# A Digital Twin Model to assess Inventory Inaccuracies in Multi-echelon Supply Chain

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**Abstract - The discrepancy between actual and recorded inventory is evident in the retail sector. This problem is "Inventory Record Inaccuracy" (IRI). Due to IRI, the replenishment system gets inaccurate information which leads to inefficiency in replenishment policies and stockouts. Our model is designed to estimate the expected IRI at each supply chain node. For interactions between retail stores and distributors in our model, we use agent-based simulation, and for processes inside the retail store/distributor, we use discrete event simulation. Additionally, this model estimates the costs of each type of error and how each type of error accumulates over time. A user interface has also been created to change the parameters in the model. This model can significantly help businesses reduce IRI costs at distributor and retail levels.**

**Keywords: Inventory Record Inaccuracy, Multi-method simulation, multi-echelon supply chain**

## I. INTRODUCTION

The supply chain is referred to as a network of entities involved in various processes and activities that generate value in the form of products and services in the hands of the end customer via upstream and downstream links. [1]Inventory at each node in the supply chain protects against fluctuations in customer demand, lead time, and supplier uncertainty. Companies often adopt software systems that use inventory and sales data to restock warehouses and retail shelves to manage inventory levels. One shortcoming of automatic inventory management systems is that replenishments are triggered based on inventory levels reported in the system, which may differ from inventory accessible in the retail shop or warehouse. Suppose the inventory management system indicates a stock level greater than the actual available inventory level. In that case, inventory is supplied too late, resulting in stockouts and the retailer's inability to meet consumer demand. If the system reports a lower than actually available inventory level, the replenishment is executed too soon, resulting in excessively high inventory levels. In both circumstances, inaccurate inventory records hinder the (expensive to build and maintain) stock management system from reaching its full potential and reduce earnings. [1]

Several empirical studies have demonstrated the mismatch between the recorded and actual inventory. An empirical study of 37 retailers found that inventory information in the inventory management system was inaccurate for more than 65 percent of inventory available. [3] A variety of factors can cause a discrepancy in inventory records. Non-paying demands or shrinkage are rarely documented because payment transactions are often used to record demands. As a result, thefts would almost probably be missed as demands, resulting in an actual inventory is lower than the reported inventory. Damages at the retail or warehouse and expired products for time-sensitive items are sometimes not recorded. [4] Finally, transaction errors may result in discrepancies. This includes outbound errors such as scanning errors at checkouts and inbound errors such as scanning errors and supplier frauds. Inventory inaccuracy can be expensive. Naturally, thefts, damages, and supplier fraud would result in direct losses for retailers and distributors. Aside from such direct losses, the disparity may result in inefficient inventory management and poor customer service.

This paper considers a supply chain with multiple retailers and distributors in which inventory records are inaccurate. Inventory inaccuracies accumulate until an inventory count is performed. After the inventory count, the inventory record is corrected. We explicitly model how various error causes contribute to inventory discrepancies and associated costs.

## II. THE PROBLEM

To manage inventory levels, companies usually employ software tools that use inventory and sales data to replenish warehouses and store shelves automatically. One weakness of automatic inventory management systems is that replenishments are triggered based on inventory levels recorded in the system, which can differ from the inventory that is actually available in the retail store or warehouse. This problem is referred to as *Inventory Record Inaccuracy (IRI).* If the inventory management system displays a stock level that is higher than the inventory level actually available, then inventory is replenished too late, which can lead to stockouts and the company not being able to satisfy customer demand. If the system displays a lower than available inventory level instead, the replenishment is made too early, leading to unnecessarily high inventory levels. In both cases, inaccurate inventory records prevent the (costly to install and operate) stock management system from unfolding its full potential and diminish profits.

*The objective of the project is to estimate the Inventory Record Inaccuracy (IRI) at different nodes in the supply chain and assess the cost implications.* IRI may have various sources, including incorrect manual adjustments of stock records, employee or customer theft, damage or spoilage, wrong shipments, or checkout errors.

## III. LITERATURE OVERVIEW OF IRI

For the presence of IRI, several studies provide empirical evidence. For instance, [1] reports that faulty records make up 51% of a retail firm's records and that this percentage varies among all retail establishments from 30% to 80%.[5]When the data of 369,567 inventory is examined from 37 retailers, [2] found that 65% of them had IRI problems. [3] report that 11.6% of the stock-keeping units suffered from IRI. The attempt by researchers to map the causes and effects of IRI and to offer managerial guidance regarding optimal approaches for addressing the IRI problem is common throughout the literature.

