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Sensitivity analysis of reverse supply chain system performance by using simulation

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Abstract.
This paper proposes a methodology of performance sensitivity analysis of reverse supply chain systems by using simulation. This paper discusses two types of reverse logistics model: PUSH-type and PULL-type. And, it proposes a generic method to analyze system performance by using discrete-event simulation and factorial experiment design. The characteristics of reverse supply chain systems (PUSH-type and PULL-type) are shown in detail. The result of these analyses would provide useful data for planning reverse supply chain systems.

Keywords. Reverse supply chain, Reverse logistics, Simulation, Performance evaluation, ANOVA

1 Introduction

Supply chain management (SCM) has received tremendous attentions both from the business world and from academic researchers during the last two decades. SCM is a set of approaches utilized to efficiently integrate suppliers, manufacturers, warehouses, and stores, so that merchandise is produced and distributed at the right quantities, to the right locations, and at the right time, in order to minimize system-wide costs while satisfying service level requirements. Problems for supplier selection [1] and performance evaluation models [2] are, for examples, discussed from various points of view.

In the last decade, due to environmental and ecological responsibility, enterprises are trying to reuse, remanufacture and recycle the used products to reduce the negative impact on environment, especially the manufacturers of the electrical consumer products. Requirements for corporate responsibility and sustainability are getting more urgent. Kara and Onut discussed a two-stage stochastic and robust programming approach to strategic planning of a reverse supply network through a case of paper recycling supply chain [3]. Kenne et al. applied a similar approach to production planning of a hybrid manufacturing–remanufacturing system under uncertainty within a closed-loop supply chain [4]. Kocabasoglu et al. discussed a investment issue on supply chains linking with reverse flows [5]. Kuma and Malegeant discussed a closed-loop supply chain thorough a case of manufacturer and eco-non-profit organization [6]. Nativi and Lee discussed RFID information-sharing strategies on a decentralized supply chain with reverse logistics operations [7]. Rahman and Subramanian scoped computer recycling operations in reverse supply chain and analyzed factors for implementing system operations [8].

Performance analysis of supply chain systems is a critical issue in its design stage. Simulation is such a generic approach that gives solutions of performance analysis of supply chain systems. Chan et al. applied simulation to analysis of impact of collaborative transportations in supply chain systems [9]. Chatfield et al. developed a supply chain simulation system by using an object-oriented modeling method [10]. Labarthe et al. proposed an agent-based modeling and simulation of supply chain systems [11]. Umeda and Lee developed a general purpose supply chain simulator [12].

Tannock et al. developed a data-driven simulation of aerospace sector's supply-chain [13]. Yoo et al. proposed a hybrid algorithm for discrete event simulation based supply chain optimization [14]. Zhang et al. used a simulation software for analysis of a demand-driven Leagile supply chain Operations Model [15]. Persson and Olhager applied a performance simulation of supply chain designs. This work is based on discrete-vent simulation technologies [16], meanwhile, Fiala used SD simulation to analyze information sharing in supply chains [17]. Tako and Robinson reviewed journal papers that use these modeling approaches to study supply chains, published between 1996 and 2006 are reviewed. A total of 127 journal articles are analyzed to identify the frequency with which the two simulation approaches are used as modeling tools for DSS in LSCM [18].

Previous researches discussed system concepts of reverse supply chain system, and proposed methodologies of performance evaluation by using simulation methodologies. This paper proposes a methodology of performance evaluation of reverse supply chain systems by using simulation and experiment design. Generic models are introduced and analysis examples of individual features will be provided [19].

2 Scenarios and models

2.1 Reverse logistics scenarios

Reverse logistics systems require taking back products from customers and the repairing, remanufacturing (value-added recovery), or recycling (material recovery) the returned products. The reverse logistics in supply chains is strongly related to all stages of a product development and is also a critical problem to all level of the industry.

There are many types of reverse logistics [20]. We, here, consider a virtual supply chain system, which is composed of the following components: Chain manager, Supplier, Manufacturer, Retailer, Customers, Collector, and Remanufacturer (Fig.1). This model supposes home electric appliances such as PCs, TVs, and refrigerators.

Supplier, Manufacturer, and Retailer are members that form arterial flows (production generation flows) in a chain. Supplier provides parts or materials to Manufacturer according as supply orders from Chain manager. Manufacturer provides products to

Retailer according as production orders from Chain manager. Retailer provides products to Customer according as Demand (Purchase) order from Customer. Customer uses products and disposes them (generates the disposed materials).

Meanwhile, Collector and Remanufacturer are members that form venous flows (reverse logistic flows) in a chain. The Collector reclaims used products from Customer, when he/she disposes the used product. And, it detaches reusable materials from the disposed product, and sends them to Remanufacturer. Remanufacturer regenerates products by using materials provided by Collector. And, it provides them to Manufacturer, such as spare-parts.

Chain Manager is a supervisor of the chain the processes order information in the chain. It receives demand order from Customer. It predicts demand in next ordering duration by using Customer's order. It also gives production orders production orders to Manufacturer and Supplier by using the predicted demands. Deliverer connects these members and carries materials from its upstream to its downstream.

