Security Modeling on the Supply Chain Networks

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ABSTRACT

In order to keep the price down, a purchaser sends out the request for quotation to a group of suppliers in a supply chain network. The purchaser will then choose a supplier with the best combination of price and quality. A potential supplier will try to collect the related information about other suppliers so he/she can offer the best bid to the purchaser. Therefore, confidentiality becomes an important consideration for the design of a supply chain network. Chen et al. have proposed the application of the Bell-LaPadula model in the design of a secured supply chain network. In the Bell-LaPadula model, a subject can be in one of different security clearances and an object can be in one of various security classifications. All the possible combinations of (Security Clearance, Classification) pair in the Bell-LaPadula model can be thought as different states in the Markov Chain model. This paper extends the work done by Chen et al., provides more details on the Markov Chain model and illustrates how to use it to monitor the security state transition in the supply chain network.

Keywords: Markov Chain Model, Security Model, Bell LaPadula Model, Information Security, and Supply Chain Networks

1. INTRODUCTION

In a supply chain network, a purchaser is a manufacturer or a retail distributor. In order to keep the price down, a purchaser sends out the request for quotation for a group of suppliers. The purchaser will eventually choose a supplier with the considerations of price and/or quality offered by a supplier [15]. Sometimes an aggressive supplier will attempt to collect the information about other suppliers so he/she can provide the best bid to the purchaser. Since most transactions are done through a computer network system such as Extranet or Internet, the confidentiality of supply chain systems becomes an important issue between suppliers and the purchaser.

Since security becomes an important component in the various services, new standards are emerging for these services. For example, the new auditing standards No. 99 provides a general guideline for the responsibilities and anti-fraud activities of a manager [12]. ISO 17799:2005 provides a general organization security structure [13].

These security standards may be influenced by existing security models. For example, ISO 17799:2005 provides a general organization security structure but many basic security principles may have been discussed and defined in various security models. While supply chain information is similar to any other information systems, it has unique features on confidential and integrity. Chen et al. proposed to use the Bell-LaPadula model and Cark Wilson model for the supply chain network [5, 7, 8]. In order to monitor the security in a supply chain network, it is necessary to model the security state transition in the Bell-LaPadula model. First, this paper first briefly conducted a literature review. Second, it introduces the Bell-LaPadula model and exemplifies how the Bell-LaPadula model is used in the supply chain network. Fourth, this paper extends the work done by Chen et al. [7, 8], provides more details on the Markov Chain model and illustrates how to use it to monitor the security state transition in the supply chain network.

2. LITERATURE REVIEW

Information Security Models

There are various models which provide policies from different aspects of security. In Bishop's textbook [5], many security models have been discussed: The Bell-LaPadula Model [2, 3], Biba Integrity Model [4], Lipner's Integrity Matrix Model [10], Clark-Wilson Integrity Model [9], and Chinese Wall Model [6]. These models discussed basic principles and guidelines for a common security system. The Bell-LaPadula model is one of the security models for information confidentiality and has been adopted by military for a long time. For example, the Bibba model provides security policy in data integrity. On the other hand, Bell-LaPadula model provides security policy to guard against unauthorized disclosure. Bell LaPadula Model has been used in military and is primarily designed for modeling confidentiality [2]. It classifies the access levels for the subject into a set of security clearances, such as: top security (TS), security (S), confidential (C), and unclassified (UC). In the mean time the objects are also been classified as corresponding security levels. It does not allow a subject to read the objects at security levels higher than the subject's current level. Every subject must belong to one and only one of the security clearance levels. In addition, every object must also belong to one and only one of the classification levels. For example, a colonel, who is in the TS security clearance, can read the Personnel files. Whereas, a soldier, who is in the UC security clearance, can read the telephone lists. The colonel can also read the telephone lists; however, the soldier cannot read the personnel files.

