

Innovative Logistics Management under Uncertainty using Markov Model

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Abstract

This paper proposes an innovative uncertainty management using a stochastic model to formulate logistics network starting from order processing, purchasing, inventory management, transportation, and reverse logistics activities. As this activity chain fits well with Markov process, we exploit the very principle to represent not only the transition among various activities, but also the inherent uncertainty that has plagued logistics activities across the board. The logistics network model is thus designed to support logistics management by retrieving and analyzing logistics performance in a timely and cost effective manner. The application of information technology entails this network to become a Markovian information model that is stochastically predictable and flexibly manageable. A case study is presented to highlight the significance of the model.

Keywords: Logistics network; Markov process; Risk management; Uncertainty management.

1. Introduction

Logistics management concerns with how to optimize the efficiency of logistics activity in a timely and cost effective manner. This can be accomplished through a well-designed logistics network. Traditional logistics network design transfers products from manufacturers to customers and accepts return of disposed products from customers to manufacturers (Lee et al., 2010). Consequently, the logistic network management can be categorized into two types with respect to the product flow, namely, outbound and inbound logistics flows. S.A (2008) claimed that capacitated network could be used to analyze possible long-term transportation to reduce the distribution cost, having demand as an uncertain parameter. The distributors who serve as middlemen in the network of suppliers, warehouses, and customers must be reliable, flexible, and cost awareness. Their role is to select suppliers that will deliver products to destination stores or warehouses and to assign warehouse to customers (Erol and Ferrell Jr, 2004). From the distributor's standpoint, their net profit will increase if logistics support increases the profit margins or reduces expenses or inventory (Magrath and Hardy, 1992). Problems arise when distributors frequently have conflicting objectives such as minimizing cost and maximizing customer's satisfaction. They must find a proper mix of cost effectiveness and level of customer's satisfaction (Erol and Ferrell Jr, 2004). The key to this right mix is management and control of distribution costs. Many firms use enterprise resource planning (ERP) and information systems (IS) as logistics management tools to attain better perceived competitive advantages (Tilokavichai and Sophatsathit, 2011). The increased emphasis on supply chain management, ERP, and the need to develop models with appropriate representation of transportation considerations must be further enhanced to achieve any measurable logistics support (Swenseth and Godfrey, 2002). Rodriguez and Vecchietti (2010) agreed that the inventory, purchasing, delivery, demand and price uncertainties were major contributing problems of the supply chain. They solved the problem using non-linear programming technique. Another essential issue in logistics management is inventory management which poses an important problem in every industry as a tradeoff between customer's satisfaction and capital investment. The research conducted by Swenseth and Godfrey (2002) demonstrated that economic order quantity models could be

incorporated into inventory replenishment decisions. As the buyer and seller marketplace can be handled through e-commerce or third-party logistics providers in order to maximize customer's satisfaction (Nevins and Money, 2008), many models and methods have been developed to accommodate such an optimization problem. However, few studies have addressed the comprehensive design of logistics networks under uncertainty.

Although some research endeavors attempt to describe uncertainty that involves in logistics activities, the analyses are conducted on pair-wise or adjacent activities. This fails to capture cross-relationships among various activities in the logistics network. We envision such intertwined relationships that are inherent to the logistics chain. We propose a working stochastic model to represent the overall logistics perspective and pertinent indicators for firms to improve logistics performance toward better business decisions. The model makes use of Markov process to link order processing, purchasing, inventory management, transportation, and reverse logistics activities under uncertainty. Analysis detail will be described in subsequent sections.

The organization of this paper is as follows. Section 2 recounts some related literature and important issues in the area. Section 3 presents the Markov model, including notation used, the meaning of parameters, variables, constraints, and others. Section 4 describes a case study to demonstrate the viability of the proposed model. Section 5 discusses some essential findings and potential future course of action.

