APPLICATION OF SIMULATION IN INVENTORY MANAGEMENT OF EOL PRODUCTS IN A DISASSEMBLY LINE

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ABSTRACT

This paper presents a simulation approach using System Dynamics (SD) technique to model the inventory buildup and behavior of disassembled parts accumulation and or consumption in a disassembly line setup. The approach is considered as a model for decision making process in a reverse-logistics environment. Given the descriptive nature of the approach, the problem is investigated under different scenarios of demand and supply of end-of-life (EOL) products to draw conclusions of the system reaction to external factors such as demand changes. This will allow the disassembly facility to examine different strategies of handling inventory of end-of-life (EOL) products and disassembled parts. System dynamics (SD) techniques are used to simulate the process and show its complexity. Numerical example is given to illustrate the approach and draw conclusions.

Keywords: Reverse supply chain, Disassembly, System dynamic, End-of-life, Inventory management

INTRODUCTION

The in-bound stream of incoming and returned end-of-life (EOL) products results in many challenges to the Original Equipment Manufacturers (OEMs) that if handled properly can represent a profitable business, as some studies showed that companies that engage in "active value recovery" have an advantage over others with "no value recovery" policy over the long term [1]. Interest in the reverse logistics has emerged during the past two decades, shifting the thinking from traditional fast introduction of new products in the market to full accountability of the products manufactured, or in other words the interest has shift from "materials recovery" to "value recovery" [1]. Now the process does not stop at the end customers. The manufacturer is obligated to bear any costs also that may arise at the end of the product life cycle to fully acquire and recover any value remaining in these items. Activities like return, inspection, disassembly, and recovery were hardly considered before and now became part of the important aspects of doing business. Companies now consider these end-of-life (EOL) products as an alternative source for secondary resources instead of virgin resources that are depleting very fast. This approach will allow the reuse of materials and parts more than once before they are finally discarded. This approach has environmental as well as economical benefits. Major challenge original equipment manufacturers (OEMs) face now is how to implement an effective reverse supply chain network that is both cost effective and efficient. The rapid increase of return of products from end customers back to the origin is a main reason behind that interest [2]. System Dynamics (SD) approach is introduced as a decision making tool to help the planner take corrective action, and simulate different scenarios in the reverse supply chain network with a disassembly facility to anticipate the behavior of the system under a
variety of situations. The system dynamics approach will allow examining the relationship between the different elements of inventory management in a disassembly context, and thus taking corrective action to minimize the overall negative impact on inventory and cost [3].

BACKGROUND AND LITERATURE REVIEW

A review of the state of the art research in the area of Reverse Logistics (RL) and Disassembly Line was published in 2010 [4]. The system dynamics was first introduced in the 1960's by Jay Forrester in his book Industrial Dynamics and mainly were applied in forward supply chain applications. It is a solution approach based on qualitative and quantitative logical thinking [5]. First models of system dynamics application in closed-loop supply chain was targeted at the automobile recycling and motivated by the recent government regulations and environmental concerns [6]. He studied the interactions between original equipment manufacturers (OEMs), consumers, and recycling companies and modeled the effect of legal and technological changes on the industry. Vlachos presented a system dynamics model for strategic remanufacturing and collection capacity planning of a single product reverse supply chain for product recovery. The model presents the analysis of system operations such as product flows and stocks, considering capacity constraints, alternative environmental protection policies involving a take-back obligation [7]. Kumar and Yamaoka apply the system dynamics modeling approach into the Japanese automobile industry to examine the relationship between reduce, reuse, recycle, and dispose of car parts. They performed qualitative and quantitative analyses on the basis of the stock flow diagram for the closed-loop supply chain [3]. Lehr and Milling examined different strategies for collection and value recovery of end-of-life (EOL) products in electronics industry through dynamic simulation technique using system dynamics methodology [1]. Poles and Cheong uses system dynamics simulation for studying and managing complex feedback systems, particularly business and social system, to model an inventory control system in a remanufacturing process where production is integral with remanufacturing. They analyzed the total inventory cost influenced by returns rate affected by the external factors [8]. Georgiadis and Vlachos examined the effect of environmental legislations in customer demand in a remanufacturing environment on long term decision making. The model is later extended to include the impact on capacity planning and collection when managing product returns at the end of its life cycle [9].

SYSTEM DYNAMICS SIMULATION STRUCTURE AND RESULTS

The philosophy behind system dynamics (SD) is founded on the concept that industrial systems are like input-output systems. The system state changes according to the change in the rate of inflow and outflow. Hence, any system can be viewed as an input-output system with input-output rates. The system dynamics (SD) model is characterized by the feedback loop that triggers the corrective, control, action. The purpose of the model using VenSim 5.9 software is to simulate the buildup of the inventory of disassembled parts under a stochastic demand and supply setting. The model describes the different activities that take place in the disassembly facilities such as arrival of end-of-life (EOL) products, disassembly, inspection, addition to
inventory (serviceable or recyclable), and ultimately dispose of. Figure 1 is a graphical representation of the inventory management model structure using a System Dynamics (SD) modeling technique developed using VenSim PLE 5.9.