A study by [4] focuses on modeling the behavior of IRI with discrete event simulation, analyzing various methods to control the behavior and limit the impact of IRI. This study includes random lead time and supply uncertainty. In this study, the detailed analysis of IRI is done for single retail node. [3] study the effect of inventory inaccuracy on store performance in fashion retail. This study, conducted in the context of a fashion retailer with 81 stores, focused on the quantitative measurement of IRI and how to compare the effect of this inaccuracy across stores. [5] Analyzed various error sources in retail supply chains and studied the influence of inventory and Point-of-Sale (demand) errors in a simulated retail outlet according to fill rate and average inventory. The study by [6] is focused on a simulation modeling approach to address the inventory inaccuracy problems in a warehouse operation. The aforementioned studies aim to calculate IRI at single-node retail or warehouse locations. Our model simulates IRI behavior for a multi-echelon supply chain.

[7] propose operational and economic impacts of inventory record inaccuracy stemming from theft-type error in a continuous-review lost sale (s, Q) inventory system. Another study by [8] focuses on inventory inaccuracies introduced by theft-type errors within the store. Our model considers all IRI causes (Transaction errors - Inbound and Outbound, Shelving errors -Theft, Spoilage, and Misplacement type errors).

Many studies have focused on the consequences of and remedies to IRI. (See [5], [9] primarily measured in terms of holding costs and customer service. However, the effects of inventory errors include inefficiencies in inventory management and process control at one stage and spread through the SC and may adversely affect the functionality of upstream nodes [9], [10]. Simulation experiments were done by researchers mainly uses Discrete Event Simulation [4], [11]. Our model is using Multi-method approach – Agent-based simulation and Discrete event simulation to quantify the IRI in the multi-echelon supply chain.

## IV. METHODOLOGY

We use simulation as a research method. This enables us to investigate the effects of various elements contributing to inaccurate inventory on various supply chain performance metrics with a dynamic system. Simulation models are frequently used when certain aspects of the supply chain cannot be accurately modelled with analytical models or when stochastic variables need to be included [12]. To understand complex systems, they are helpful. Simulation models cannot optimize a supply chain. Instead, they enable analysts to assess the effectiveness of a particular supply chain configuration [13].

Our model simulates a supply chain with multiple retailers, distributors, and a single factory. *Multi-Method Simulation (MMS)* simulates processes within the node and interactions between the nodes. *Discrete event simulation (DES)* is a method used to model real-world systems that can be decomposed into a set of logically separate processes that autonomously progress through time. Each event occurs on a specific process and is assigned a logical time (a timestamp). DES is used in this model for a sequence of events like demand generation, order processing, error calculations, etc., within each node. In *Agent-Based Simulation (ABS)* a system is modeled as a collection of autonomous decision-making entities called agents. Each agent individually assesses its situation and makes decisions based on rules. ABS is used for interactions between the nodes. Factory, Retailers, and Distributors act as agents in the model. ABS is used for custom behavior regarding error parameters, reorder points, cost structure, etc.

### A. Error Modeling

Let $S_k$ = Amount of sales during period k

D = Demand during period k

$Y_k$ = Reorder Quantity

I = Recorded Inventory

IA = Actual Inventory

$Error_k$ = Discrepancy between the actual and the recorded inventory during period k.

In a perfect world with no IRI: I = IA

In real life with IRI: IA = I - $Error_k$

Theft Error = min $\{\alpha D_k, I_k\}$

Misplacement Error = $\theta * I_k$

Spoilage Error = $\beta$ max $\{I_k - D_k, 0\}$

Outbound error = $\delta * D_k$

Inbound error= $\gamma * Y_k$

Where $\alpha$ is rate of theft $\alpha >= 0$, $\theta \in [0,1]$ is misplacement rate $\theta \in [0,1]$, $\beta \in [0,1]$ is spoilage rate. Inbound and outbound errors are uniformly distributed with $\gamma \in [-\infty,1]$ and $\delta \in [-\infty, 1]$.

$\mathbf{Error_k} = \sum E(\min\{\alpha D_k, I_k\}) + \sum E(\delta * \min(D_k, I_k)) +$

$\sum E(\gamma * Y_k)) + \beta \sum E(\min\{D_k, I_k\}) - (\theta + \beta) \sum E(I_k)$

$Error_k$ is the total error made until period k.