2. Literature Review

2.1 Logistics Network Model

Traditional business model is articulated in three stages: production, distribution, and sales. Each one of these stages is usually managed by a different company, or by a different branch of the same company (S.A, 2008). Logistics activities for distribution products start from order processing, inventory management, purchasing and procurement, transportation, and reverse logistics (Lai et al., 2010; Wu and Huang, 2007; Aptel and Pourjalali, 2001; Ngai et al., 2008). A logistics network model thus becomes very important in logistics management (Listes, 2007). Lee, et al. (2010) developed a sustainable logistics network under uncertainty using stochastic programming to attain cost savings and pollution reduction as a result of sharing material handling equipment and infrastructure. El-Sayed, et al. (2010) developed forward-reverse logistics network design under risk model to maximize the total expected profit. The problem was formulated in a stochastic mixed integer programming and decision making process. Pishvae, et al. (2009) applied a stochastic programming model with an integrated forward/reverse logistics network design under uncertainty to minimize the total costs including fixed opening cost, transportation cost, and processing costs. S.A. (2008) applied stochastic programming to design capacitated network analyzing possible long-term transportation of oil derivatives by pipeline, truck, railway, and ship so as to reduce the distribution cost. Moreover, Wilcox, et al. (2011) applied Markov model to handle reverse logistics operations and related financial management of the reverse logistics/return processes. Lee, et al. (2010) applied stochastic programming in reverse logistics to minimize cost and time. Listes (2007) developed a supply and return network using stochastic programming in demand and forecasting, transportation, and reverse logistics. One of the reasons why the transportation issue has become the mainstay of logistics management is because the annual transportation costs are the largest expense in logistic system where the majority of costs incurred depend on volume of products (S.A, 2008). The aforementioned models have wide range of applications in logistics reliability, liquidity, cost efficiency, time reduction, etc. However, previous researches assumed that the logistics network was a continuous process, and hence the design parameters for the logistics network mostly focused on forward logistics or reverse logistics. Table 1 summarizes some of the techniques and logistics activities for logistics models from previous studies.

2.2 Risk Management

Logistics have become a major component of competitive strategy to enhance organizational productivity and profitability. Unfortunately, the constituent activities in the logistics chain do not operate without chances of failure to meet the desired objective. This window of missing the pre-established target is known as risk. Hence, risk management in logistics activities is a very important factor of competitive advantage formula. El-Sayed, et al. (2010) proposed a multi-period multi-echelon forward and reverse logistics network model under risk to maximize the total expected profit. Ramanathan (2010) explored the relationships between logistics performance and customer loyalty that affected by risk characteristics of products and efficiencies of the websites in terms of price and ambiguity of

products. Cope, et al. (2010) delivered actionable policy recommendations based on consumer preferences for different approaches to food management by risk communication such as sharing knowledge of consumer risk perceptions and information needs. Tsao (2011) developed an inventory model with non-instantaneous delivery under trade credit and logistics risk. The model determined the optimal replenishment policy for a retailer, given uncertainties in a supply chain which were due to unforeseeable disruption or various types of defect such as shipping damage, missing parts, misplaced products and disasters, etc.

2.3 Stochastic process and Markov model

Stochastic programming is an optimizing technique using probabilistic information to solve large scale probabilistic optimization problems (Yu and Li, 2000). Markov decision process is a sequential decision-making stochastic process characterized by five elements: decision epochs, states, actions, transition probabilities, and rewards (Puterman, 1994). Many areas of science and technology use Markov chain to resolve complex problems of the underlying factors attributing to different types of transitions, reverse transitions, and repeated transitions (Ataharul Islam and Chowdhury, 2006; S.A, 2008). Markovian formulations are useful in solving a number of real-world problems under uncertainties, such as determining inventory levels for retailers and scheduling maintenance for manufacturers (Zhao et al., 2010). It provides more flexibility in statistically examining multiple transitions simultaneously and predicts the future state of a system from its present state ignoring its past history. Therefore, Markov chain is more effective at providing predictive information for managers and offers likelihood estimations for future outcomes (Wilcox et al., 2011). Its probabilistic nature renders the technique ideal for solving logistics problems under uncertainties, such as determining inventory level for retailers, scheduling maintenance for manufacturers, scheduling/planning in production management, and resource planning for time, cost, and human (Gayon et al., 2009). In addition, as the Just-in-Time (JIT) mode is introduced, the branches need not stock large inventories. The inventory cost can also be reduced (Zhao et al., 2010). A transient state can be formally defined as state from which the unit can change before leaving the system. Examples of transient states that could be considered might include purchasing, replenishment, distribution, etc. The goals are minimum cost, minimum time, and maximum profit.

