics will be defined later.

Based on the SCOR, agility metrics all require a sustainable increase or decrease in supply, from the supply side or to the customer. Sustainability is a mandatory condition. For example, upside supply chain flexibility is defined as “the number of days required to achieve an unplanned sustainable 20% increase in quantities delivered"[19]. In the short run, by making redundancy in the supply chain, sourcing from unauthorized distributors seems to improve supply chain flexibility. However, because sourcing from unauthorized channels is unlikely to provide a sustainable stream of material flow, and as it is not the common practice, based on the metrics definition it does not contribute to chain flexibility and agility. Therefore, agility metrics are excluded from the study.

From the finical performance side, asset level (from balance sheet), sale revenue (from income statement), cost of goods sold (from income statement), sales and general and administrative costs (from income statement), and irregular, special, or extraordinary gain/loses (from income statement) are chosen. These are the basic blocks that form many financial ratios as well as supply chain cost measures[25]. Also, the cash-to-cash cycle has been exclusively studied.

6.3. Analysis

6.3.1 Perfect Order Fulfillment (from OEM to customer)

The SCOR model defines perfect order fulfillment as "the percentage of orders meeting delivery performance with complete and accurate documentation and no delivery damage. Components include all items and quantities on-time using the customer's definition of on-time, and documentation—packing slips, bills of lading, invoices, etc" [19].

Perfect order fulfillment is composed of four distinct level-two metrics: percentage of orders delivered in full, delivery performance to customer commit date, documentation accuracy, and perfect condition. Each component receives a score of 1 if it is judged to be perfect or receives a score of 0 if not perfect. If the sum of the scores equals the number of components (which is four) the order line is perfectly fulfilled[19].

- Percentage of orders delivered in full: "The percentage of orders where all of the items are received by customer in the quantities committed. An order is considered delivered 'in full' if all items ordered are the items actually provided, and no extra items are provided and all quantities received by the customer match the order quantities" [19]. This component is concerned about quantity.

As was mentioned before, OEMs source from unauthorized distributors due to tight supply or supply constraints. In the short run, sourcing from unauthorized distributors helps OEMs to keep the current level or even improve this metric. That is, deliveries may be deemed to be "perfect" even if there are counterfeits involved.

- Delivery Performance to Customer Commit Date: "The percentage of orders that are fulfilled on the customer's originally scheduled or committed date. An order is considered delivered by the original customer commitment date if the order is received on time as defined by the customer and the delivery is made to the correct location and customer entity" [19].

Sourcing from an unauthorized channel contributes to this metric. For example, in a case where an OEM is not able to acquire the subcomponents of a product from genuine manufacturers or franchised distributors, sourcing from unauthorized distributors helps the OEM to fulfill its customers' demands within the committed time frame.

- Documentation accuracy: "The percentage of orders with accurate documentation supporting the order, including packing slips, bills of lading, invoices, etc. All documentation must be complete, correct, and readily available when and how expected by the customers. An order is considered to have accurate documentation when the following are accepted by the customer: shipping documentation, payment documentation, compliance documentation, other required documentation" [19].

Items acquired from unauthorized distributors, particularly brokers, are usually lacking the certificates of conformance and acquisition traceability [9]. As long as customers do not ask for such documents, it will not cause any trouble for the OEM. However, in case the customer asks for these documents, OEM will most likely not be able to deliver them.

- Perfect condition: “The percentage of orders delivered in an undamaged state that meet specification, have the correct configuration, are faultlessly installed (as applicable), and accepted by the customer. An order is considered to be delivered in perfect condition if all items are delivered undamaged, meet specification and have the correct configuration (as applicable), are faultlessly installed (as applicable) and accepted by the customer, and are not returned for repair or replacement within the warranty period” [19].

As unauthorized distributors’ internal practices are usually not audited, and as they might source from unreliable suppliers, items acquired from unauthorized distributors are prone to have a lower quality. This lower quality results in a higher probability of failure during installation or warranty period. Therefore, sourcing from unauthorized channels would have a negative effect on this component and might result in a significant cost and liability for the OEM.

- Financial Impacts

Perfect order fulfillment has a direct impact on sales revenue and the company’s liability and intangible asset value. A higher perfect order fulfillment leads to higher sales revenue, brighter company image, and mitigation of the risk of liability. If a company fails to fulfill its committed obligation, it will lose sales revenue, its reputation can be degraded, and it might face serious financial penalties. Boeing faced such consequences when it could not deliver the Boeing 787 on time[26]. On the other hand, a high rate of failure during the installation or warranty period due to counterfeits can pose a significant cost for the OEM (particularly as genuine manufacturers do not provide warrantees for articles acquired from unauthorized channels), cause the OEM to be taken to court, and deteriorate OEM image as well. Therefore, regarding this metric, it is hard to make an absolute verdict about the impact of sourcing from unauthorized channels. It brings some benefits to the OEM but also some threats. OEMs need to analyze costs and benefits associated with sourcing from unauthorized channels based on their specific contexts in order to make a right decision.

6.3.2 Order Fulfillment Cycle Time

Order Fulfillment Cycle Time is defined as “the average actual cycle time consistently achieved to fulfill customer orders. For each individual order, this cycle time starts from the order receipt and ends with customer acceptance of the order”[19]. This metric is a means of measuring the lead time.

Order fulfillment cycle time is composed of three distinct level-two metrics: source cycle time, make cycle time, and delivery cycle time. If the sum of the scores equals the number of components (which is three), the order fulfillment cycle time is perfectly fulfilled[19].

- Source cycle time: “The average time associated with source processes” [19].

Source cycle time = (Identify sources of supply cycle time + select supplier and negotiate cycle time) + schedule product deliveries cycle time + receive product cycle time + verify product cycle time + transfer product cycle time + authorize supplier payment cycle time

As unauthorized distributors are not as credible as authorized channels, whenever an OEM sources from them, it faces a significantly higher risk of receiving counterfeit parts or low quality articles. This higher risk demands a tighter verification process. In other words, the nature of unauthorized distributors results in a longer source cycle time. However, when the authorized distributor is out of stock or when there are some time prerequisites, OEMs may choose unauthorized distributors in order to get their orders faster.

- Make cycle time: The SCOR model defines make cycle time as “the average time associated with make processes”[19].

Make Cycle Time = (Finalize Production Engineering Cycle Time) + Schedule Production Activities Cycle Time + Issue Material/Product Cycle Time + Produce and Test Cycle Time + Package Cycle Time + Stage Finished Product Cycle Time + Release Finished Product to Deliver Cycle Time

When an OEM is not able to acquire its required articles from authorized channels, sourcing from unauthorized distributors helps an OEM to fulfill customer demands and keep the production line running. In this case, unauthorized distributors help the OEM to maintain its planned make cycle time. In contrast, lower quality items acquired from unauthorized channels may lead to a higher rework/remake rate, which in turn increases the make cycle time.

- Delivery cycle time: "The average time associated with deliver processes"[19].

Delivery cycle time = MAX {[receive, configure, enter and validate order cycle time + reserve resources & determine delivery date cycle time + (consolidate orders cycle time + schedule installation cycle time) + build loads cycle time + route shipments cycle time + select carriers and rate shipments cycle time], receive product from make/source cycle time} + pick product cycle time + pack product cycle time + load vehicle & generate shipping documentation cycle time + ship product cycle time + (receive and verify product cycle time)

Regarding the components of delivery cycle time, the effects of sourcing from unauthorized channels and the presence of counterfeits on this metric are negligible.

- Financial Impact: On the side of financial performance, the most obvious impact of any changes in order fulfillment cycle time is on the cash-to-cash cycle. Cash-to-cash is the average days required to turn a dollar invested in raw material into a dollar collected from a customer[27].

