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An Inventory Model Using System Dynamics Analysis for Declining Items in a Supply Chain

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Abstract- An integrated inventory model of the supply chain for degrading products among a supplier, a manufacturer, and a customer was created by Rau et al. in 2004. The ideal order lot-size and delivery number n was determined under the least joint cost of the supply chain by using a mathematical model. In order to determine the ideal inventory policy and order timing, Rau et al. focused mostly on conventional statistical and mathematical calculations. However, they did not go into greater detail about the complicated dynamics that arise from time evolution. The inventory model of decaying objects must be carefully and methodically considered in order to accurately reflect the operating process. Thus, in order to suggest a novel order system and carry out a systematic simulation, we employ system dynamics thinking in this research. The developed model's validation and model testing results demonstrated the suitability of the system dynamics simulation approach. In the end, the ideal least joint cost of the supply chain was found using the system dynamics simulation.

Keywords- Deteriorating inventory; Supply chain; System dynamics

I. INTRODUCTION

Appropriate inventory management has emerged as a crucial operational activity and a source of revenue in order to meet consumer and market demands (Chorpa and Menidl, 2001; Minner, 2003; Ranjan and Susmita, 2011). Companies' capacity to reduce costs and maintain production consistency is greatly impacted by effective inventory management (Krajewski et al., 2010). Real-world restrictions on product inventory could include degradation, dates for consumption (DOC), and vaporisation. We can refer to that as depreciating inventory. Understanding the characteristics and types of degradation is crucial for creating inventory models with deterioration (Wee, 1999; Alamri and Balkhi, 2007; Hsu et al., 2010; Yi et al., 2010). Deterioration is the term for characteristics such as wear and tear, decreased usefulness, and loss brought on by the physical depletion of items or use. According to Ghare and Schrader (1963), degradation falls into one of three groups:

(1) Direct spoiling: fruits, vegetables, shellfish, and easily decomposing foods.
(2) Physical depletion: this includes vaporising liquids and petrol.
(3) Deterioration: like a medicine becoming bad or an electronic gadget losing its usefulness over time.

Based on an examination of the literature, we discovered that most researchers working on inventory-related projects utilised mathematical computation to arrive at an estimated optimal solution. The dynamics complex linked to time evolution was not further discussed by them (Rau et al., 2004; Ping et al., 2007; Kung et al., 2010; Yong et al., 2010). We suggested a new order system of inventory model in this research, which is based on the Rau et al. (2004) model. After that, we built a system dynamics model and ran simulations and tests on it. By building an analytical system dynamics model, we want to address the intricate dynamics of the supply chain inventory model for decaying products. There are six sections in this study. The introduction is in Section 1. The study's assumptions and annotations are explained in Section 2. Section 3 provides an overview of the Rau et al. (2004) investigation. The model of system dynamics is shown in Section 4. Model analysis and a numerical example are provided for applications in Section 5. Section 6 concludes with a final statement.

II. ASSUMPTIONS AND NOTATIONS

2.1 Basic Assumptions

The following presumptions formed the basis of the inventory model's development:

1. The order cycle is understood.
2. Only one customer, one manufacturer, and one supplier are taken into account.
3. Only one thing is taken into account.
4. The ratio of raw inputs to finished items is 1:1.
5. The rates of production and demand are steady and predictable.
6. The pace of production exceeds the rate of demand.
7. The pace of degradation is steady and deterministic.
8. Without any shortages.
9. Rather than considering a single delivery per order, several lot-size deliveries are taken into consideration.
10. Every delivery has the same lot size.

2.2 Notations

T Order cycle
n Number of deliveries per order cycle T
t Delivery cycle
n* Optimal delivery number
D Demand rate of finished goods for a buyer (constant)
ϴB Deterioration rate of finished goods for a buyer (constant)
tB Inventory consumption period for a buyer
WB Inventory quantity on hold of finished goods from time 0 to time tB
qB Maximum inventory level of finished goods per receiving for a buyer
AB Ordering cost of finished goods for a buyer (constant)
FB Receiving cost of finished goods for a buyer (constant)
HB Holding cost of finished goods per unit per unit time for a buyer (constant)
PB Cost of a deteriorated unit for a buyer’s finished goods (constant)
TCB Total cost for a buyer

III. THE STUDY OF RAU ET AL. (2004)

Rau et al. (2004) created an inventory model for degrading products in a supply chain, including suppliers, producers, and buyers. In his study, he compared two inventory model cases: one without shortage and one with shortage.