Logistics models were developed by many techniques such as stochastic programming, Markov decision process, EOQ, etc., as summarized in Table 1. These techniques in turn were further applied to outbound, inbound, or reverse logistics in a pair-wise fashion. The lack of holistically integrated study of these activities left logistics problems hard to reckon with. The advent and application of information technology merely speeds up routine activities but leaves the inherent complexity untouched. The introduction of Markov model to analyze transition probabilities in logistics activities entails a promising means to tackle such obstacles. As transitional capability of the Markov process can represent multi-stage flow of logistics activities under uncertainty, the resulting representative model can be used for further study on minimizing costs, time, opportunity loss, and maximizing flexibility, where different activities can be transited within the logistics distribution network.

2.4 Logistics activity based costing

Supply chain management requires accurate cost data regarding all activities and process within the organizations. Activity-Based Costing (ABC) can significantly contribute accurate cost data regarding all activities in supply chain management (Askarany et al., 2010; Gunasekaran et al., 2004). Gupta and Galloway (2003) demonstrated the managerial implications of an Activity-Based Costing/Management (ABC/M) system for various operation management decisions relating to product planning and design, quality management and control, inventory management, capacity management, and work force management that support decision-making of operation managers. Schulze, et al. (2012) applied ABC model in supply chain environment for inter-firms cost saving opportunities. Baykasoglu and Kaplanoglu (2008) applied ABC with business process modeling and analytical hierarchy approach for effective costing services of land transportation companies. Hung (2011) integrated approaches of ABC and management such as five forces analysis, risk analysis, decision making, analytic network process, and fuzzy goal programming for precise costing, managerial constraints, competitive advantage analysis, and risk management.

3. Proposed Markov model

The model is a formulation of the logistics network design that consists of outbound, inbound, and reverse logistics. This model serves as a basis for numerous studies on logistics activity relationship to accomplish a set of designated

objectives. Qin, et al. (2009) designed the logistics network between stochastic demand and inventory control to minimize cost under a predefined service level. The granularity of description detail depends on the context and focus of logistics problems under study. The proposed model is applied to a case study of the logistics network design for a distribution business. Preliminary analysis has established the working scenarios given in the previous section. During the course of the research, it was discovered that though many distributors claimed to place high priority on regular logistics activities, a few distributors had monitored related data with the same degree of intensity and depth of analysis on sales effort. The actual site was conducted at XYZ Company which is a large ceramic tile and sanitary ware manufacturer in Thailand. The true identity was withheld for confidentiality. XYZ has total annual income over 7.5 billion Baht, part of which about 150 million Baht was spent on transportation in 2011. Meanwhile, XYZ presently handles approximately 80,000 items that make up 75 product types from 392 vendors. The average vendors' lead time is 8 days which account for the total inventory values of 890 million Baht. There are 1,200 staffs serving logistics activities, or 75 percent of all employees. Over 150,000 customers visit the branches annually. There are 164 vehicles or 90 percent of all of vehicles being deployed in customer delivery, which usually takes 2 days. The main obstacle that hinders profitability is logistics management. Therefore, the ultimate goals of this case study do not limit to only demonstrate how the proposed Markovian information model copes with the risk involved in the company's logistics network, but also exploitation of the model to optimize the costs incurred. We calculated logistics costs from financial statement of XYZ such as wages, transportation, fuel, repair, communication, depreciation of vehicles and others, insurance, utilities, interests, and administrative costs expended in percentage of sales. However, we could not reveal all real data. As such, an overall logistics cost structure is categorized in four groups as follows: 1) interests from logistics activities, 2) transportation, packaging, fuel, depreciation of vehicles, and other relating maintenance costs, 3) wages, allowances, and welfares for logistics activities, and 4) other costs such as communication, miscellany, depreciation, utilities, taxes, and other administrative costs.