## V. SIMULATION MODEL

We conducted a multi-method simulation in which retail stores, distribution centers, and a factory act as agents. An agent-based simulation is used for interactions between retail stores and distribution centers. Ports of these agents are connected through which agents can send and receive messages and orders.

In each agent, supply chain processes like getting an order, order processing, updating inventory, restocking, and error adjustment occur (see a flowchart of simulation in retail agent). In retail agents, Daily demand ($D_k$) from the customer is fulfilled by the retailer. If demand from a retailer is less than the inventory level available at a retail store, demand gets fulfilled. Theft and outbound errors are calculated when demand gets satisfied. As the inventory level reaches to reorder point, the retailer places an order with the distributor. Inbound error is calculated when inventory arrives from the distributor after lead time. Spoilage and misplacement errors are calculated as a percentage of the available inventory in each period.

The retailer will order products by sending messages to the distributor. It requires us to create a new agent type– order. The parameter amount is added to set the number of products this retailer requests from the distributor. The parameter destination is added to set the ports to which this order should arrive. Agent Shipment is also created with parameter amount and function toString. The parameter amount is added to get the number of products this retailer requests from the distributor. toString function is added to set the destination of shipment.

In retail agent: A table function is a function defined in the table form. A table function works when the user defines a function by giving a few (argument, value) pairs. Import demand data in the table function in (day, mean aggregate daily demand) format using paste from clipboard option. Demand generator is a periodic event which generates demand for each day.

In check demand function, If the inventory level is greater than demand, demand gets fully satisfied and inventory level changes to inventory level minus demand. If the inventory level is less than demand, demand gets partially satisfied and order gets placed to the distributor.

In order from distributor event, distributor sends order from distributor port to retailer port in lead time. Periodic event measures the errors at particular processes in supply chain. In this setting, when the actual inventory reaches to zero (stockout), inventory records get corrected.

For the distributor node, when an order enters from the retailers, it gets queued in a First-In-First-Out (FIFO) manner. It delays order for order processing for some amount of time. Delivery and outbound errors are calculated when the order get satisfied. The distributor places an order to the factory when the inventory level reaches to reorder point. Inbound error is calculated when an order is received from the factory.

Distributor checks orders from retailers and satisfy if order amount is greater than inventory available. Orders from the retailers enter in FIFO manner and waits for some time for order processing. After this order processing order gets delivered to retailer with delay of sometime.

The model in this paper was implemented using Anylogic PLE software.