The Bell-LaPadula Model for Supply Chain Networks

In a supply chain network, prices offered by suppliers are often confidential due to competition and also are not a public information in the buyer's company. The confidentiality of the supplier information is essential in nowadays competitive business world. Chen et al. [3] proposed to use the Bell-LaPadula model for the supply chain network. In order to investigate the security in the supply chain model, it is necessary to be able to model the security state transition in the Bell-LaPadula model. This paper first briefly introduces the Bell-LaPadula model. Then it exemplifies how the Bell-LaPadula model is used in the supply chain network. This paper also explains what a Markov Chain model is and how to use it in the supply chain network.

According to the Bell-LaPadula model, we can classify the employees (or subjects) in the purchasing company into several security clearance levels and different information (or objects) into different security classification levels. For simplicity, assuming that there are two security clearance levels for all employees in a purchasing company. They are the top officer and other employees. The top officer can access or read two documents: both supplier evaluations and purchasing decision. On the other hand, other employees can only access (read) two documents: the public bidding notices and the public purchasing price list. The top officer can also access the documents which a general employee can access. Other employees cannot access documents for both supplier evaluations and purchasing decision. Table 1 shows security classifications and clearance levels for a purchasing company and its suppliers [7, 8].

Security Classification	**Purchasing Company Personnel and Their Suppliers**	**Documents/ Information**
Top Secret (TS)	Managers in the purchasing company	Purchasing decisions; supplier evaluations
Secret (S)	Other employees in the purchasing company	Company profiles about suppliers and products
Confidential (C)	An individual supplier	Price bidding from a individual supplier
Unclassified (UC)	All the suppliers	Public bidding notices from the purchasing company to all the suppliers

References: See [7] and [8]

Table 1. Security Classifications in a Supply Chain Network

3. MARKOV CHAIN MODEL

A Markov process is a stochastic process which states that the probability of a system at a state depends only on the previous state, not on the previous history of getting to the previous state. If the states are discrete and their transitions at discrete points in time, it is called a Markov chain [1]. In other words, a stochastic process M(t) is a Markov chain if at any n time points $t_1 < t_2 < \ldots < t_n$, there are n corresponding states $m_1, m_2, \ldots, m_n$, the probability that the system is at state m_n at time t_n, given that the system was at state m_{n-1} at time t_{n-1} and etc, the system was at state m_1 at time t_1 is equal to the probability that the system is at state m_n at time t_n, given that the system was at state m_{n-1} at time t_{n-1}. That is,

$$P(M(t_n)=m_n \mid M(t_{n-1})=m_{n-1}, \ldots, M(t_1)=m_1) = P(M(t_n)=m_n \mid M(t_{n-1})=m_{n-1})$$

where m_i is the state of the process at time t_i ($t_1 \leq t_i \leq t_n$), i=1, …, n.

This says that the probability that the Markov process is in state m_n at t_n, depends only on the state m_{n-1} at t_{n-1}.

Suppose p(0) represents the vector of the probability that the system is in one of those n states at time 0,

$$p(0)=\begin{bmatrix} p_1(0) \\ p_2(0) \\ \ldots \\ p_n(0) \end{bmatrix}, \quad \sum_{i=1}^{n} p_i(0) = 1$$

where $p_i(0)$ represents the probability of the system is in state i at time 0.

Then the probability that the system is in one of those n states at time 1 is represented by p(1),

$$p(1)=\begin{bmatrix} p_1(1) \\ p_2(1) \\ \dots \\ p_n(1) \end{bmatrix}, \qquad \sum_{i=1}^{n} p_i(1) = 1$$

where $p_i(1)$ represents the probability of the system is in state i at time 1.
And P(1)=T p(0),
where T is the transition probability matrix,

$$T=\begin{bmatrix} p_{11} & p_{21} & \dots & p_{n1} \\ p_{12} & p_{22} & \dots & p_{n2} \\ \dots & \dots & \dots & \dots \\ p_{1n} & p_{2n} & \dots & p_{nn} \end{bmatrix}, \qquad \sum_{j=1}^{n} p_{ij} = 1, \text{ for}$$

i=1,2,…,n

and p_{ij} is the probability of the system in the state j, give it was in the state i.