Our study will focus on the inventory model without shortages for each supply chain partner. This article covers inventory models for buyers, producers, raw materials, suppliers, and integrated inventory.

3.1 Inventory model of a buyer’s finished goods

The finished goods inventory level at the extreme point:

$$q_B = \frac{D}{\theta_B}\left[e^{\theta_B t_B} - 1\right]$$

and the inventory quantity of finished goods for the buyer from time 0 to t_B is:

$$W_B = \frac{q_B - Dt_B}{\theta_B}$$

The total cost for finished goods for the buyer per T can be expressed as the sum of the order cost, receiving cost, holding cost, deterioration cost, i.e.

$$TC_B = \frac{A_B}{T} + F_B \times \frac{n}{T} + W_B \times H_B \times \frac{n}{T} + [q_B - Dt_B] \times H_B \times \frac{n}{T}$$

3.2 Inventory model of a producer's finished goods

Maximum inventory level of finished goods for a producer during period as:

$$q_P = \frac{P}{\theta_P}(1 - e^{\theta_P t_P}) = q_B$$

Inventory quantity on hold of finished goods for a producer from time 0 to t_P is:

$$W_P = \frac{Pt_P - q_B}{\theta_B}$$

The total finished goods cost for the producer per T can be expressed as the sum of the set-up cost, delivery cost, holding cost, deterioration cost, as follows:

$$TC_P = \frac{S_P}{T} \times n + F_P \times \frac{n}{T} + W_B \times H_P \times \frac{n}{T} + [Pt_P - q_P] \times P_P \times \frac{n}{T}$$

3.3 Inventory model of a producer's raw materials

Quantity of raw materials per delivery from a supplier to a producer's warehouse can be expressed using the following equation:

$$q_{PW} = \frac{P}{\theta_{PW}}[e^{\theta_{PW} t_P} - 1]$$

Inventory quantity on hold of raw materials from time 0 to t_P is:

$$W_{PW} = \frac{q_{PW} - Pt_P}{\theta_{PW}}$$

The total cost for the producer's raw materials warehouse per T can be expressed as the sum of the receiving cost, holding cost, and deteriorating cost, as follows:

$$TC_{PW} = F_{PW} \times \frac{n}{T} + W_{PW} \times H_{PW} \times \frac{n}{T} + [q_{PW} - Pt_P] \times P_{PW} \times \frac{n}{T} \qquad (9)$$

3.4 Inventory model of supplier's raw materials

Total quantity of raw materials receiving (planned) from a supplier's vendor during period T is:

$$q_S = \frac{q_{PW}}{(1-\theta_S)^t}$$

Inventory quantity on hold of raw materials for supplier from time 0 to t is:

$$W_s = \frac{(q_{PW} - q_s)}{\ln(1-\theta_s)}$$

The total raw materials cost for the supplier per T can be expressed as the sum of the order cost, delivery cost, holding cost, deterioration cost, as follows:

$$TC_s = \frac{A_s}{T} + F_s \times \frac{n}{T} + W_s \times H_P \times \frac{1}{T} + [q_s - q_{pw}] \times P_s \times \frac{n}{T}$$

3.5Integrated inventory model

The integrated total cost for the buyer, producer and supplier, TC, as follows

$$TC = TC_B + TC_P + TC_{PW} + TC_S$$

IV. MODEL OF SYSTEM DYNAMICS

Jay W. Forrester created system dynamics (SD) modelling and simulation at the Massachusetts Institute of Technology in 1961 for the purpose of simulating and analysing intricate socioeconomic systems. Since then, SD has been used to solve dynamic industrial management issues and support company policymaking (Forrester, 1961; Senge, 2006; Erma et al., 2010). Here are a few relevant studies: Sterman (2000) talks about case studies including the SD methodology's modelling of logistical difficulties. By using SD, Minegishi and Thiel (2000) uncover the intricate logistic behaviour of the food business. Their research clarifies how factors in food production are coordinated. In order to accurately portray the behaviour of the supply chain network under investigation, Ozbayrak, M. et al. (2007) created a systems dynamics model of a manufacturing supply chain system. By creating the causal and feedback loops, this technique may be applied to the modelling of complex, nonlinear, multi-loop feedback systems.