Cash-to-cash =Total inventory days-of-supply+ days-sales-outstanding (A/R) – average-payment-period to suppliers (A/P)

Inventory days-of-supply is a ratio of inventories to cost of goods sold[27]. It estimates the number of days that inventory, in its different forms, stays in the system before getting sold.

C2C is a metric that assesses a company's efficiency in managing its cash[28]. It expresses operational performance in financial terms and can be derived from information readily available in published financial statements [29]. The C2C metric holds importance from an accounting and supply chain management perspective. For accounting, the metric can be used to measure company liquidity and valuation. For supply chain management activities, it serves as a measurement bridging the processes into and out of the firm [30]. C2C is a composite metric. It reflects the interaction of a firm with its suppliers through accounts payable and raw materials inventory, the interaction of a firm with its customers through accounts receivable and finished goods inventory, and the operational efficiency of the firm itself through work in process inventory. A case study by Ruth Banomyong [28] shows that it is to some extent possible to specify the dominant party along a supply chain by considering the result of C2C calculation for all the companies along the chain. The dominant company usually is the one that has the lowest C2C cycle.

When an OEM is not able to source its required articles from an authorized channel, not sourcing them from an unauthorized channel will increase the company's order fulfillment cycle time, which in turn increases C2C cycle time, specifically through increasing inventory days-of-supply. On the other hand, while sourcing from unauthorized channels keeps the production line running, it will not always help an OEM to keep its normal lead time. It may cause a longer source cycle time and it may even result in a longer make cycle time. Therefore, here again it is not possible to make an absolute verdict about the impact of sourcing from unauthorized channels. It brings some benefits to the OEM but also some threats. OEMs need to analyze costs and benefits associated with sourcing from unauthorized channels based on their specific contexts in order to make a right decision.

6.3.3 Total Supply Chain Management Cost

Total Supply Chain Management Cost is defined as "the sum of the costs associated with the SCOR processes to Plan, Source, Deliver, and Return"[19].

TSCMC = Cost to (plan + source + make + deliver + return + mitigate supply chain risk)

- Cost to plan: "The sum of the costs associated with planning." The impact of sourcing from an unauthorized channel on this metric is negligible [19].

- Cost to Source: "The sum of the costs associated with sourcing." Cost to source is the sum of two distinct components: cost for supplier management and cost for material acquisition management[19].

Cost to source = Sum of cost for (supplier management + material acquisition management)

Where

Supplier management cost = Material planning + planning procurement staff + supplier negotiation and qualification + etc.

Material acquisition management cost = Bidding and quotations + ordering + receiving + incoming material inspection + material storage + payment authorization + sourcing business rules + inbound freight and duties + etc.

As an unauthorized channel is considerably less creditable than an authorized channel, whenever an OEM sources from one, it incurs a significant cost in the area of income material inspection. In addition, as unauthorized distributors are not audited by genuine manufacturers, an OEM would be obligated to do qualification itself. This imposes another cost on the OEM. On the other hand, an OEM might pay a lower price for items acquired from unauthorized channels.

- Cost to make: The sum of the costs associated with make. It is almost the same as cost of goods sold[19]. Therefore, cost to make is the sum of all direct costs attributable to the production of the goods or services sold by a company.

Cost to make = COGS = Cost of (direct labor + direct material + direct equipment)

In case of the presence of low quality parts among the income material, this cost may increase. Lower part quality affects the production process by increasing rework, remake, and scrap level, which in turn increases cost to make.

- Cost to deliver and/or install: "The sum of the costs associated with deliver and/or install"[19]. Cost to deliver and/or install is composed of two components: cost of sales order management and cost of sales customer management.

Cost to deliver = Sum of cost of (sales order management + customer management)

Where,

Sales order management = Inquiry & quotations + order entry & maintenance + channel management + order fulfillment + distribution + transportation + outbound freight and duties + installation + customer invoicing/accounting + new product release/phase-in + etc.

Customer management = Financing + post-sales customer service + handling disputes + field repairs + enabling technologies + etc.

Counterfeits mainly affect the customer management costs. The lower quality of counterfeits contributes to a higher field failure rate. Counterfeits increase the cost of post-sales customer service, handling disputes, and field repairs. As was mentioned before, genuine manufacturers provide no service for the parts acquired from unauthorized distributors. Therefore, an OEM needs to cover the total cost.

- Cost to return: "The sum of costs associated with returning defective products to supplier and receiving defective products from customer"[19].

Cost to return = Sum of cost to return (to sources + from customers)

In the case of sourcing from unauthorized channels, suppliers do not provide any after sale service to OEMs. Therefore, an OEM has to take all the costs associated with defective components individually. On the other hand, due to higher failure rate of counterfeits, the rate of returns from customers increases. These two factors contribute to a higher cost to return for the OEM.

- Financial Impacts: Total supply chain cost has a direct impact on the income statement. It influences cost of goods sold (COGS), sale and general and administrative costs (SG&A), and special or extraordinary losses. A higher cost of source and make increases COGS and a higher cost to deliver/install increases either SG&A or irregular, special, or extraordinary losses. Regarding the metric components, we cannot absolutely infer that sourcing from unauthorized channels increases the total supply chain cost, as an OEM may pay a lower price to unauthorized distributors. However, there is probability for a higher cost. OEMs may accept this temporally higher cost because they need to fulfill their obligations, the expected revenue justifies it, or because the possible goodwill costs outweigh this cost.

6.3.4 Capacity Utilization

The SCOR model defines capacity utilization as "a measure of how intensively a resource is being used to produce a good or service" [19]. When sourcing from authorized channels is not possible, an OEM can maintain its capacity utilization by sourcing from unauthorized distributions. In the presence of demand, higher capacity utilization leads to a higher sales revenue and, therefore, a higher profit. However, a higher level of capacity utilization may stem from tighter product inspections, higher rework/remake/scrap rate, or higher rates of field failure.

6.4. Qualitative phase conclusion

Sourcing from unauthorized distributors comes at a cost. It raises concerns about an OEM's supply chain performance and financial performance. As Table 2 illustrates, order fulfillment cycle time, perfect order fulfillment, total supply chain management cost, and capacity utilization are the main supply chain metrics that are influent. On the other hand, sales revenue, asset level, liabilities, cost of goods sold, sale and general and administrative cost, and days of inventory outstanding are the main financial parameters that are alerted. These financial parameters are the building blocks of many financial ratios.

Due to qualitative approach limits, we are not able to judge the overall impact of counterfeits and sourcing from unauthorized channels on OEMs. We believe that the overall impact differs from one situation to another. Obviously, there is a trade-off involved. In some cases it might be beneficial for OEM to source form unauthorized channel, while in some other situation, these benefits might be outweighed by the risks.

Table 2 Impact of counterfeits and sourcing from unauthorized distributors in the OEM supply chain and financial performance

<table>
<tr><td rowspan="3">Order Fulfillment Cycle Time</td><td>Source Cycle Time</td><td colspan="2" rowspan="3">- C2C</td></tr>
<tr><td>Make Cycle Time</td></tr>
<tr><td>Delivery Cycle Time</td></tr>
<tr><td rowspan="4">Perfect Order Fulfillment</td><td>Percentage of Orders Delivered in Full</td><td colspan="2" rowspan="4">- Sales Revenue
- Intangible Asset (Company Image)
- Company Liabilities</td></tr>
<tr><td>Delivery Performance to Customer Commit Date</td></tr>
<tr><td>Documentation Accuracy</td></tr>
<tr><td>Perfect Condition</td></tr>
<tr><td rowspan="7">Total Supply Chain Management Cost</td><td>Cost to Plan</td><td colspan="2"></td></tr>
<tr><td rowspan="2">Cost to Source</td><td>Cost for Supplier Management</td><td rowspan="6">- Cost of Goods sold (COGS)
- Sale, General & Administrative costs (SG&A)
- Intangible Asset (Company Image)
- Irregular, Special or Extraordinary Gain/Loses</td></tr>
<tr><td>Cost for Material Acquisition Management</td></tr>
<tr><td>Cost to Make</td><td>Scrap Level (Rework/Remake/Disposal)</td></tr>
<tr><td>Cost to Deliver and Install</td><td>Customer Management</td></tr>
<tr><td rowspan="2">Cost to Return</td><td>Cost to Return to Source</td></tr>
<tr><td>Cost to Return from Customer</td></tr>
<tr><td>Capacity Utilization</td><td colspan="3">Sale Revenue</td></tr>
</table>

7 Quantitative phase

During this phase, based on the SCOR model, a deterministic discrete event simulation model and its metric are developed. Perfect Order Fulfillment and Order Fulfillment Cycle time are used to measure supply chain performance and operating profit margin is used to gauge OEM financial performance. Experiments are conducted through a design of experiment table. We compared the effects of different alternatives to the situation when OEM is entirely sourcing its required raw material form authorized channel.