The model was applied to internal logistics process, where financial data were provided by XYZ. The data reflected a twelve-state Markov chain, with almost all transitions between states was tracked by ERP system. The model is not intended to yield an exhaustive list of possible states or transitions, but rather an example demonstrates the utility of the model. Its flexibility could be customized to suit individual distributor setting based on their logistics policy. The analysis breakdown of XYZ logistics network by Markov process is shown in Figure 1. We measured the number of transactions, cost per transaction, and time spent in each activity from ERP. Cost per transaction is calculated from logistics cost structure. This is a unit performance measure of any logistics activity at a given stage. For example, order processing (O_1) and inventory management at branch (I_1 and I_2) both have cost per transaction of 144 Baht. This is because all three activities are executed at the same ERP node (this is architectural dependent on ERP configuration). The total logistics activity costs divided by all transactions executed at this node is therefore $24,500,000 / (1,119 + 155,094 + 14,448) = 144$ Baht. Similarly, a reflexive link at O_1 designates a pending status of 1,119 transactions at 144 Baht that affected the annual income by 16,543,457 Baht or about 3 percent.

Figure 1 displays the probability that associates with each transition in the logistics activity network. The latter represents a complete logistics chain based on Markov process at time t (in month), $t = 1, 2, \dots, n$. A sale transaction starting at a branch can be filled with probability 0.91 and delivery to customer by the branch with probability 0.43. If the branch is out of stocks with probability 0.08, a purchase order is initiated with probability 0.99 in accordance with normal branch replenishment by the distribution center (DC). In order to minimize the expected transportation cost, XYZ needs to establish a viable delivery decision based on available information. The result will furnish several alternate routes, each of which is associated with uncertainty that is translated into time, cost, flexible course of action for customer, and adaptability to JIT principle that altogether meeting the demands in the given period $(t, t+j)$, where j is the number of transition steps in the Markov chain.

Figure 2 shows the transition matrix Q of the logistics network depicted in Figure 1. A state describes the option of the logistics activity at time t . The entry S_{ij} represents the transition probability from state i to state j . A transaction (row-wise) beginning at O_1 will remain in O_1 with 0.01; transit to I_1 with 0.91; and to I_2 , with 0.08.

Consider when a customer places an order at the branch office. The order is filled and eventually delivered to the customer by the same branch office. According to the analysis breakdown, there are seven possible routes to get from order processing (O_1) to transportation to customer (T_2) as shown in Table 2. The state of a delivery to customer is determined only by previous state. In the first route, we begin at O_1 and proceed to I_1 then T_2 with probabilities 0.91 and 0.43, respectively. In the second route, the items are out of stock (I_2) which calls for additional issuance of a purchase

order at purchasing and procurement (P_1). Upon replenishing stock (I_1), the items are sent to transportation to customer (T_2) with probabilities 0.08, 0.99, 0.26, and 0.43, respectively. In the third route, similar scenarios to the second route are resulted. Fortunately, DC carries sufficient desired items to fill the stock at the branch office and the case is closed. The fourth route is similar to the second, except replenishments go to DC first before being discharged to the branch office, while the fifth route relays replenishments to cross dock and follows the same track. The only undesirable situation occurs in the sixth route where orders are returned due to wrong shipment, quantity, or quality that must be reprocessed to fulfill the order. Nevertheless, the risk is low (0.0050) but the penalty is extremely costly. Finally, the seventh route exhibits a typical order request to DC, filled, and return with the desired product to the branch before shipping it to the customer by the same branch.

To determine the probability of going from A to B in one transition, denoted by $P(AB)$, follow the established Markov process. Hence, the probability P that an order will be delivered to customer by branch based on all of the above scenarios is

$$P = P(O_1I_1)P(I_1T_2) + P(O_1I_2)P(I_2P_1)P(P_1I_1)P(I_1T_2) + P(O_1I_2)P(I_2Id_1)P(Id_1I_1)P(I_1T_2) + P(O_1I_2)P(I_2P_1)P(P_1Id_1)P(Id_1I_1)P(I_1T_2) + P(O_1I_2)P(I_2P_1)P(P_1Id_2)P(Id_2I_1)P(I_1T_2) + P(O_1I_1)P(I_1T_2)P(T_2R_1)P(R_1I_1)P(I_1T_2) + P(O_1I_1)P(I_1Id_1)P(Id_1I_1)P(I_1T_2)$$