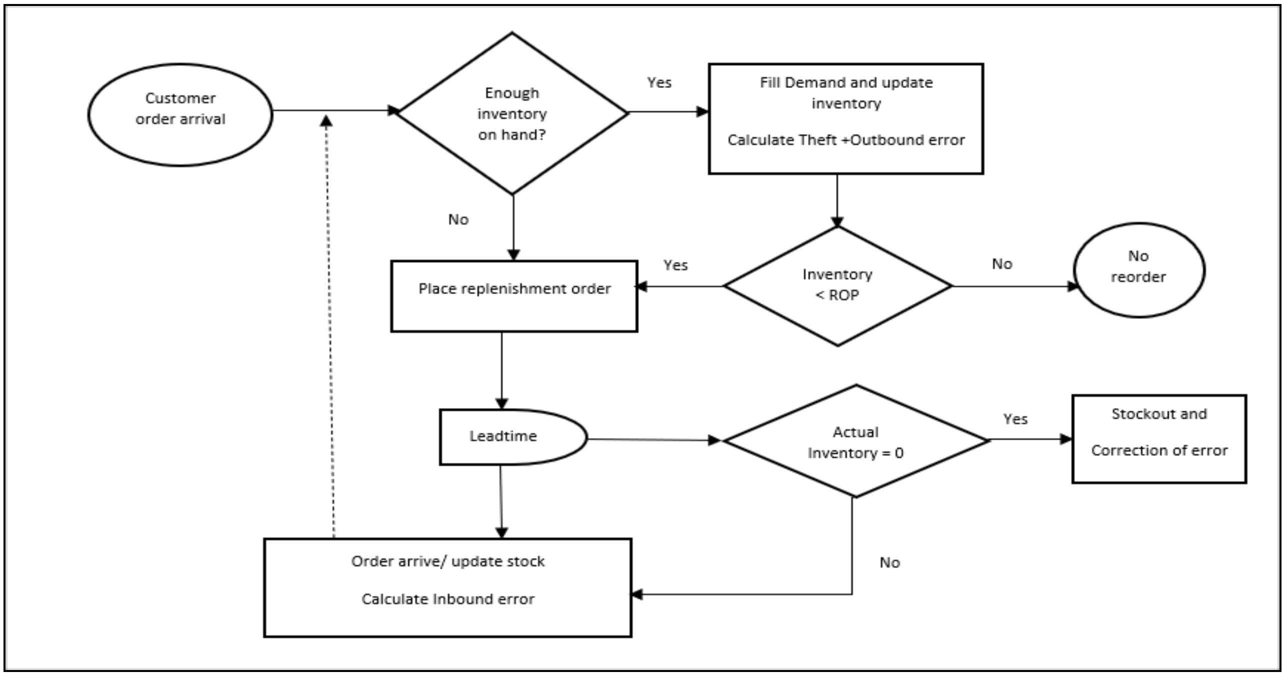


*Fig.1 Flowchart of simulation*

IRI has two effects on items. First, the items affected by IRI become unsalable. Thus, IRI-related cost includes the opportunity cost of selling those items. Second, the cost of replenishment of those items and the cost of incorrect information to the inventory replenishment policy. Finding a cost for incorrect information is challenging. For practicality, we use λ to represent the cost of one unit of mismatch between actual inventory and records [4]. This model gives IRI cost due to each type of error and IRI cost as a percentage of total revenue.

## VI. NUMERICAL ANALYSIS

Simulating IRI accumulation for a complex supply chain consisting of 10 retail stores, two distributors, and a supplier. Our simulation model uses discrete and constant time intervals. Each simulation runs for 290 time periods. Aggregate demand per day from customers can be imported into the model; hence no assumptions about demand distribution are taken. The model incorporates various causes of inventory inaccuracy. The parameters for the errors are selected from various examples in the literature. The transaction errors are assumed to be uniformly distributed, Inbound errors = uniform distribution (−1%,1%) and outbound errors= uniform distribution (−2%,2%) (Morey, 1985; Rosetti et al., 2010). The shelving parameters are defined as theft error = 1% and spoilage error = 0.5% (Rekik et al., 2008, 2009; Yan et al., 2011).

The model includes a simulation experiment where the user can manually set up parameters like rates of error, costs per unit, and ROP. It is assumed that the model starts with zero IRI when the inventory records and actual physical stock equal to the reorder level. The orders from 5 retail stores get placed with 1 distributor, and the orders from the other five retail stores get placed with another distributor. The orders from the retail store get fulfilled in First-In-First-Out (FIFO) manner. Retailer and distributor follow continuous (Quantity ordered, Reorder Point) policy utilized with (2000,200) for a retail store and (10000,2000) for the distributor. All units of items are in thousands. Lead time is uniformly distributed between (0.5,1) days, and demand are taken from publicly available data of major US retailer. Table 1. shows the observed results for 10 retail stores obtained from the numerical study with assumed error parameters from the literature.

| Retail Store ID | Stockouts | Inbound Error | Outbound Error | Error |
|---|---|---|---|---|
| **1** | 9 | 10 | 37 | 613 |
| **2** | 14 | -40 | -13 | 790 |
| **3** | 11 | 70 | 15 | 788 |
| **4** | 7 | 18 | -1 | 116 |
| **5** | 10 | -10 | 20 | 600 |

| | | | | |
|---|---|---|---|---|
| **6** | 9 | -19 | 19 | 122 |
| **7** | 6 | 7 | -10 | 345 |
| **8** | 20 | -18 | -26 | 570 |
| **9** | 10 | 32 | 20 | 450 |
| **10** | 8 | 15 | 17 | 316 |

*Table 1. Expected average IRI (in thousands of units) due to each type of error in each retail store*

The stockout refers to the amount of time where the actual physical stock dropped to zero. Each error column denotes the average number of IRI accumulated in the system for each cause of IRI in 290 days. Based on the number of items affected by each type of error, strategic decisions can be made to reduce the IRI in each store.