We used Vensim (Ventana Systems Inc., 2004) as the modelling and simulation program for system dynamics in this work. Professional simulation software with a graphical user interface is called Vensim. Based on the feedback loops and causal linkages, we may operate a system. A system dynamics model has four different kinds of items: (1) connections, (2) stock, (3) converters (or auxiliary), and (4) flow. The pace at which the stock variables change is represented by the flow variables that either fill in or consume the stock. Stock variables, also known as state variables, are the main accumulations in the system. General variables are used to represent converters, which are intermediate variables for computations. Lastly, basic arrows are used to symbolise the connections that show the cause-and-effect paths.

4.1 Diagram of Causal Loops

According to the logic and function of integrated inventory model of a supply chain for deteriorating items, we designed the causal loop diagram as figure 1. The diagram is consisting of a buyer, a supplier, and a producer which needs to be considered by having distinct inventories of raw material and completed items. As indicated in figure 1, we may achieve the following logics. A producer's stock of completed items falls as consumer demand rises. A producer's completed products inventory rises in tandem with an increase in their finished goods inventory. A producer's inventory of completed items rises and their inventory of raw materials falls as their order number rises. A producer's raw material inventory rises and the supplier's overall inventory falls as their order number rises. A supplier's overall inventory rises in tandem with an increase in orders.

We created a system dynamics simulation schematic in accordance with figure 1. Next, we suggested a new order system in by adding an order signal to it.

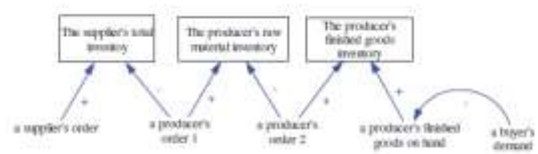

Fig 1. Casual loop diagram

We must talk about the degree of influence of objectives by entering several important decision-making qualities and elements once Vensim has created the cause and effect loop diagram of the integrated supply chain model. The first step is to enter the values of the variables. The example used here is an adaptation of Rau et al. (2004). The following are the values of the variables:

- Cycle T of planning: a unit of time (e.g., one week).
- The buyer's criteria are as follows: degradation cost (P_B) = \$110 per unit; deterioration rate (q_B) = 0.08; ordering cost (A_B) = \$300 per order; receiving cost (F_B) = \$25 per receiving; holding cost (H_B) = \$15 per order; and demand rate (D) = 12,000 units per week.
- Production rate (P) = 24000 units per week; set-up cost (S_P) = \$500 per setup; delivery cost (F_P) = \$150 per delivery; holding cost (H_P) = \$12 per unit per week; deterioration cost (P_P) = \$90 per unit; deterioration rate of finished goods (q_p) = 0.095; receiving cost of raw material (F_{Pw}) = \$20 per receiving; holding cost of raw material (H_{PW}) = \$10 per unit per week; deterioration cost (P_{PW}) = \$85 per unit; deterioration rate of raw material (q_{PW}) = 0.09; raw materials reorder point (P_W_order_point) = 50.
- The supplier's specifications include: deterioration cost (P_S) = \$75 per unit; deterioration rate (q_s) = 0.1; reorder point (S_order_point) = 150; ordering cost (A_S) = \$250 per order; receiving cost (F_S) = \$125 per

receiving; holding cost (H_S) = \$8 per unit each week.

4.2 The new order system that is being presented

Policy 1: Using the flow chart shown in Figure 2 to simulate the order system.

Policy 2: Changing the order system to a newly suggested order system, with the flow chart shown in figure 3.