Thus, $P = (0.91)(0.43) + (0.08)(0.99)(0.26)(0.43) + (0.08)(0.01)(0.62)(0.43) + (0.08)(0.99)(0.41)(0.62)(0.43) + (0.08)(0.99)(0.26)(1.0)(0.43) + (0.91)(0.43)(1.0)(0.03)(0.43) + (0.91)(0.01)(0.62)(0.43) = 0.43$

This tells us that an order has a 43% chance to reach the branch for on-time delivery. If we consider all possible two-step transitions based on the same scenarios, we obtain $Q^2 = Q \times Q$ as shown in Figure 3.

As the values of the Q matrix are derived from company's internal item tracking of logistics activities over several periods, it is possible to predict the expected number of sale order transactions, or the number of transactions in each delivery type, by customer, by branch, by vendor, etc., for enterprise resource planning and increase customer's satisfaction.

4. Case studies and managerial implications

Firms in various industries are implementing logistics systems to reduce costs and increase profits. Due to the unpredictable nature of logistics, firms must strive to achieve high service level agreement to attain customer's satisfaction. The proposed model will offer top executives to set the target of logistics performance indicators based on information from Markov model such as lead time to customer, opportunity cost, transportation, and inventory costs. Logistics manager can exercise the above policy to meet the target by predicting possible routes to preventing subsequent problems and risks. They can monitor and identify implementable solutions bearing potential risks and problems to arrive at viable course of action. The food and beverage sector, for instance, must have intensive control over both incoming and outgoing logistics of raw materials and finished goods owing to their perishable nature. Moreover, stricter regulations and consumer awareness impose higher requirements for food quality and safety (Losito et al., 2011). As uncertainty and unpredictability of food demands are a normal problem of this sector, they must pay close attention to distribution level problems such as lead time, abrupt and abnormal demands (Kumar and Nigmatullin, 2011). Bozkir and Sezer (2011) examined food demand prediction by applying chi-squared automatic interaction detection, classification, and regression trees, while others resort to tools such as Just-in-Time (JIT) for cost reduction (Zarei et al., 2011). We studied FF Company who produces fruits and fresh vegetables ready to cook and eat for export to European countries. The company is certified with EURAPGAP, BRC, and BRC/IOP. They encountered a big opportunity loss problem as sales plummeted from 7% down to 3%. The main causes are the high price and shortage of unseasonal agricultural raw materials which in turn affect freight quality and disposal cost.

The logistics activity relationship matrix of FF Company consists of order processing and inventory management which are mutually dependent on average duration (days) of supply to customers, inventory management, purchasing/procurement, and measured by economic order quantity and reorder point (Kumar and Nigmatullin, 2011). Typically, perishable food transportation involves multiple variables such as distribution centers, product varieties, carriers, vehicles, and customers. These variables attribute to another utmost important controlled variable, i.e., temperature which often fluctuates by many factors. Besides, the delivery vehicles usually have multiple customer deliveries per cycle (White III and Cheong, 2012; Ahumada and Villalobos, 2011).

In Table 3, there are six possible routes from order processing (O) to transportation to wholesaler (T). The state of a

delivery to the wholesaler is determined only by previous state. In the first route, we begin at O and proceed to purchasing and procurement issuance of a purchase order (P). After that fruits and vegetables are cut and pack for ready to cook and eat (M). Finally, the items are sent to transportation to wholesaler in Europe by air (T) with probabilities $P(O-P-M-T)$. In this route, raw material and finished goods are not buffered anywhere. As such, the hand-off between states can be treated as a JIT delivery. In the fifth route, the concern is on raw material (I_1) that must have enough quantity and in good quality. Thus, the Markov model can support managers in making decision and predict on customer's demand, opportunity loss, EOQ, reorder point, disposal cost, etc.