Suppose the probability that the system is in one of those n states at time s is represented by p(s),

$$p(s)=\begin{bmatrix} p_1(s) \\ p_2(s) \\ \dots \\ p_n(s) \end{bmatrix}$$

where $p_i(s)$ represents the probability of the system is in state i at time s.

Then $P(s)=T(T(\dots(Tp(0))))=T^s\, p(0)$,
where T is the transition probability matrix,

4. MARKOV CHAIN MODEL FOR SUPPLY CHAIN NETWORK

The n states in Markov Chain model are all the possible combinations of (Security Clearance, Classification) pair in the Bell-LaPadula model. These (Security Clearance, Classification) pair are created using all possible allowed combinations of security clearance levels of subjects and classification levels of objects in the Bell-LaPadula model. If there are u levels of security clearance of subjects and there are v classification levels of objects for each level of subjects in a supply chain network, then there are uv allowed (Security Clearance, Classification) pair levels for the top security clearance because by the Bell-LaPadula model all subjects in the top security clearance levels are allowed to access all documents on or below its classification levels. Likewise there are (u-1)v allowed (Security Clearance, Classification) pair levels for the next security clearance., and so forth. The lowest security clearance level has v allowed (Security Clearance, Classification) pair levels. Overall there are $u!v^u$ possible combinations of (Security Clearance, Classification) pair or $u!v^u$ different states in the Markov Chain model.
For example, in the Bell-LaPadula model discussed above, there are two security clearance of subjects (i.e. u=2) and there are two classification levels of objects (i.e. v=2). There are total eight states in the Markov Chain model (See Table 2). In order to use Markov Chain model for the supply chain network, we must assume that the number of all possible documents can be read for the subjects in the top security clearance is uv+(u-1)v+…+v=v(u+1)u/2. The number of all possible documents can be read for the subjects in the next top security clearance is (u-1)v+…+v=v(u-1)u/2 and so forth.

Markov Chain State	**Combination of (Security Clearance, Classification) pair**
1	(top officer, supplier evaluation) (general employee, bidding notice)
2	(top officer, buying decision) (general employee, bidding notice)
3	(top officer, bidding notice) (general employee, bidding notice)
4	(top officer, retail price) (general employee, bidding notice)
5	(top officer, supplier evaluation) (general employee, retail price)
6	(top officer, buying decision) (general employee, retail price)
7	(top officer, bidding notice) (general employee, retail price)
8	(top officer, retail price) (general employee, retail price)

Table 2. Markov Chain States in a Supply Chain Network

By Bell-LaPadula model, (Security Clearance, Classification) pairs are independent of each other, then
Probability (system in the state 1 at time t) = Probability (state (top officer, supplier evaluation) (general employee, bidding notice) at time t)
= Probability (state (top officer, supplier evaluation)) * Probability (state supplier evaluation))

Suppose the probability that the system is in one of those eight states at time 0 is represented by p(0), we have

$$p(0)=\begin{bmatrix} p_1(0) \\ p_2(0) \\ p_3(0) \\ p_4(0) \\ p_5(0) \\ p_6(0) \\ p_7(0) \\ p_8(0) \end{bmatrix}, \quad \sum_{i=1}^{8} p_i(0) = 1$$

where $p_i(0)$ represents the probability of the system is in state i at time 0. Then the probability that the system is in one of those n states at time 1 is represented by p(1),

$$p(1)=\begin{bmatrix} p_1(1) \\ p_2(1) \\ p_3(1) \\ p_4(1) \\ p_5(1) \\ p_6(1) \\ p_7(1) \\ p_8(1) \end{bmatrix}$$

where $p_i(1)$ represents the probability of the system is in state i at time 1.
And
P(1)=T p(0),
where T is the transition probability matrix,

