Value of Sparse RFID Traceability Information in Asset Tracking during Migration Period

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Agenda

• Summary
• Background
• RTI rental service industry
• Location inference model
• Numerical study
• Implication and discussion
Summary

• Proposal of location inference model using sparse RFID event data and evaluate the model
  – Useful to accelerate RFID deployment in the migration
  – Develop of configurable traceability data generator

• Implication
  – Evaluate possible contractual issue in returnable transport item (RTI) service industry
Background

• Gradual deployment of RFID in SCM
  – Starting from major retailers’ mandates

• What can we do to accelerate RFID deployment?
  – Standards development
    • EPCglobal and ISO issue sufficient specifications
  – Cost reduction (Tag, Reader/Writer, IS, etc)
    • Tag reuse process is a solution
    • RTI is compatible to this reuse
  – Cost and benefit sharing model in open supply chain
    • Notion that late adopters earn more benefit than early adopters

Choose RTI rental service industry and propose a model to shows benefit of RFID to early adopters
• **Returnable transport item (RTI)**
  – Pallet, case, crate, etc
  – Made of durable material and used multiple times

• **RTI service provider (RSP)**
  – RTI Service provider rents RTI to companies for their transportation
  – Contract types
    • Shipper rents, returns RTIs and pays rental fee (Referred to as A type contract in the paper)
    • Shipper rents RTIs and pays fee, but consignee returns RTIs (Referred to as B type contract in the paper)
  – Charge daily basis
RTI Service Provider (cont’d)

- **Challenges of RSPs**
  - Increase turnover rate
  - Decrease lost of RTIs

- **How do RSPs value RFID-enabled location information?**
  - Provide value-added service to customers
    - Provide location information to customers to optimize rental fee
  - Control asset
    - Optimize number of RTI

RSPs have already started evaluating RFID for their asset management
Location Inference Model

• Assumed situation
  – An RSP use inferred location information of an RTI that is rented to customers but is not returned for a certain period

• Steps to build a model
  1. Define RTI circulation area
  2. Define random variables and develop a formula from the assumption
  3. Develop another formula from temporal dependency of RTI circulation
  4. Incorporate the event data information and develop a model
• **Assumption**
  - $n$ nodes (circles)
  - Transportation lanes (arrows)
  - An RTI is present at one of the nodes
  - Zero lead-time between nodes
Definition of Random Variables and Development of Formula

- **Random variable**
  - $X_i[t]$: whether or not an RTI is present at $N_i$ at time $t$
  - $X[t]$: Random variable vector
  - $P(X[t])$: Probability distribution of $X[t]$

- **Basic formula**
  - RTI is present at one of the nodes

$$\sum_{i=0}^{n-1} P(X_i[t]) = 1 \quad \text{Eq. (1)}$$
Temporal Dependency

• Location of RTI at time $t$ is dependent on that of at the previous time frame ($t-1$)

$t - 1$  $t$  $t+1$

$N0$  $N0$  $N0$

$N1$  $N1$  $N1$

$N2$  $N2$  $N2$

$\vdots$  $\vdots$  $\vdots$

$Nn-1$  $Nn-1$  $Nn-1$
Development of Formula from Temporal Dependency

- Probability distribution of $X[t+1]$ is dependent only on probability distribution of $X[t]$

- Define conditional probability distribution $\Phi$

$$P(X[t+1]) = \Phi[t]P(X[t])$$

Eq. (2)

$$\Phi[t] = P(X[t+1] | X[t])$$

$$= \begin{bmatrix} P(X_0[t+1] | X_0[t]) & P(X_0[t+1] | X_1[t]) & \cdots & P(X_0[t+1] | X_{n-1}[t]) \\ P(X_1[t+1] | X_0[t]) & \ddots & \ddots & \cdots \\ \vdots & \ddots & \ddots & \ddots \\ P(X_{n-1}[t+1] | X_0[t]) & \cdots & \cdots & P(X_{n-1}[t+1] | X_{n-1}[t]) \end{bmatrix}$$
• **Three steps to develop location inference model**
  – (1) Location inference without RFID event data
  – (2) Location inference with RFID event data from one node
  – (3) Location inference with RFID event data from multiple nodes
(1) Without Event Data

- **Event data is not available (no RFID implementation)**
  - RTI is at $N_0$ at time $t = 0$ ($P(X[0])$ is known)
  - Observation period is $t = T$
  - $\Phi$ from $t = 0$ to $t = T-1$ is known
  - Utilize Equation (2)

\[
P(X[T]) = \prod_{t=0}^{T-1} \Phi[t] P(X[0])
\]

Eq. (3)
• **Event data is available at one of the nodes**
  
  - Use the observation data (RTI is observed at one RFID-installed node at time $t_1$)
  - Infer location of RTI at time $t = T$
  - $\Phi$ from $t = t_1$ to $t = T-1$ is known
  - Evidence vector $e_R[t_1]$ ($e_R[t_1] = \{0, 0, \ldots, 1, 0, 0\}$)

\[
P(X[T]) = \left( \prod_{t=t_1+1}^{T-1} e_{R[t]} \neq X[t] \right) P(e_R[t_1])
\]