7.1. Supply Chain Simulation and Modeling

Using simulation to understand the supply chain and improving it is a common practice. A review of some papers in this area shows that scholar have utilizing simulation models to gain a deeper insight about a wide range of different problems. Spengler and Schröter [31], based on a closed-Loop Supply Chain, modeled an integrated production and recovery system for supplying electronic equipment spare parts to evaluate possible strategies for meeting spare-parts demand for electronic equipment in the end-of-life. Vlachos, Georgiadis, and Iakovou [32] developed A system dynamics model for dynamic capacity planning of manufacturing facilities in reverse supply chain concerning economic and environmental constrains. Kelepouris, Miliotis, and Pramatari [33] modeled a two echelon supply chain to understand impact of replenishment parameters and information sharing on the bullwhip effect. Spedding and Sun [34] used discreet event simulation to model a semi-automated Printed CirQuit Board (PCB) assembly line and integrated it with the Activity Based Costing (ABC) method. Persson and Araldi [35] developed a set of generic supply chain blocks based on the SCOR model in the ARENA environment. Holweg and Bicheno [36] point out the rule of simulation in enhancing the organizations level of knowledge about the importance of supply chain management. Persson and Olhager [37] used simulation to develop a model for a manufacturer of mobile communication systems in order to evaluate alternative designs of supply chain. Bhaskaran [38] modeled a stamping pipeline in an automobile supply chain to improve the performance of chain by controlling schedule instability and the inventory.

Supply chain models can be used to improve our knowledge about the supply chain and the importance of it [36]. Modeling helps companies to become more aware of their supply chain dynamics and efficiency. It provides reliable information to root supply chain decision-makings processes into facts rather than mere knowledge or emotions. Simulation models can be used to evaluate SCM policies (such as inventory management policies) and predict the outcome of different alternatives [39] and to quantity the costs and benefits associated with different scenarios[40]. Supply chain models make it possible to test various hypotheses at a low cost and without disturbing the real system [41].

There is a variety of approaches to build a supply chain model. In general, the most popular supply chain models can be grouped into the following categories: analytical models, spreadsheet models, system dynamic models, and discrete event simulation models [40][42]. Each modeling approach has its own limitation, strength and weaknesses. Problem statement, study objectives, and the particular conditions associated with the study determine the most appropriate model for a specific system. There is a shortlist of pros and cons of each modeling approach below.

Due to their long time-use in the logistic industry and their low cost as well as high approachability, analytical models of supply chain are highly popular. However, these models suffer from their disability to incorporate a wide range of variables, their hard time to cover stochastic input variables, and their limitation to a particular set of assumption. Supply chains are usually stochastic systems. Demand, lead time, processing times, machine breakdowns, available supply and other input variables usually have a probabilistic nature. It is really hard to capture these stochastic behaviors with analytic models. Incorporating stochastic behaviors in an analytical model would lead to highly complex or unsolvable mathematical formulas[42]. Analytical models are developed based on a particular scenario. The results are only valid in the domain of that scenario. In simulation, it is easily possible to change the scenarios and perform different experiments with the same model [35] and to incorporate a wide rand of variables. Simulation helps in understanding causality [40]. On the other hand, developing analytical models usually require a high level of mathematical knowledge; however, developing simulation models dose not need such sophistication.

Spreadsheet models are usually too simple and highly idealized. They barely can capture dynamic of system, stochastic variables, or complex causalities [40]. However, there are cheap and easy to develop.

System dynamic models are mathematical descriptions of a system. Each model is composed of a number of variables which are related together through mathematical formulas. All variables need to be explained and coupled together through these formulas. Therefore, it is assumed that important factors and their causal relations are known in advance. In a system dynamic environment, to form a model, a modeler has just two different types of blocks: stock and flow diagrams and casual loops. A stock represents a system state variable, such as an inventory or a buffer. A flow is a rate, for example, a production rate or a shipment rate. Casual loops, positive or negative, represent the feedbacks [4]. It is hard to capture a high level of details just through these two modeling tools, which in turn, results in a high amount of idealizations and aggregations. For example, it might be necessary to aggregated a number of events and model all of them with a single rate. On the other hand, the modeler need to assume that the flows along the chain have a continues nature (they are rates), even though they may occur at discrete points at time in real system. Therefore, a deviation between system dynamic outputs and real system might be unavoidable: "SD differs significantly from a traditional simulation method, such as discrete-event simulation where the most important modeling issue is a point-by-point match between the model behavior and the real behavior, i.e. an accurate forecast. Rather, for an SD model it is important to produce the major "dynamic patterns" of concern (such as exponential growth, collapse, asymptotic growth, S-shaped growth, damping or expanding oscillations, etc)" [32]. even though system dynamic models represent the evaluation of output variables over the time, in presence of a particular set of input variables with fully determined value at the moment, they are not event driven (Inputs and outputs are not dependent on time). Participant needs to alter the value of inputs manually. Finally, most SD models are not able to incorporate particular stochastic behavior at their input variables, such as, normal distribution [40].Despite the mentioned limitations, system dynamic models are powerful tools to describe the dynamic of supply chain and the effects of supply chain policies at a high level of aggregations. They provide insight about the impact of any change in input variable on the output variables over the time. It is not easy to acquire such an understanding through other models. On the other hand, regarding the cost of system dynamic software, they are more approachable.

In contrast with spreadsheet, analytical, and system dynamic models; discrete event simulation provides a more flexible and comprehensive environment to capture the complex nature of supply chain. One may select discrete event modeling and simulation due to its ability to incorporate a wide range of variables, its ability to capture the stochastic behavior of supply chains, its ability to represent individual events, its ability to reveal causalities, and its dynamic (time-based) nature as well as its simplicity. However, a sophisticated programming knowledge or the high cost of the discrete event simulation software along with the long process for developing model may make it less approachable. Our study is aimed at understanding causalities among a number of parameters through investigating different scenarios. Discrete event modeling provides a proper environment to do so.

7.2. Model Formulation and Translation

In this section, we describe our approach for formulating, translating, and verifying the simulation model.

7.2.1 Model Formulation

Figure 3 is business scope diagram of our model. Business scope diagram is one of the tools introduced by SCOR. It represents the scope of the supply chain that is captured by simulation model. Simulation model is composed of two suppliers (one authorized distributors and one unauthorized distributor), OEM, and Customer. Beside flow of material and information, the model partially covers the cash flow between supply chain members. Incorporating cash flow allows us to study the effect of supply chain policies on the financial performance of the original equipment manufacturer. It provides a more holistic approach to study SCM policies.