For service industry such as hospitals, logistics activities consist of purchasing, physical supply, receiving, inventory management, internal distribution to medical units, and management information systems. Distribution operations usually focus on inventory scheduling decisions. The variables involved are: when to place order and deliver to each care unit. Therefore the activities balance through the purchasing cycle (Lapierre and Ruiz, 2007). Moreover, distribution of suppliers such as central warehouse or direct vender distribution and volume of medicine being distributed affect logistics performance of the hospital (Aptel and Pourjalali, 2001). In this case, the speed of service is an important variable in servicing the patients. The Markov model can be deployed to improve such a work flow to reduce cost, increase customer's satisfaction, and safe health care of patients.

It is apparent that Markov model can be applied in several industries such as food, electronics, fashion, and services. It helps solve problems such as over stock, severe delays, inaccurate product forecasts, inefficient service flow, lost sales and liquidity. The information from Markov model can be used to set target, predict opportunity cost, time, service level, reduce inventory, eliminate bullwhip effect, and improve communication. One direct IT application is direct manufacturer to customer sales (in the case of Compaq) which in the context of the proposed logistics network model is just a jump from regular sale order distribution channel in the supply chain, bypassing wholesalers and retailers to customers. The risk paid off beautifully.

5. Conclusion and future research

This paper has explored the logistics network activity management under uncertainty. In order to account for the uncertain characteristics of the logistics network, the Markov model has been developed where the demands of outbound logistics, inbound logistics, and returned product from customers are assumed to be stochastic parameters with known distribution. The model addresses some recalcitrant logistics activity problems that have high holding costs and uncertain demands. The application of Markov chain provides relevant predictions for managers and likelihood estimations for future outcome. Since logistics management is a part of the strategic map that attributes to the firm's competitive advantage (Quezada, 2009), we selected a case study of a large-scale logistics network firm to demonstrate the viability of the proposed model. The results have not only shown product distribution alternatives, but also demonstrated an integrated systematic method that yielded cost effective logistics network performing at high customer's satisfaction level.

The case study shown in Figure 1 also encompasses a number of valuable information to be extracted. The opportunity loss in order processing with probability 0.01 or 16,543,457 Baht is caused by inadequate stock to fill the order. This in turn will affect liquidity situation because the branch does not generate sales and remains to reckon with creditors. Although XYZ has its own DC that is equipped with automatic inventory replenishment system, but the risk of being out of stock exists. Analysis on activity flow can determine the time spent, associated costs, and risk involved of a sale order (O_1), encountering out of stocks situation (I_2), issuing a corresponding PO (P_1), before proceeding to either DC stocks (Id_1) or cross dock (Id_2). Therefore, top executive, middle managers, operation managers, and other parties involved could communicate, discuss, or lay out strategic planning to be in-line with organization objectives. Moreover, the company can cooperate with vendors and customers using the result information obtained from Markov analysis to meet the target logistics mission, while minimizing cost, time, improving customer's satisfaction and competitive advantage over its competitors. It is thus apparent that the information is attributive to decision making in planning and controlling resources, transportation, and risk management.

The enormity of cumulative uncertainties that are inherent to all stages of the logistics chain has prompted us to delve into the overall cost structure. From the externally imposing service level and demands from customers and competitors, various holding costs, transportation cost, JIT lot size, etc., have affected the entire downstream operations in branches and vendors alike. We also found that the unraveled uncertainties could in fact be directly translated into anticipatory risks that the company could mitigate or avoid. Thus, we can predict lead time reduction by

JIT, as well as the associated costs derived from suppliers and customers' data. Future research will explore organization cost analysis by applying ABC that incorporates additional variables such as number of staffs in each logistics activity, vehicles, transportation zones, sales representatives, vendors, order distribution, and working time in each logistics activity. A precautionary warning is that adoption of ABC in smaller firms needs more attention than larger firms in light of risk and uncertainty involved.

The proposed model can very well suit different industries such as food, electronics, machinery, fashion, and service sectors, as long as there are logistics activities involved. In particular, we are gathering in-depth information on food industry as the perishable nature mandates a highly efficient logistics network to reduce time-to-market which is the life line of their business survival. We also plan to apply the proposed technique on returned goods from stocks at branch to DC (R_2), customer to branch stocks (R_1), and DC stocks to vendors (R_3), thereby minimizing costs of exchange, staging, scrap (due to damage), and out dated stock clearance. Owing to the volume of such returned goods, efforts to reduce the probability of loss sales ignited an innovative in-house product development to churn out artistically design of blending piece scrap to a new product line. The outlook is promising as demand steadily grows. Our future work will incorporate dynamic prediction by a weighted coefficient of variables. Consequently, the introduction of Markovian information model will be conducive toward effective minimizing cost and predicting future outcome that further enhances the competitive advantage of the firm.