T=

$$\begin{bmatrix} p_{11} & p_{21} & p_{31} & p_{41} & p_{51} & p_{61} & p_{71} & p_{81} \\ p_{12} & p_{22} & p_{32} & p_{42} & p_{52} & p_{62} & p_{72} & p_{82} \\ p_{13} & p_{23} & p_{33} & p_{43} & p_{53} & p_{63} & p_{73} & p_{83} \\ p_{14} & p_{24} & p_{34} & p_{44} & p_{54} & p_{64} & p_{74} & p_{84} \\ p_{15} & p_{25} & p_{35} & p_{45} & p_{55} & p_{65} & p_{75} & p_{85} \\ p_{16} & p_{26} & p_{36} & p_{46} & p_{56} & p_{66} & p_{76} & p_{86} \\ p_{17} & p_{27} & p_{37} & p_{47} & p_{57} & p_{67} & p_{77} & p_{87} \\ p_{18} & p_{28} & p_{38} & p_{48} & p_{58} & p_{68} & p_{78} & p_{88} \end{bmatrix},$$

$$\sum_{j=1}^{8} p_{ij} = 1, \text{ for } i=1,2,\ldots,8$$

and p_{ij} is the probability of the system from state I to state j.
Suppose that
P (top officer, supplier evaluation) $=a_{11}$
P (top officer, buying decision) $=a_{12}$
P (top officer, bidding notice) $=a_{13}$
P (top officer, retail price) $=a_{14}$
P ((general employee, bidding notice) $=b_{11}$
P) (general employee, retail price)$=b_{12}$

where

$$\sum_{j=1}^{4} a_{ij} = 1 \text{ and } \sum_{j=1}^{2} b_{ij} = 1$$

By Bell-LaPadula model, at time 0
P(state 1) = a_{11} b_{11}
P(state 2) = a_{12} b_{11}
P(state 3) = a_{13} b_{11}
P(state 4) = a_{14} b_{11}
P(state 5) = a_{11} b_{12}
P(state 6) = a_{12} b_{12}
P(state 7) = a_{13} b_{12}
P(state 8) = a_{14} b_{12}
Then at time 1,

P(1)=T p(0)=

$$\begin{bmatrix} p_{11} & p_{21} & p_{31} & p_{41} & p_{51} & p_{61} & p_{71} & p_{81} \\ p_{12} & p_{22} & p_{32} & p_{42} & p_{52} & p_{62} & p_{72} & p_{82} \\ p_{13} & p_{23} & p_{33} & p_{43} & p_{53} & p_{63} & p_{73} & p_{83} \\ p_{14} & p_{24} & p_{34} & p_{44} & p_{54} & p_{64} & p_{74} & p_{84} \\ p_{15} & p_{25} & p_{35} & p_{45} & p_{55} & p_{65} & p_{75} & p_{85} \\ p_{16} & p_{26} & p_{36} & p_{46} & p_{56} & p_{66} & p_{76} & p_{86} \\ p_{17} & p_{27} & p_{37} & p_{47} & p_{57} & p_{67} & p_{77} & p_{87} \\ p_{18} & p_{28} & p_{38} & p_{48} & p_{58} & p_{68} & p_{78} & p_{88} \end{bmatrix} \begin{bmatrix} a_{11}b_{11} \\ a_{12}b_{11} \\ a_{13}b_{11} \\ a_{14}b_{11} \\ a_{11}b_{12} \\ a_{12}b_{12} \\ a_{13}b_{12} \\ a_{14}b_{12} \end{bmatrix},$$

where

p_{12}=Probability (in state 2 at time 1 | in state 1 at time 0)
= Probability (in state (top officer, buying decision) (general employee, bidding notice) at time 1, given in state (top officer, supplier evaluation) (general employee, bidding notice) at time 0)
= Probability (in state (top officer, buying decision) at time 1, given in state (top officer, supplier evaluation) at time 0) Probability (in state (general employee, bidding notice) at time 1, given in state (general employee, bidding notice) at time 0),
and
p_{15}=Probability (in state 5 at time 1 | in state 1 at time 0)
= Probability (in state (top officer, supplier evaluation) (general employee, retail price)at time 1, given in state (top officer,

supplier evaluation) (general employee, bidding notice) at time 0)
= Probability (in state (general employee, retail price)at time 1, given in state (general employee, bidding notice) at time 0)