Arrows depict the flow of material, information, and cash between supply chain members. Forward material flow initiates form distributors, continues to OEM and ends up to Customer. Reverse material flow, occurs due to after sale service, happens either between Customer and OEM or between OEM and authorize distributor. There is no reverse material flow form OEM to unauthorized distributor. Information flows sequentially: from Customer to OEM and form OEM to distributors. Cash also flows sequentially, however, in both directions: from Customer to OEM and vice versa as well as form OEM to distributors and vice versa. However, as an exception, there is no cash flow from unauthorized distributors to OEM.

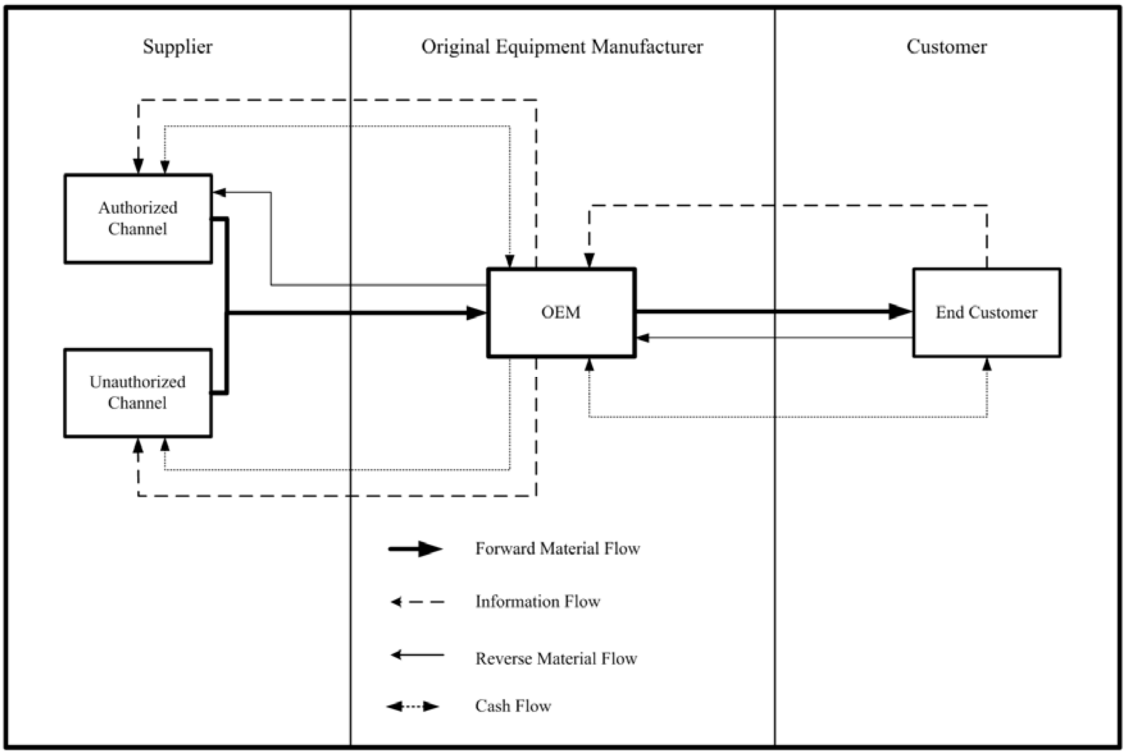

Figure 3 Business scope diagram

Every member of the chain is molded through a combination of SCOR management processes (Figure 4). After modeling each member, these individual models are coupled together at their boundaries and through source, return, and plan processes. The result is the extended supply chain.

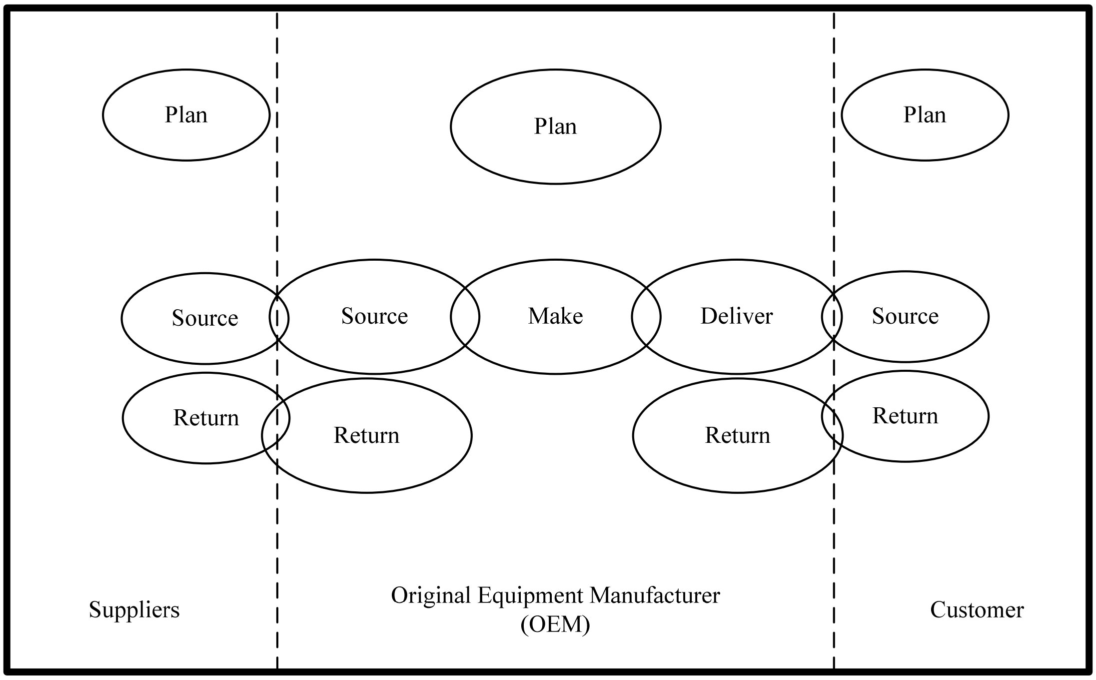

Figure 4 Simulation model extent based on the SCOR processes

Models are abstracted simplified representation of reality. However, regarding modeling objective, they need to incorporate a proper level of details. A high level of detail may result in complex ambiguous models and a low level of detail may lead to a model that does not correspond to the real system in domain of interest. Supply chains, as complex systems, can highly be detailed. The choice of the level of detail is therefore an important issue in supply chain modeling. In many cases, it would be more practical to model different members of the chain at different level of details [35][39]. Our model, as a descriptive model, does not need to be highly detailed as for instance a manufacturing optimization or operational control model needs [37]. Neither all SCOR process nor all SCOR process elements are incorporated in model (Figure 4 - Figure 5). OEM is molded in more detail than Customer and suppliers.

From the Customer side, source (S2), plan-source (P2), and source-return defective product (SR1) are included. As the Customer is the final Customer (end consumers), it is not required to include other processes. From the supplier side, deliver (D1), plan-deliver (p4), and deliver-return defective product (DR1) are included. Suppliers' inter-organization processes are not relevant to our study, and therefore, they are discarded. It is assumed that suppliers follow make to stock strategy. That is, once they receive OEM order, providing that they have the item on the stock, they immediately ship it. If OEM, due to any reason, cannot source from authorized channel, it will source from unauthorized distributors. Unauthorized distributors are modeled as an unlimited source of raw materials. Eventually, OEM is modeled through source (S2), make (M2), Deliver (D2), plan-source (P2), deliver-return defective product (DR2), and source-return defective product (SR2). OEM follows make to order strategy. That is, source, make, and deliver processes all are triggered based on the specific Customer orders.