**Methodology of System Dynamics (SD) Simulation Model**

The first step in the model is to inspect the end-of-life (EOL) products and those pass inspections are sent to the failed EOL inventory. After that, products are sent to be disassembled and others are disposed of or recycled. It is assumed that certain as product age increase its probability to qualify for disassembly and further processing decreases. As parts become older it gets expensive to recover its value by performing disassembly operations, and they become more and more suitable for recycling rather than value recovery, repair, or remanufacturing. After the decision is made to perform the disassembly operation, the end-of-life (EOL) product will be routed through the designated workstations, in this work the assumption is that each part is disassembled separately in a different workstation, meaning no coupling of tasks at any workstation. After the part is disassembled, it will be added to the inventory, and if rejected after disassembly it is either disposed of or recycled. Once the demand for these items occur, a withdraw against the current inventory of parts will occur and the balance is usually carried to the next period. The simulation model is capable of describing number of complex entities in the inventory system such as queue size, work-in-process, inventory level, as the entities are routed in the system and inventory is generated and added. The output file will provide a daily inventory size of the different parts disassembled and the demand occurrences.

Figure (1) Model Structure of Inventory Management of EOL using SD Approach
Simulation Outlook and Results
The system dynamics model for the inventory management of end-of-life (EOL) products was developed using the components strategy approach and VenSim PLE5.9 simulation software. The first step is the model setting for time and units. Initial time and final time were set at 0 and 300 respectively and with a time step of 0.125. The units of time selected as weeks and type of integration used is Euler's method. To illustrate the interdependencies between the model elements and the effects of external forces, a sudden hike in demand known as step input demand scenario is examined using the model. The initial demand was set at 100 units/week, and a sudden demand increase by 20%. This sudden increase in demand caused a gradual increase of the current end-of-life (EOL) products inventory of 38.90% from 1,800 units to 2,500 units within 28 weeks span. The inventory of end-of-life (EOL) products drops after that for 15 consecutive weeks. The system reaches equilibrium state at week 60 with a steady level of end-of-life (EOL) products of 2,300 core products on hand, or 31.4% of the initial level at week 0. As a result of a sudden increase in demand, the current inventory of “reusable” parts are depleted to cope with the demand before it is started to build up inventory as the disassembly operations starts. The inventory reaches its lowest level of 300 disassembled parts in 15 weeks span, before it stabilize again at 375 parts level in week 60. The inventory policy under sudden hike in demand can be built on the premises of the inventory system behavior. Thus, it is realistic to permit shortages in the early stages of the hike in demand. However, the equilibrium state maybe reached sooner if sufficient buffer stock is kept to take back the impact of such demands. The figures clearly show that the inventory system reacts slowly to the sudden positive change in demand, destabilizing the system before regains control.

Thus, the sudden hike in demand can not only be satisfied by increasing the rate of inspection, sorting, and disassembly. It is important to realize that the increase in end-of-life (EOL) products inventory is because of the increase of the collection of products from the end customers back to recovery to satisfy the higher demand for the disassembled parts. A collection and transportation network has to exist to ensure smooth availability of end-of-life (EOL) products.
System Dynamics (SD) Original Model Sensitivity Analysis

The original model of the end-of-life (EOL) products inventory system assumes the demand is 100 units/week. To test the model behavior when some changes occur, the following two scenarios are presented and tested, when all other parameters remain unchanged: i) when the demand changes from 100 to 112 units/week, and ii) when the disassembly time changes from 8 to 16 minutes/ product. The changes on the inventory of end-of-life (EOL) products and inventory of reusable parts inventory are shown in the following figures (3) and (4).

Figure (3) Changes in EOL Inventory Level Scenario (i) and (ii)

An increase in demand of 12 units a week, equivalent to 12%, resulted the initial on hand inventory of end-of-life (EOL) core products to be increased to 2,300 unit’s levels to cope with the demand of disassembled parts. Similarly, the increase in disassembly time triggers the increase of the inventory level of end-of-life (EOL) products to 1,200 units, equivalent to 50%.

Figure (4) Changes in Parts Inventory Level Scenario (i) and (ii)

Increase in the demand and/or the increase of the disassembly time both have a negative effect on the inventory of reusable parts, causing a drop in the inventory level, before disassembly rate increases. It is clear that the system reacts better and twice as faster when the demand changes, compared to changes in the system parameter itself such as the increase of the disassembly time. In the first case, where the demand increases by 12% to 112 units/week, the drops to near 200 parts inventory and recover by week 45. In case of disassembly time changes, there is a sharp decrease in reusable parts inventory due to continuous demand and low line yield of parts, yet above the 200 parts level, and it takes longer time to stabilize again.
CONCLUSIONS
In this paper, a System Dynamics (SD) model of inventory management problem in a disassembly line was developed and tested under demand fluctuation scenario. The probabilistic nature of the problem is assumed to provide more accurate results compared to deterministic models, hence a better understanding of the system long term behavior under external factors uncertainty. Problem methodology and model is presented using commercial software VenSim PLE 5.9. In future research, other factors such as price fluctuation or seasonal effect can be added. The, sensitivity analysis is applied to examine the impact on the inventory of disassembled parts and core products when : i) demand increases and ii) disassembly time doubles. In conclusion, the System Dynamics (SD) model is a decision making tool that helps planner forecast the long term system behavior under certain market condition and changes.

REFERENCES