By Bell-LaPadula model, (Security Clearance, Classification) pairs are independent of each other, then
p_{16}=Probability (in state 6 at time 1 | in state 1 at time 0)
= Probability (in state (top officer, buying decision) (general employee, retail price) at time 1, given in state (top officer, supplier evaluation) (general employee, bidding notice) at time 0)
= Probability (in state (top officer, buying decision) at time 1, given in state (top officer, supplier evaluation) at time 0) Probability (in state (general employee, retail price)at time 1, given in state (general employee, bidding notice) at time 0)
By this means, the probability of the system state at time 1 can be calculated straightforward (Examples of calculating p(1), see Appendix).

5. RESEARCH RESULTS AND CONCLUSION

By combining the subjects and objects possible security levels, all possible states can be listed in the Markov Chain model.
In conclusion, since the confidentiality policy for the supply chain networks can be modeled by Bell-LaPadula model, Markov Chain model can be used successfully to simulate the state transitions dynamically for the Supply Chain networks.
As we mentioned early, security standards today are emerging but many basic security principles in the standards can be traced back to existing security models. These standards and models are further impacting on the business strategy for the managers in an enterprise [16]. ISO/IEC 17799:2005 provides "guidelines and general principles for initiating, implementing, maintaining, and improving information security management in an organization. The objectives outlined provide general guidance on the commonly accepted goals of information security management." [13]. The Markov Chain model discussed in this paper shows the process of the secured state during the time period in the supply chain network. Any state which does not belong to one of the possible state is considered as impeaching the security. For example, in the previous section only those eight states are allowed. If a general employee is conducting supplier evaluation, which is not in one of those eight states, the system will not allow the process to proceed to the next possible state and managers will be warned on security impeachment. In reality, a supply chain network is fairly complex. A large manufacturer may have more than 500 suppliers for various parts acquisition in different time periods. The Markov Chain model can help the managers to understand the status of each supplier and then implement necessary security strategy for the organizations.

6. APPENDIX

Examples of Calculating the State Transition Probabilities

Suppose that a purchasing company first evaluates a group of suppliers before sending out a bid notice and setting the retail price. Then it repeats the whole process. Assume that
P (top officer, supplier evaluation) =a_{11}=0.8
P (top officer, buying decision) =a_{12}=0.1
P (top officer, bidding notice) =a_{13}=0.08
P (top officer, retail price) =a_{14}=0.02
P (general employee, bidding notice))=b_{11}=0.7
P (general employee, retail price)=b_{12}=0.3

Probability (in state (top officer, buying decision) at time 1, given in state (top officer, supplier evaluation) at time 0)=1
Probability (in state (top officer, supplier evaluation) at time 1, given in state (top officer, supplier evaluation) at time 0)=0
Probability (in state (top officer, bidding notice) at time 1, given in state (top officer, supplier evaluation) at time 0)=0
Probability (in state (top officer, retail price) at time 1, given in state (top officer, supplier evaluation) at time 0)=0

Probability (in state (top officer, buying decision) at time 1, given in state (top officer, buying decision) at time 0)=0
Probability (in state (top officer, supplier evaluation) at time 1, given in state (top officer, buying decision) at time 0) = 0
Probability (in state (top officer, bidding notice) at time 1, given in state (top officer, buying decision) at time 0) = 1
Probability (in state (top officer, retail price) at time 1, given in state (top officer, buying decision) at time 0) = 0

Probability (in state (top officer, buying decision) at time 1, given in state (top officer, bidding notice) at time 0) = 0
Probability (in state (top officer, supplier evaluation) at time 1, given in state (top officer, bidding notice) at time 0)=0
Probability (in state (top officer, bidding notice) at time 1, given in state (top officer, bidding notice) at time 0)=0
Probability (in state (top officer, retail price) at time 1, given in state (top officer, bidding notice) at time 0)=1