SCOR model [19] defines "source make to order product" process as "The processes of ordering and receiving product or material that is *ordered (and may be configured) only when required by a specific Customer order*. The intention of Source-to- Order is to maintain inventory ordered (and/or configured) specifically for Customer orders only. The product is ordered, received and identified in stock using this Customer order reference (order designated inventory). The product is typically identifiable throughout the sourcing process, by the reference to the Customer order attached to or marked on the product or packaging and in the warehouse management or ERP system." The make process in make to order environment happens when "Products are completed, built or configured only in response to a Customer order, the Customer order reference is attached to the production order, attached to or marked on the product upon completion of the make process and referenced when transferring the product to Deliver. The product is identifiable throughout the Make process, as made for a specific Customer order" [19]. The "deliver make to order product" process is defined as "The processes of delivering product that is sourced, configured, manufactured, and/or assembled from standard raw materials, parts, ingredients or sub-assemblies, in response to a specific firm Customer order. A reference to the Customer order is exchanged with the sourcing or makes process and attached to or marked on the product. Products in stock are identifiable by Customer order through labeling and inventory data management" [19]. The "Source Return Defective Product" is a process that is associated with the source process. It is "The return and disposition determination of defective products as defined by the warranty claims, product recall, non-conforming product and/or other similar policies including appropriate replacement" [19]. The "Deliver Return Defective Product", which is coupled to deliver process, is "The receipt and disposition determination of defective products as defined by the warranty claims, product recall, non-conforming product and/or other similar policies including appropriate replacement" [19].

High level flow chart is an essential tool for defining the system and formulating the simulation model. A high-level flow chart helps the modeler to obtain a fundamental understanding of the system logic. It graphically depicts the interaction of major processes, the role of inputs and outputs, and the flow of information, material and cash along the chain [41]. As Figure 5 illustrates, the simulation model initiate with generating Customer order (P2: Customer). Once OEM receive the Customer order, it tries to source it from authorized channel (P2: supplier and OEM – D2: supplier – S2: OEM). If due to any reason OEM fails to source form authorized channel, it either rejects the order or sources it from unauthorized channel. Upon receiving the raw material, it will be inspected by OEM (S2: OEM). Providing that it passes the inspection, OEM will authorize supplier payment. On the other hand, raw material will be deployed to make process (M2: OEM). If raw materials fail the inspection, OEM needs to repeat the sourcing process.

Make process is composed of production, test, and reworks stations (M2: OEM). All items go through production and test stages. However, If an item fail during the make process's test, it will go to rework station. Once OEM gets assured about product quality, it will be delivered to the Customer. Customer pay

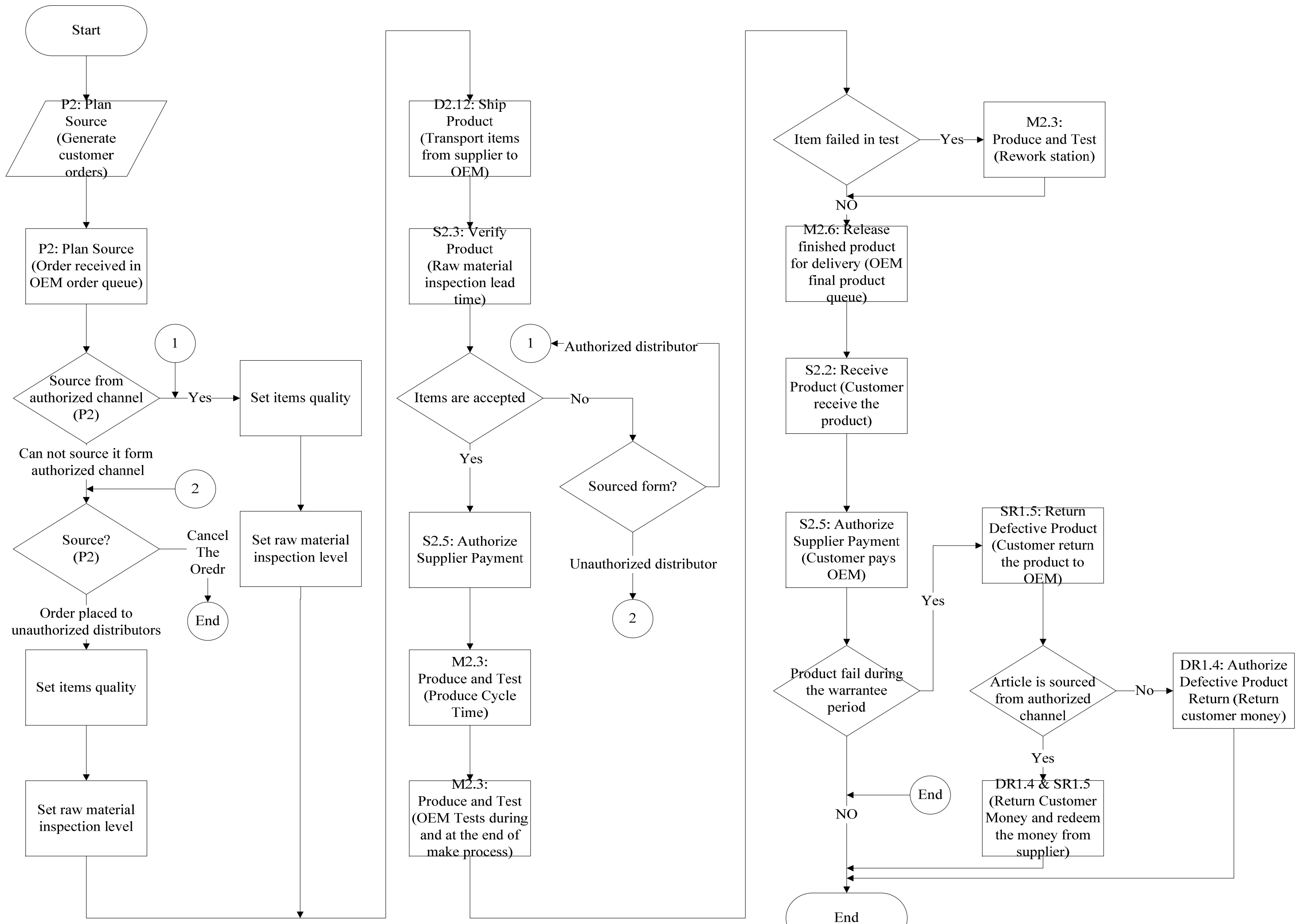

Figure 5 High-level flow chart

the OEM as soon as it receives the product (S2: Customer). If an item fails during their warrantee period, Customer sends it back to OEM (SR1.5: Customer) and redeem its money (DR1.4: OEM). On the other hand, OEM deals with deliver-return products based on their raw material suppliers. If raw material is sourced from authorized distributor, OEM will also redeem the raw material price from the supplier. However, if it is sourced from unauthorized distributors, OEM incurs all the cost individually. It is because genuine manufacturers provide no after-sale service for items sourced from unauthorized supplies. Regarding Perfect order Fulfillment definition (defined in section 7.2.2), orders are perfectly fulfilled providing that they do not fail during the warrantee period. As OEM refunds the full price of products that fails during the warrantee period, OEM only gains profit form orders that are perfectly fulfilled.

7.2.2 Inputs and Performance Measures

Model inputs are grouped in two categories: constant inputs and variables inputs. Constants inputs are those inputs that stay constant between different simulation experiments. Customer demand and processes cycle times (source lead time, raw material inspection cycle time, production cycle time, test cycle time, rework cycle time) belong to this group. Setting these inputs as contacts, it helps to eliminate the noises.

Variable inputs are those that their values intentionally change form one experiment to another one based on the experiment table. That is, this set is assumed to be the cause factor of the model response factors (performance measures). Probability of sourcing form unauthorized channel, probability of canceling orders, raw material quality and failure rates, unauthorized channel raw material price, and goodwill cost form this group. Model differentiate between items sourced from authorized channel and unauthorized channel through items quality as well as after-sale service availability. Item quality affects the probability of failure during material inspection, make process, and warrantee period. It is worthy to mention that simulation participant can alter the value of any model input, both constant and variable ones, at his/her own preference. It builds a high level of flexibility in the model. The values of constant inputs are assumed through careful consultation with experts. As a comparative study, we are interested in trends and not the absolute values.