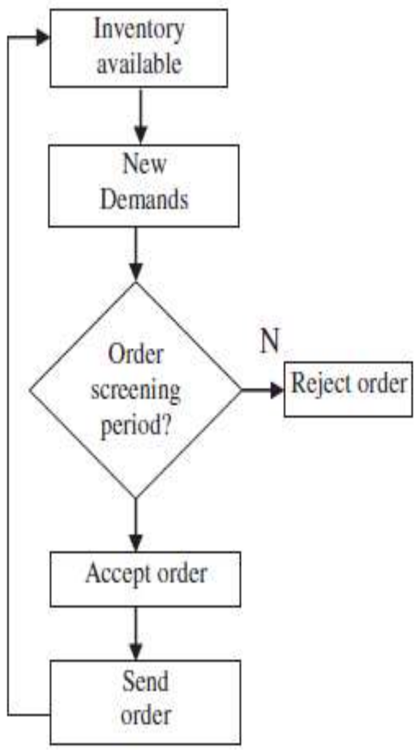

Fig 2. The Order System

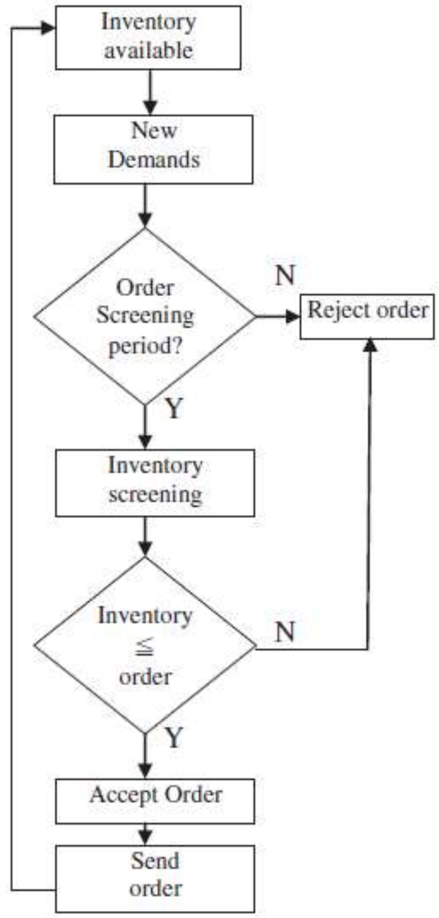

Fig 3. Proposed new order system

The following describes the setting and action logics of each choice attribute as well as the time-dependent casual factor function in the suggested order system.
(a) The legislation on supplier orders

S_order_signal × q_s = V_shipping
These include the following S_order_signal calculation logic:
If S_inventory < S_order_point
S_order_signal = 1, else S_order_signal = 0.

(b) Law governing the producer's raw material order

q_{pw}× PW_order_signal = S_shipping
Among them, the PW_order_signal calculation logic is as follows:
If PW_inventory < PW_order_point

PW_order_signal = 1, else PW_order_signal = 0.

4.3 Model testing and validation

Model testing is essential to reflect the model's validity and practicability once dynamic systems have been modelled. Model testing may boost decision makers' trust in the model's validity, which in turn can help them make the right corporate decisions. Structure evaluation, parameter assessment, extreme situations, border adequacy, dimensional consistency, behaviour anomaly, behaviour reproduction, and sensitivity analysis are among the items pertaining to model testing validation (Sterman, 2000). After that, we tested the model independently based on those factors, and the findings indicated that our model was suitable.

V. APPLICATION-SPECIFIC MODEL ANALYSIS AND NUMERICAL EXAMPLES.

We compared Rau et al.'s (2004) order systems to the suggested new one in this study. After a week of simulation, the Rau et al. (2004) model and the suggested one were shown to be consistent and divergent. Rau et al. (2004) and the suggested order system had total costs of 35,394 and 33,566 USD, respectively, during week one. The delivery numbers are both 23. The comparison shows that the suggested new order system has a lower total cost.

VI. CONCLUSION

In this publication, we extend the research of Rau et al. (2004). We use system dynamics to simulate an inventory model for degrading products in a supply chain. We created a dynamic system model to analyse inventory policy and its impact on cost dynamics. Customers routinely alter their expectations, requiring suppliers and producers to adjust their inventory models to save costs for each other. This work proposes modifying Rau et al.'s (2004) order system to use a system dynamic model and simulation for a more comprehensive, long-term solution. The simulation findings indicate that the system dynamics simulation approach is appropriate for studying time evolution.

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