Probability (in state (top officer, buying decision) at time 1, given in state (top officer, retail price) at time 0) = 1
Probability (in state (top officer, supplier evaluation) at time 1, given in state (top officer, retail price) at time 0) = 0
Probability (in state (top officer, bidding notice) at time 1, given in state (top officer, retail price) at time 0) = 0
Probability (in state (top officer, retail price) at time 1, given in state (top officer, retail price) at time 0) = 0

Probability (in state (general employee, retail price)at time 1, given in state (general employee, bidding notice) at time 0) = 0.5
Probability (in state (general employee, bidding notice)at time 1, given in state (general employee, bidding notice) at time 0) = 0.5
Probability (in state (general employee, retail price)at time 1, given in state (general employee, retail price) at time 0) = 0.5
Probability (in state (general employee, bidding notice)at time 1, given in state (general employee, retail price) at time 0) = 0.5

Probability (in state (top officer, buying decision)at time 1, given in state (general employee, bidding notice) at time 0) = Probability(in state (top officer, buying decision = 0.1)
Probability (in state (top officer, supplier evaluation) at time 1, given in state (general employee, bidding notice) at time 0) = Probability (in state (top officer, supplier evaluation) = 0.8
Probability (in state (top officer, bidding notice) at time 1, given in state (general employee, retail price) at time 0) = Probability (in state (top officer, bidding notice)=0.08
Probability (in state (top officer, retail price)at time 1, given in state (general employee, retail price) at time 0)= Probability(in state (top officer, retail price)=0.02

Then

$$P(0)=\begin{bmatrix}0.56\\0.07\\0.056\\0.014\\0.24\\0.03\\0.024\\0.006\end{bmatrix}$$

$p_{11}= p_{22}= p_{33}= p_{44}= p_{55}= p_{66}= p_{77}= p_{88}=0$
$p_{12}=0.5, p_{13}=0, p_{14}=0, p_{15}=0, p_{16}=0.5, p_{17}=0, p_{18}=0$
$p_{21}=0, p_{23}=0.5, p_{24}=0, p_{25}=0, p_{26}=0, p_{27}=0.5, p_{28}=0$
$p_{31}=0, p_{32}=0, p_{34}=0.5, p_{35}=0, p_{36}=0, p_{37}=0, p_{38}=0.5$
$p_{41}=0.5, p_{42}=0, p_{43}=0, p_{45}=0.5, p_{46}=0, p_{47}=0, p_{48}=0$
$p_{51}=0, p_{52}=0.5, p_{53}=0, p_{54}=0, p_{56}=0.5, p_{57}=0, p_{58}=0$
$p_{61}=0, p_{62}=0, p_{63}=0.5, p_{64}=0, p_{65}=0, p_{67}=0.5, p_{68}=0$
$p_{71}=0, p_{72}=0, p_{73}=0, p_{74}=0.5, p_{75}=0, p_{76}=0, p_{78}=0.5$
$p_{81}=0.5, p_{82}=0, p_{83}=0, p_{84}=0, p_{85}=0.5, p_{86}=0, p_{87}=0$

P(1)=T p(0)=

$$\begin{bmatrix}0&0&0&0.5&0&0&0&0.5\\0.5&0&0&0&0.5&0&0&0\\0&0.5&0&0&0&0.5&0&0\\0&0&0.5&0&0&0&0.5&0\\0&0&0&0.5&0&0&0&0.5\\0.5&0&0&0&0.5&0&0&0\\0&0.5&0&0&0&0.5&0&0\\0&0&0.5&0&0&0&0.5&0\end{bmatrix}\begin{bmatrix}0.56\\0.07\\0.056\\0.014\\0.24\\0.03\\0.024\\0.006\end{bmatrix},$$

$$=\begin{bmatrix}0.01\\0.4\\0.05\\0.04\\0.01\\0.4\\0.05\\0.04\end{bmatrix}$$

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