The following SCOR level one metrics are used as model performance measures: Perfect Order Fulfillment form Reliability metrics and Order Fulfillment Cycle Time from Responsiveness metrics. In addition, in order to understand the effect of sourcing policies on the OEM financial performance, OEM operating profit margin is measured too. As it is described in chapter 6.2, agility metrics are excluded from the study.

SCOR model[19] defines Perfect Order Fulfillment as “the percentage of orders meeting delivery performance with complete and accurate documentation and no delivery damage. Components include all items and quantities on-time using the Customer’s definition of on-time, and documentation – packing slips, bills of lading, invoices, etc”. Perfect Order Fulfillment, itself, is composed of four distinct level two metrics: Percentage of Orders Delivered in Full, Delivery Performance to Customer Commit Date, Documentation Accuracy, and Perfect Condition. Out of these four metrics, perfect condition extents to warrantee period. That is, an order is considered to be delivered in perfect condition “if all items delivered undamaged, meet specification and has correct configuration (as applicable), faultlessly installed (as applicable) and accepted by the Customer, and not returned for repair or replacement within the warranty period”.

Order Fulfillment Cycle Time is “the average actual cycle time consistently achieved to fulfill Customer orders. For each individual order, this cycle time starts from the order receipt and ends with Customer acceptance of the order”[19] [19]. Order Fulfillment Cycle is actually the Cumulative cycle time for all activities that are required to fulfill the order. It reflects the responsiveness of the chain. [19]

Operating profit margin is a measure of profitability that is calculated by dividing operating profit (profit before interest and taxes) to sale revenue. It indicates how will a company is running its entire business form an operational standpoint. That is, by excluding financial costs (interests and taxes), this metric solely indicates operational efficiency of a company [25]. Also, by taking sale revenue, cost, and operating profit into consideration; operating profit margin provides a more accurate picture of company finical performance than measure such as profit or cost. Even though we measure OEM profit and total cost, but we do not use them as performance measures.

7.2.3 Model Translation

There is a range of general and tailored programming languages as well as simulation software for making simulation models. On the other hand, commercial vendors also offer specific supply chain simulators such as IBM Supply Chain Simulator and G2-e-SCOR.

ExtendSim, which is originally released in 1987 as extend, represents a family of Multi-purpose simulation software that provide interactive block diagram model building with a user-friendly graphic interface (GUI) as well as programming ability. It is a multi-domain environment, so users can dynamically model continuous, discrete event, discrete rate, agent-based, linear, non-linear, and mixed-mode systems. As ExtendSim supports the programming ability, users are able to develop their own blocks, make their own libraries, or customize the available blocks and environment. It also provides a 2D or 3D environment for visualization.

Our model is developed with ExtendSim OR version 7, which is a member of ExtendSim family. The following ExtendSim OR blocks are used to built the simulation model: Executive, Create, Queue, Information, Set, Get, Select item out, Select item in, Simulation variable, Constant, Random number, Write, Throw item, Catch item, Equitation(I), Activity, Math, Mean and Variance, and Exit. We strongly believe that the functions of these blocks are transferable to any general simulation software. ExtendSim internal database is used for storing and retrieving data.

7.2.4 Verification and Validation

Verification and validation have a vital importance in molding process[37]. They are prerequisites to credible and reliable use of a model and its results. Verification is defined as the process of determining if a model is consistent with its specification. Validation is the process of determining the degree to which the model is an accurate representation of the real system at the domain of interest [43]. To put it simply, verification is concerned about “Building the model correctly”, while validation deals with “Building the correct model” [41].

Our Model is developed based on the Divide-and-Conquer Approach. That is, the final model gradually evolved from a simple model in a series of small steps. At the end of each step and before adding new blocks to the model, model was verified. Divide-and-Conquer Approach made it easy to find the errors and fix the deviations. Eventually, the final model was verified through animation as well as comparing the outputs of the model to their analytically expected values in known scenarios.

V&V cannot prove that a model is correct and accurate for all possible conditions and applications, but, rather, it can provide evidence that a model is sufficiently accurate [43]. Our model is developed based on a generic supply chain, and therefore, it is not meaningful or possible to validate it. However, as the model is a descriptive high level model, it is practical to say that the model is valid in the domain of its assumption and simplifications.

7.3. Experiment Setup

Experiments were conducted through a fractional two level design of experiment with 5 main parameters (2^{5-1}_{V}). Table 3 shows cause factors and their associated minimum and maximum levels. 2^{5-1}_{V} DOE results in sixteen different treatments. These treatments are categorized in two different groups. First group represents the situations when OEM is able to source all its required articles from authorized distributor (Su=-1 and C = -1). Second group represents the situation when OEM is not able or willing to source all its required articles from authorized distributes. In this case, OEM may source the remaining part from unauthorized distributor (Su=1 and C=-1), OEM may reject the orders that cannot be sourced from the OEM as soon as it receives the product (S2: Customer). If an item fails during their warrantee period, Customer sends it back to OEM (SR1.5: Customer) and redeem its money (DR1.4: OEM). On the other hand, OEM deals with deliver-return products based on their raw material suppliers. If raw material is sourced from authorized distributor, OEM will also redeem the raw material price from the supplier. However, if it is sourced from unauthorized distributors, OEM incurs all the cost individually. It is because genuine manufacturers provide no after-sale service for items sourced from unauthorized supplies. Regarding Perfect order Fulfillment definition (defined in section 7.2.2), orders are perfectly fulfilled providing that they do not fail during the warrantee period. As OEM refunds the full price of products that fails during the warrantee period, OEM only gains profit form orders that are perfectly fulfilled.

7.4. Simulation Outcomes and Analysis

As Figure 6 shows, in comparison with reference point, the factors that have a significant effect on the Perfect Order Fulfillment Cycle Time are Qu, interaction of Su and Qu (Su.Qu), and Su respectively. It shows that regarding this metric, quality of raw material is the highest concern and sourcing volume stands afterward. Su is directly proportional to Perfect Order Fulfillment Cycle time. An increase in Su results in a longer Perfect Order Fulfillment Cycle time. On the other hand, an increase in Qu or Su.Qu leads to a shorter Perfect Order Fulfillment Cycle time. It is worthy to remember that model does not have any capacity limitation. Therefore, cancelling or accepting an order does not have any impact. In addition, sourcing procedure stays identical between authorized and unauthorized distributors. Therefore, effects of different OEM sourcing procedures, distributors' procedures, and transportation are eliminated.

Table 3 DOE levels

Factor Name	Symbol	-1 (Min)	1 (Max)
Percentage of orders sourced from unauthorized distributor	Su	0	50% of orders
Percentage of orders received but cancelled	C	0	25% of orders
Unauthorized distributor raw material quality (Qa stands for authorized distributor raw material quality)	Qu	0.30Qa	Qa
Acquisition cost – Unauthorized distributor (Ca strands for authorized distributor acquisition price)	Cu	0.25Ca	Ca
Goodwill Cost (P stands for OEM profit when OEM entirely source form authorized distributer; Su=-1 & C=-1)	Cg	0$	.33P

Figure 7 illustrates effects of Qu and Su on Perfect Order Fulfillment Cycle time. Point (1) refers to reference point (all items are sourced from authorized distributor). If the quality of items coming from unauthorized distributor is as high as authorized distributors (Qu=1), then sourcing from unauthorized distributor almost has a negligible negative effect on Perfect Order Fulfillment Cycle time. However, if the quality of items coming from unauthorized distributor is lower than authorized distributors (-1<=Qu<1), then sourcing form unauthorized distributer increases Perfect Order Fulfillment Cycle time. The magnitude of this increase depends on the sourcing volume and the quality of items coming from unauthorized distributor. In the worst case (Qu=-1 and Su=1), it results in 57 percent increase. In a more moderate case (Qu=-1 and Su=0), it result in 35 percent increase.

