

A System Dynamics Framework for an Integrated Forward-Reverse Supply Chain with Fuzzy Demand and Fuzzy Collection Rate under Possibility Constraints

Debabrata Das and Pankaj Dutta

Abstract— Reverse supply chain management has been an area of growing attention during the last decade in industry as well as in academia due to its high economic impact, increasing social awareness and strict legislations. In this paper, we develop a simulation model based on system dynamics methodology to analyze the long-term behavior of a multi-echelon forward-reverse supply chain with fuzzy demand and fuzzy collection rate by incorporating various recycling activities, namely; collection, product refurbishing, component reuse and refurbishing, and raw material recovery. The uncertainty issues associated with acquisition and collection of used product in the proposed reverse logistics network has been quantified using possibility measures. In the proposed model, it is assumed that the customer can exchange their old used product with a fresh new product in a primary market or a relatively better refurbished product in a secondary market at a discounted price. In the simulation study, we compare the bullwhip effects of different logistics participants over time with and without product exchange policy. Our results suggest that the inclusion of product exchange policy in the primary as well as in the secondary market reduce the order variation and bullwhip effect at both retailer and distributor level. Finally, sensitivity analysis is performed to examine the impact of various parameters on recovery process and bullwhip effect.

Keywords— Reverse Supply Chain, Bullwhip Effect, Fuzzy Collection Rate, System Dynamics, Possibility Measures

1. INTRODUCTION

IN a world of finite resources and disposal capacities, recovery of used products and materials is a key to support the growing population at an increasing level of consumption. Pagell *et al.* [1] pointed out that product remanufacturing is the most desirable option for end-of-life product management than a scrap or spares recovery since it minimizes the environmental impacts, results in lower loss of value, and can create new market opportunities. Refurbished products are often offered as an alternative to the original products in a secondary market to the customers those are attracted by the brand, but do not wish to pay the price of a new product (e.g. electronics and automobile) [2].

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In the present study, we address the benefits of employing product exchange (PE) policy both in primary as well as in secondary markets to increase the collection rate of used products and consequently selling of refurbished products.

Fleischmann *et al.* [3] provided a review of the quantitative models for reverse logistics in which they reported that most of the papers in the area of integrated reverse logistics are confined to single issues while comprehensive approaches are rare as variety of factors are involved in a general framework and the complexity of their interdependencies. System dynamics (SD) is a powerful methodology for obtaining the insights of these kinds of problems having dynamic complexity; but there are very few literatures which modeled the integrated aspects of forward and reverse supply chain using SD. Spengler and Schroer [4] modeled an integrated production and recovery system for supplying spare parts using SD to evaluate various strategies. Georgiadis and Vlachos [5] developed a SD model to evaluate the effect of environmental issues on long-term decision making in collection and remanufacturing activities.

In real supply chain problems, input data or parameters are frequently imprecise because some information is either incomplete or unobtainable. Fuzzy set theory gives a strong mathematical structure to capture such imprecise and to model a real decision-making problem. In this paper, we develop a SD framework for an integrated forward-reverse supply chain by incorporating fuzzy demand, fuzzy collection rate and fuzzy satisfaction rate of demand. The uncertainty issues associated with acquisition and collection of used product have been quantified using possibility measures.

As the quality and quantity of used products return to the collection points are uncertain in the reverse channel, the systematic distortion is inevitable and bullwhip effect may occur at retailer, distributor and manufacturer level. There are very few literatures that consider order variations and bullwhip effect in an integrated reverse supply chain ([6]-[7]), but it is yet to receive attention in the context of SD framework ([8]-[9]).

In this paper, we propose a SD framework for an integrated reverse logistics (RL) network to analyze the forward as well as backward movements of product through different stages of supply chain network with three way recovery (TWR), namely; product refurbishing, component reuse & refurbishing, and raw material recovery. We bring

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