In the literature, the most frequently used relation between holding cost (h) and purchasing cost (c) is h = 0.2c; however, there is no general relation for the selling price (p). For our purposes, the accuracy of these costs is not relevant as long as they satisfy h>c>p and justifies a profitable opportunity for the decision maker to be in the business. Hence, we use the following setup: h = 0.2 c and p = 2 c [4]. In the numerical study we are assuming for distributor: $ 1 as selling cost per item, $ 0.1 as holding and ordering cost per item and for retailer: $1 as purchasing cost, $ 2 as selling cost, $0.2 as holding and ordering cost per item. These costs can be changed manually at runtime. Also, Table 3. shows the projected IRI cost as a percentage of total revenue at each store

| Distribution Center | Inbound Error | Outbound Error | Theft Error | Spoilage Error | Misplacement Error | Delivery Error |
|---|---|---|---|---|---|---|
| **1** | 186 | -18 | 941 | 1882 | 1800 | 250 |
| **2** | 200 | -3 | 1018 | 2036 | 1900 | 208 |

*Table 2. Expected average IRI (in thousands of units) due to each type of error in each distribution centre*

| Retail Store | IRI Cost as % of Total Revenue | Retail Store | IRI Cost as % of Total Revenue |
|---|---|---|---|
| **1** | 2.28% | **6** | 0.64% |
| **2** | 0.75% | **7** | 0.35% |
| **3** | 0.78% | **8** | 1.10% |
| **4** | 0.45% | **9** | 0.84% |
| **5** | 1.19% | **10** | 0.92% |

*Table 3. Expected IRI cost as a percentage of total revenue*

## VII. CONCLUSION

This model provides an estimated expected IRI for each retailer and distributor in the supply chain using multi-method simulation. This model breaks down the number of items affected due to each cause of IRI and the associated costs. Companies can set company-specific parameters for order quantity, reorder point, costs, and error parameters with the help of a user-friendly interface. IRI estimates will help reduce stockouts due to IRI by accounting for IRI in replenishment decisions. In future work, an improvement of the model formulation will be explored by estimating error parameters for each node within the mode.

## VIII. REFERENCES

[1]
M. Christopher, "Logistics and supply chain management, creating value-adding networks.," Financial Times Prentice Hall, Harlow, 3rd ed., 2005.

[2]
E. S. Y. D. Yacine Rekik, "Inventory Inaccuracy in Retail Stores Due to Theft: An Analysis of the Benefits of RFID," International Journal of Production Economics 118(1):189-198, 2009.

[3]
A. R. Nicole DeHoratius, "Inventory Record Inaccuracy: An Empirical Analysis," Management Science , Voulme 54, Issue 4, 2008.

[4]
H. L. L. Ö. Aykut Atali, "If the Inventory Manager Knew:Value of Visibility and RFID under Imperfect Inventory Information.," Stanford University., 2004.
[5]
S. B. G. Yun Kang, "Information inaccuracy in inventory systems: stock loss and stockout," IIE Transactions , 2005.
[6]
G. M. S. d. L. W. D. Amir Shabani, "Inventory record inaccuracy and store-level performance," International Journal of Production Economics , 2021.
[7]
H. K. Okyay, "Detailed Inventory Record Inaccuracy Analysis," Graduate Theses and Dissertations-University of Arkansas, Fayetteville , 2014.
[8]
M. A. W. D. W. R. M. Heather Nachtmann Ph.D, "The Impact of Point-of-Sale Data Inaccuracy and Inventory Record Data Errors," Journal of Business Logistics 31(1):149 - 158, 2010.
[9]
A. Kamaludin, "A simulation approach for modelling and investigation of inventory inaccuracy in warehouse operation," Loughborough University. Thesis. https://hdl.handle.net/2134/6750, 2010.
[10]
A. S. R. &. K. N. Hassan Zadeh, "Inventory record inaccuracy due to theft in production-inventory systems," Int J Adv Manuf Technol 83, 623–631 , 2016.
[11]
M. M. T. Hongyan Dai, "The Impacts of RFID Implementation on Reducing Inventory Inaccuracy in a Multi-Stage Supply Chain," International Journal of Production Economics 139(2), 2011.
[12]
M. B. S. C. G. L. Porta, "Inventory record inaccuracy in supply chains: the role of workers' behavior," International Journal of Physical Distribution & Logistics Management, Vol. 44 Iss 10 pp. 796 - 819, 2014.
[13]
M. B. Thomas J. Kull, "Investigating the the Effects of Daily Inventory Record Inaccuracy in Multichannel Retailing," Management Faculty Research and Publications. 252. , 2013.
[14]
B. S. T. N. Riddalls C.E, "Modelling the dynamics of supply chains," International Journal of System Science -31 , pp. 969-976, 2000.
[15]
D. K. P. S.-L. E. Simchi-Levi, Designing and Managing the Supply Chain: Concepts, Strategies, and Case Studies, McGraw-Hill, New York , 2000.