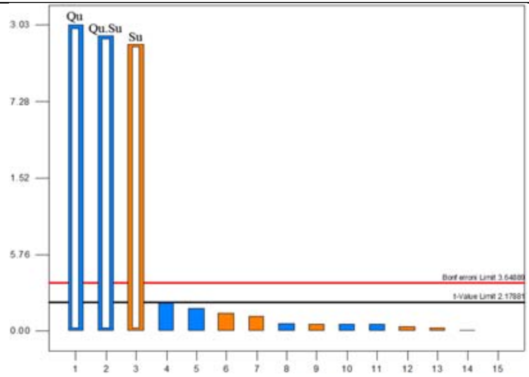

Figure 6 Pareto Chart (Significant cause factors)

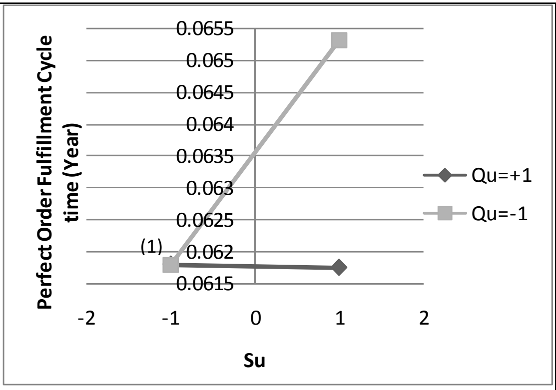

Figure 7 Impact of Su and Qu on Perfect Order Fulfillment Cycle time

If we calculate Perfect Order Fulfillment based on the committed orders, the most important factors that have an effect in comparison with reference point are Qu, Su, and the interaction of Su and Qu (Su.Qu). As Figure 8 shows, the extent of their impact is almost same. Qu and Su.Qu are directly proportional to Perfect Order Fulfillment. An increase in Qu or Su.Qu leads to a higher Perfect Order Fulfillment. On the other hand, an increase in Su results in a lower Perfect Order Fulfillment.

Figure 9 illustrates effects of Qu,Su.Qu, and Su on Perfect Order Fulfillment. Point (1) refers to reference point (all items are sourced from authorized distributor). If the quality of items coming from unauthorized distributor is as high as authorized distributors (Qu=1), then sourcing from unauthorized distributor has almost no effect on Perfect Order Fulfillment. However, if the quality of items coming from unauthorized distributor is lower than authorized distributors (-1<=Qu<1), then sourcing form unauthorized distributer has a negative effect on Perfect Order Fulfillment. The magnitude of this effect depends on the sourcing volume and the quality of items coming from unauthorized distributor. In the worst case (Qu=-1 and Su=1), it results in 33 percent decrease. In a more moderate case (Qu=-1 and Su=0), it result in 17 percent decrease.

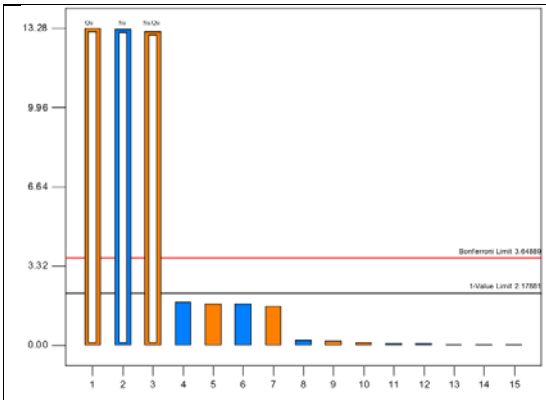

Figure 8 Pareto Chart (Significant cause factors)

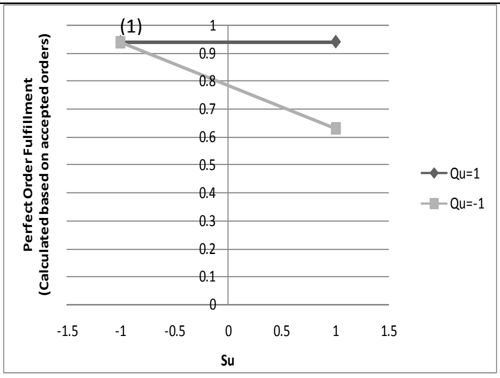

Figure 9 Impact of Su and Qu on Perfect Order Fulfillment (based on the committed orders)

If we calculate Perfect Order Fulfillment based on the received orders, the most important factors that have an effect in comparison with reference point are C, Su, interaction of Su and Qu (Figure 10). Su, Qu, and their interaction almost have the same impact extent; however, the impact of C is almost two times greater. It is because cancelling the orders immediately decreases the Perfect Order Fulfillment; however, sourcing form unauthorized channeling may result in a lower Perfect Order Fulfillment only providing that product fails. Qu and Su.Qu are directly proportional to Perfect Order Fulfillment. An increase in Qu or Su.Qu leads to a higher Perfect Order Fulfillment. On the other hand, the higher the Su or C, the lower the Perfect Order Fulfillment.

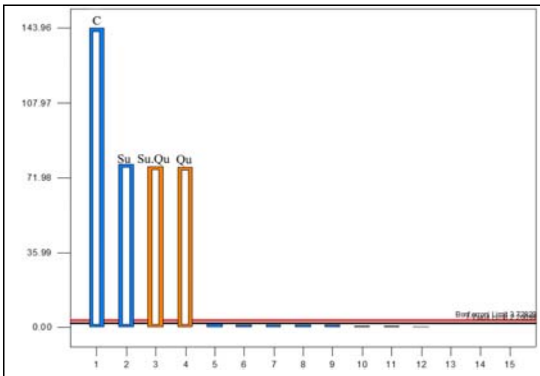

Figure 10 Pareto Chart (Significant cause factors)

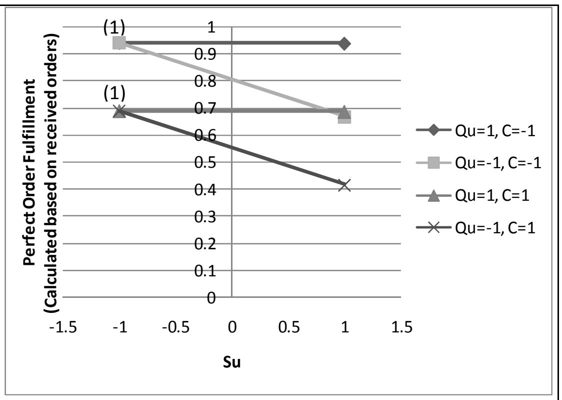

Figure 11 Impact if C, Su and Qu on Perfect Order Fulfillment (based on the received orders)

Figure 11 illustrates effects of C, Qu and Su on Perfect Order Fulfillment (calculated based on the received orders). Point (1) refers to reference point (all items are sourced from authorized distributor). Cancelling the orders has a negative impact on perfect order fulfillment as big as cancellation size. On the other words, as much as OEM cancels the orders, Perfect Order Fulfillment declines. In the worst case (C=1), perfect order fulfillment decrease for 25 percent. In a more moderate case (C=0), perfect order fulfillment decrease for 12.5 percent. Regardless of percentage of cancellation, If the quality of items coming from unauthorized distributor is as high as authorized distributors (Qu=1), then sourcing from unauthorized distributor has a negligible effect on Perfect Order Fulfillment. However, if the quality of items coming from unauthorized distributor is lower than authorized distributors (-1<=Qu<1), then sourcing form unauthorized distributer has a negative effect on Perfect Order Fulfillment. The magnitude of this effect depends on the sourcing volume and the quality of items coming from unauthorized distributor. In the worst case (Qu=-1 and Su=1), it results in 33 percent decrease. In a more moderate case (C=-1, Qu=-1 and Su=0), it result in 13 percent decrease. It is interesting that the effect of fifty percent sourcing from unauthorized distributor at its lowest quality(C=-1, Qu=-1, Su=1) is almost same with the effect of cancelling twenty five percent of orders (C=1 and Su=-1). Solely regarding this metric, sourcing form unauthorized distributors seems to be a better option to OEM rather than cancelling customer orders.