Eq. (4)
(3) With Event Data from Multiple Nodes

- Event data is available at some of the nodes
  - Use the last observation data (observed at RFID-installed node at time = $t_1$ and not observed any of the RFID-installed nodes b/w time $t_1+1$ and $T-1$)
  - Infer location of RTI at time $t = T$
  - $\Phi$ from $t = t_1$ to $t = T-1$ is known
  - Evidence vector $e_R[t_1]$

$$P\left( X[T] \right) = \left( \prod_{t=t_1+1}^{T-1} e_{R_k}[t]^\Phi X[t](k=0,1,...)[t] \right) \cdot \left( \prod_{k=0}^{T} e_{R_k}[t_1] \right)$$

Eq. (5)
Numerical Study

• Evaluate proposed model

• Steps
  – Generate traceability data by using traceability data generator
  – Compute $\Phi[t]$
  – Infer location by using observed event data and $\Phi[t]$

• Common scenario
  – An RTI is shipped from RSP at time $t = 0$
  – Observed at time $t_1 = 3$
  – Observation periods are 5 days, 10 days and 15 days
Node for RSP

RTI is provided to each node on request. (Links to nodes are omitted)

Legend

Node: [Mgmt method, Max RTI, delay (day/dist)]

Link: Demand (mean/STD)

Node 0

Node 1: [LIFO, 50, 3/RND]

Node 2: [LIFO, 50, 3/RND]

Node 3: [LIFO, 60, 3/RND]

Node 4: [LIFO, 40, 3/RND]

Node 5: [LIFO, 60, 3/RND]

Node 6: [LIFO, 40, 3/RND]

Node 7: [LIFO, 25, 3/RND]

Node 8: [LIFO, 15, 3/RND]
## Configuration Parameters of Traceability Data Generator

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>RTI inventory management policy</td>
<td>RTI inventory management policy employed by each node. Three types of configuration (FIFO, LIFO, random) are available.</td>
</tr>
<tr>
<td>Maximum RTI inventory level</td>
<td>Maximum number of RTIs held at each node. RTIs exceed this number are returned to RSP facility.</td>
</tr>
<tr>
<td>Reuse period</td>
<td>A period that is necessary for each node to be able to reuse the RTIs received. It is presumable RTIs have goods on them and need some time to remove the goods.</td>
</tr>
<tr>
<td>RTI replenishment flag</td>
<td>Whether the company that runs the node is a customer of an RSP or not. If the number of RTIs is in short, replenishment of RTI is made if the company is a customer of the RSP.</td>
</tr>
<tr>
<td>Link demand</td>
<td>Lind demand. Normal distribution is assumed and mean and standard deviation are assigned.</td>
</tr>
<tr>
<td>Numbers of RTIs per rent</td>
<td>Fixed RTI numbers with which RSPs’ customer can rent per time.</td>
</tr>
<tr>
<td>Warm-up period</td>
<td>Warm-up period of the simulator</td>
</tr>
</tbody>
</table>
## Simulation Settings

<table>
<thead>
<tr>
<th>Case</th>
<th>Number of RFID installed nodes</th>
<th>RFID installed nodes</th>
<th>Last observed node</th>
</tr>
</thead>
<tbody>
<tr>
<td>(A)</td>
<td>0</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>(B)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(B-1)</td>
<td>1</td>
<td>N1</td>
<td>N1</td>
</tr>
<tr>
<td>(B-2)</td>
<td>1</td>
<td>N3</td>
<td>N3</td>
</tr>
<tr>
<td>(B-3)</td>
<td>1</td>
<td>N7</td>
<td>N7</td>
</tr>
<tr>
<td>(C)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(C-1)</td>
<td>2</td>
<td>N1, N5</td>
<td>N1</td>
</tr>
<tr>
<td>(C-2)</td>
<td>2</td>
<td>N3, N5</td>
<td>N3</td>
</tr>
<tr>
<td>(C-3)</td>
<td>2</td>
<td>N5, N7</td>
<td>N7</td>
</tr>
<tr>
<td>(D)</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>(D-1)</td>
<td>3</td>
<td>N1, N3, N5</td>
<td>N3</td>
</tr>
<tr>
<td>(D-2)</td>
<td>3</td>
<td>N3, N5, N7</td>
<td>N7</td>
</tr>
<tr>
<td>(E)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(E-1)</td>
<td>4</td>
<td>N1, N3, N5, N7</td>
<td>N3</td>
</tr>
<tr>
<td>(E-2)</td>
<td>4</td>
<td>N1, N3, N5, N7</td>
<td>N7</td>
</tr>
</tbody>
</table>
5 Days Observation Period
10 Days Observation Period

: Simple calculation (reciprocal of # of possible nodes)
15 Days Observation Period

: Simple calculation (reciprocal of # of possible nodes)
Observation

• **Benefit of the model**
  – Successfully differentiate probability of RTI existence
  – Less successful in longer observation period but still better than simple calculation

• **Impact of number of RFID installed nodes**
  – The more nodes RFID is installed, the higher the probability becomes
Discussion

• Model proposal
  – Propose a location inference model from sparse RFID event data and show the effectiveness of the model

• Issues
  – Assumptions of model
    • Validity of developing RTI supply chain network
  – Assumptions of traceability data generator
    • Used to compute conditional probability distribution matrix
    • Need to confirm the assumption of the generator
Implication

• **Contract type**
  - A type contract (shipper is responsible for returning the RTI) may not be feasible
    • Consignees may return RTIs to shipper that are not come from the shipper
    • Consignees should stock RTIs separately based on where they come from, which reduces the efficiency at consignees
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11. Z. Ghahramani, Learning Dynamic Bayesian Networks. Berlin: Springer-Verlag,
Questions