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Table 1. Summary of techniques, activity flow, and measurement of logistics network.

Related literatures	Techniques	Logistics activities						Measurement					Parameters of Uncertainty			
		D	I	W	P	O	T	R	C	T	P	S		W	L	
Swensethand Godfrey, 2002	EOQ	x	x				x	x	x							x
Listes, 2007	Stochastic programming	x						x	x		x	x				x
Zhao et al., 2010	Markov modeling	x	x	x	x	x	x	x								x
Lee et al., 2010	Stochastic programming	x	x	x		x	x	x	x							x
Kim et al., 2011	Stochastic optimization	x	x		x	x	x				x			x		x
Mutha&Pokharel, 2009	Mathematical model		x		x		x	x	x				x			
El-Sayed et al., 2010	Stochastic programming	x	x		x			x			x					x
Pishvae et al., 2009	Stochastic programming	x	x				x	x	x		x					x
Wilcox et al., 2011	Markov modeling		x					x							x	x
Qin et al., 2009	Stochastic programming	x	x				x		x			x				x
Horvath et al., 2005	Markov modeling		x					x						x		x
S.A, 2008	Stochastic programming	x	x				x		x							x
Yu and Li, 2000	Stochastic programming	x	x	x					x							x

Logistics Activities: D: Demand & Forecasting, I: Inventory Management, W: Warehouse Management, P: Purchasing & Procurement, O: Order Processing, T: Transportation, R: Reverse Logistics. Measurement: C: Cost, T: Time, P: Profit, S: Service Level, W: Waste/defect, L: Liquidity.

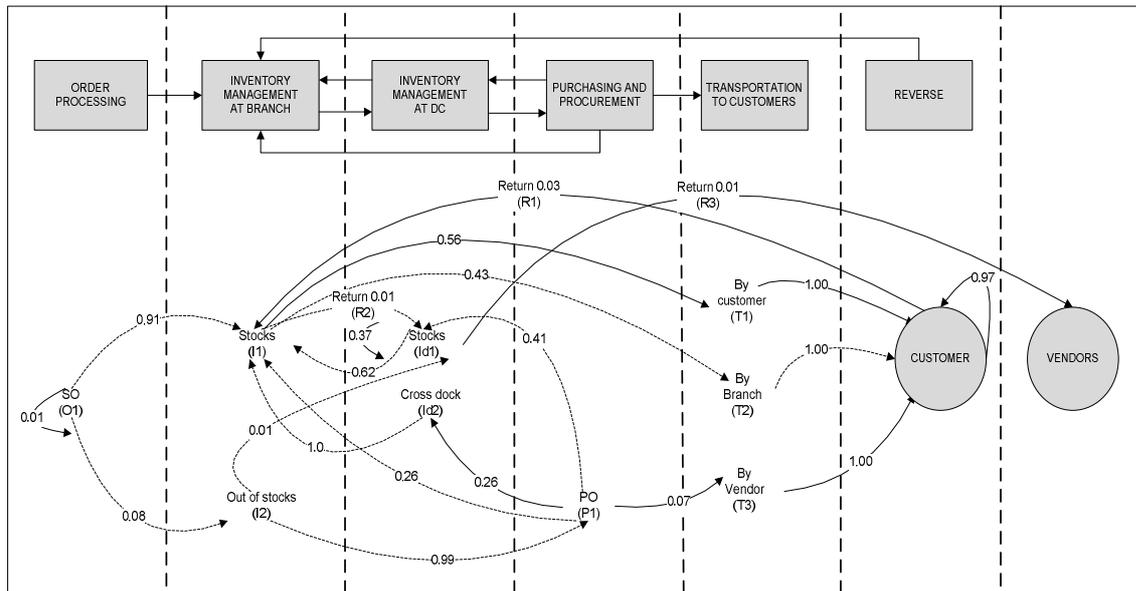


Figure 1. Breakdown of XYZ logistics network.