As Figure 12 represent, in comparison with reference point, the most important factors that have a significant effect on OEM operating profit margin are Qu, Su.Qu, Su, Su.Cu, and Cu respectively. Here again quality of Items coming from unauthorized distributor has the highest impact. Surprisingly, unauthorized distributor price has the lowest impact (more than two times smaller than Qu). It means that in long run (our simulation model time horizon is one year), even solely regarding OEM financial performance, raw material quality is a more conclusive factor. When authorized distributor quality is higher than unauthorized distributor quality, regarding this metric, it is a wiser decision to source form authorized ones even at a higher price. Qu and Su.Qu are directly proportional to operating profit margin. An increase in Qu or Su.Qu leads to a higher net profit margin. On the other hand, an increase in Su, Cu, or Su.Cu results in a lower operating profit margin.

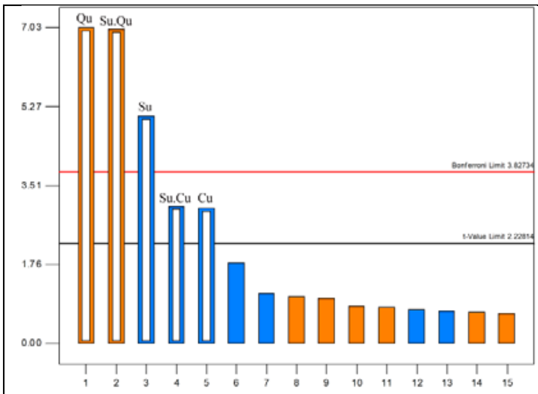

Figure 12 Pareto Chart (Significant cause factors)

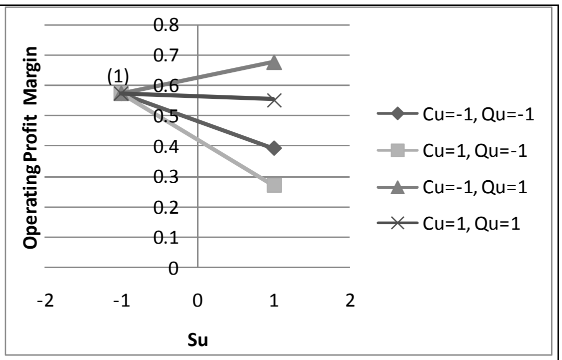

Figure 13 Impact of Su, Qu and Cu on operating profit margin

Figure 13 illustrates effects of Qu, Su.Qu, Su, Su.Cu, and Cu on OEM operating profit margin. Point (1) refers to reference point (all items are sourced from authorized distributor). If the price of unauthorized distributor is as high as authorize one, then sourcing form it will never improve the operating profit margin in comparison with sourcing form authorized ones. Even in the best case, when the quality is also as high as authorized one, sourcing form unauthorized ones slightly decrease the operating profit margin. However, when price of unauthorized distributor is lower than authorized ones, the situation differs. In this case, the combination of quality (Qu), price (Cu), and percentage of items sourced from unauthorized channel determine the impact. At the best case, when (Qu=1, Cu=-1, and Su=1), operating profit margin is improved by 17 percent. However, when quality of items coming from unauthorized distributor drops, this improving effect fades. After passing a quality threshold, even at the lowest price (Cu=-1), sourcing form unauthorized distributor will decrease operating profit margin. In case of our model, this threshold is equal to about Qu=0.3 (Qu=0.3 means that the quality of items coming from unauthorized channel is 75 percent of quality of items coming from authorized channel).At the worst quality and best price (Cu=-1, Qu=-1, and Su=1), sourcing from unauthorized channel decreases operating profit margin by forty six percent in comparison to reference point. This lose is almost three time bigger than the gain of best case (17pecent improve) and it just happens because of quality. At the worst quality and worst price (Cu=1, Qu=-1, Su=1), sourcing from unauthorized channel decreases operating profit margin by 118percent in comparison to reference point.

As mentioned before, quality of raw material has a stronger impact on the operating profit margin rather than price of raw material. In case of (Su=1 : OEM source fifty percent of the required raw material from unauthorized distributor), going form highest price to lowest price (Cu=1 to Cu=-1) changes the Operating profit margin by about 22 percent. However, at the same acquisition size, going form highest quality to lowest quality changes operating profit margin by about 70percent or 100percent. Therefore, benefit of a low price can be cancelled out by a low quality.

7.5. *Quantitative phase conclusion*

When OEM source form unauthorized channel, among the considered factors in this study, quality of raw material is the most important concern. Sourcing volume and raw material price stand afterward. Regarding the Perfect Order Fulfillment ,calculated based on the received orders, negative impact of cancellation is greater than negative impact of sourcing form unauthorized channel (almost two times). It roughly implies that, just regarding this metric, sourcing from unauthorized channel is a more favorable decision rather than cancelation. The exact impact emerges from the cancellation size as well as quality and the number of item sourced from unauthorized distributor. Regarding the study reference point, sourcing form unauthorized distributor always has a negative impact on Perfect Order fulfillment cycle time and perfect Ordered fulfillment. Extent of this impact is determined by raw material quality, sourcing volume, and their interaction. For instance, this impact is negligible in some cases. Regarding operating profit margin, quality, sourcing size, and price determine the impact. Comparing to other significant factors, price has the lowest influence and after passing a quality threshold, even at the lowest price, sourcing from unauthorized distributor decrease the operating profit margin.

8 Overall Conclusion

Whenever OEM is not able or willing to source form authorized channel, its options narrow down to the following alternatives: waiting until the item become available in authorized channel (backlogging the orders), sourcing from unauthorized channel, or cancelling customer orders. In some cases, sourcing form unauthorized channels is inevitable. As the qualitative phase showed, there is a trade-off involved in sourcing from unauthorized channels. While it may help to enhance some metrics, it may degrade some others. The correct decision needs to be made based on the each business particular circumstance. Regarding our simulation model and supply chain metrics, sourcing from unauthorized channel never results in a higher performance rather than sourcing from authorized channel. Regarding the financial performance, represented through operating profit margin, the improvement may happen in rare cases and its magnitude is not significant.

As the quantitative study showed, whenever OEMs source from unauthorized channel, quality of raw material should mostly be the highest concern of OEMs. Therefore, whenever they face the unauthorized channels, they should employ proper risk mitigation methods to reduce the risk of acquiring counterfeits or low quality articles. A low price alone does not imply that sourcing form unauthorized channel is profitable. Indeed, raw material price and sourcing size showed to be less influential on the studied metrics.

Besides mitigating the risk of low quality items and counterfeits along with enjoying from genuine manufacturer warrantee, franchise agreements typically contains a number of provisions that protect the customers by ensuring product integrity and traceability. Proper handling, storage and shipping procedures, failure analysis and corrective action support, certificates of conformance, acquisition traceability, and other value-added services are among the benefits that a franchised distributor provides for its Customers. Unauthorized distributors, at least as they do not have such an agreement with the manufacturers, have limited means to offer the mentioned benefits[9].

The quantitative phase of this study was based on a generic supply chain and a two level design of experiment. While this is a proper setting to screen out insignificant factors and to understand the general behavior of parameters, it is not an adequate model to quantify the interactions. A more elaborated model and some case studies are required in this regard. Formulating the interactions between parameters, valuating the quality threshold, and a wider clarification of financial impacts of sourcing decisions could be the next step of this study.

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