Table 2. Routes from order processing (O_1) to transportation to customer (T_2).

C	Route	Prob	Lead Time (hours)	Cost per transaction (Baht)
1	$O_1-I_1-T_2$	0.3913	42	144+124 = 268
2	$O_1-I_2-P_1-I_1-T_2$	0.0089	201+42 = 243	144+22+23+124 = 313
3	$O_1-I_2-Id_1-I_1-T_2$	0.0002	24+42 = 66	144+22+68+124 = 358
4	$O_1-I_2-P_1-Id_1-I_1-T_2$	0.0087	22+177+24+42 = 265	144+22+23+68+124 = 381
5	$O_1-I_2-P_1-Id_2-I_1-T_2$	0.0089	22+189+12+42 = 265	144+22+23+50+124 = 363
6	$O_1-I_1-T_2-R_1-I_1-T_2$	0.0050	42+360+42 = 444	144+124+144+124 = 536
7	$O_1-I_1-Id_1-I_1-T_2$	0.0024	12+24+42 = 78	144+114+68+124 = 450

C: Case, Prob: Probability

$$Q = \begin{matrix} & O_1 & I_1 & I_2 & Id_1 & Id_2 & P_1 & T_1 & T_2 & T_3 & R_1 & R_2 & R_3 \\ \begin{matrix} O_1 \\ I_1 \\ I_2 \\ Id_1 \\ Id_2 \\ P_1 \\ T_1 \\ T_2 \\ T_3 \\ R_1 \\ R_2 \\ R_3 \end{matrix} & \begin{bmatrix} 0.01 & 0.91 & 0.08 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0.01 & 0 & 0 & 0.56 & 0.43 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0.01 & 0 & 0.99 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0.62 & 0 & 0.37 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.01 \\ 0 & 1.0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0.26 & 0 & 0.41 & 0.26 & 0 & 0 & 0 & 0.07 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0.03 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.97 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix} \end{matrix}$$

Figure 2. The transition matrix of the logistics network.

$$Q^2 = \begin{matrix} O_1 \\ I_1 \\ I_2 \\ Id_1 \\ Id_2 \\ P_1 \\ T_1 \\ T_2 \\ T_3 \\ R_1 \\ R_2 \\ R_3 \end{matrix} \begin{bmatrix} 0.001 & 0.0091 & 0.0008 & 0.0099 & 0 & 0.0792 & 0.5096 & 0.3913 & 0 & 0 & 0 & 0 \\ 0 & 0.0062 & 0.0037 & 0 & 0 & 0 & 0.56 & 0.43 & 0 & 0 & 0 & 0.0001 \\ 0 & 0.2636 & 0 & 0.4096 & 0.2574 & 0 & 0 & 0 & 0.0693 & 0 & 0 & 0.0001 \\ 0 & 0.2294 & 0 & 0.1431 & 0 & 0 & 0.3472 & 0.2666 & 0 & 0 & 0 & 0.0137 \\ 0 & 0 & 0 & 0.01 & 0 & 0 & 0.56 & 0.43 & 0 & 0 & 0 & 0 \\ 0 & 0.5142 & 0 & 0.1543 & 0 & 0 & 0.1456 & 0.1118 & 0.07 & 0 & 0 & 0.0041 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0.0291 & 0 & 0.0003 & 0 & 0 & 0.0168 & 0.0129 & 0 & 0.9409 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

Figure 3. Two-step transitions matrix.

Table 3. Routes from order processing (O) to transportation to wholesaler (T).

Case	Routes	Probability
1	O-P-M-T	P(O-P-M-T)
2	O-P- I1-M-T	P(O-P- I1-M-T)
3	O-P-M-I2-T	P(O-P-M-I2-T)
4	O-P-I1-M- I2-T	P(O-P-I1-M- I2-T)
5	O- I1-M-T	P(O- I1-M-T)
6	O- I1-M-I2-T	P(O- I1-M-I2-T)

O: order processing, P: purchase order, M: wholesaler, I1: raw material, I2: finished goods, T: transportation

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