The configuration of these members is shown in Fig.1 and Fig.2. These models are based on an analogy between arterial-venous blood flows in a human body and material-flow in a supply chain. Solid lines are production generation flow (arterial-flow), meanwhile, dashed lines are reverse logistics flow (venous-flow) in Fig.1 and Fig.2. Arterial-flows and venous-flow should be synchronized with each other. The system synchronizes venous flows with arterial flows.

2.2 Reverse logistics models

The flow from Customer to Remanufacturer by way of Collector is a reverse logistics flow. Customer sends "used-products" to Collector, when Customer disposes them. The role of Collector is to distinguish reusable materials from the disposed products, and stores them. This paper introduced two types of logistics model that controls this reverse logistics flow: PUSH-type and PULL-type.

The PUSH-type is that Collector and Remanufacturer sends reverse products to Manufacturer in an orderly manner. In PUSH-type, remanufactured products are sequentially pushed into Manufacturer, synchronizing with occurrence of reverse. Remanufactured product would be kept as material inventory in Manufacturer. In PUSH-type, remanufactured products are sequentially pushed into Manufacturer, synchronizing with occurrence of reverse. Remanufactured product would be kept as material inventory in Manufacturer (Fig.1).

Meanwhile, the PULL-type is that Collector and Remanufacturer work according as PULL signals from their downs-streams. In PULL-type, reverse products are stocked at Collector. These products stay at there, during no PULL signal from Remanufacturer. And, Remanufacturer does not work until it receives PULL signal. In Fig. 2, Collector works as "Stock-driven" mode. Collector continuously observes stock volume at Remanufacturer. It starts to produce products when the stock volume is smaller than the stock-replenishment level, and continues to work until the stock volume is equal to or greater than the stock-volume level. This works according to the following operational sequences:

1. Collector periodically observes stock volume data at Remanufacturer.
2. Collector starts producing while stock volume at Remanufacturer goes down below the stock-replenishment level.
3. Collector stops producing when the stock volume reaches the stock-volume level.

This logic is also applied to the case of between Remanufacturer and Manufacturer.

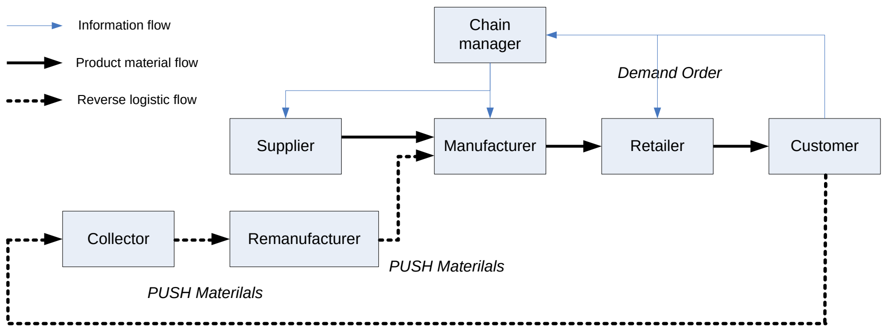

Fig. 1. PUSH-type reverse logistics model

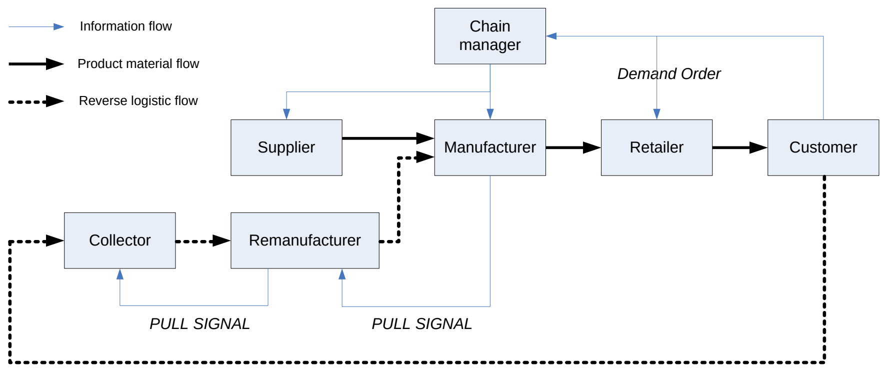

Fig. 2. PULL-type reverse logistics model

3 System sensitivity analysis by using simulations

3.1 Preliminary experiments and Experiment design

We, first of all, did preliminary experiments to extract major of this system model. The conditions of this experiment are: simulation duration (100 days), Customer's orders interval (5 days), Distribution function of customers' demands (Uniform distribution between 6 lots to 10 lots (U(6,10)), and Collection rates of Collector (high level (0.6) and low level (0.2)). This experiment result demonstrates that models and collection rates are major factors giving effects on system performance. Table.1 represents the differences between PUSH-type reverse and PULL-type reverse. The PULL system indicates higher utilization of Collector than the PUSH system. In

PUSH system, the Collector works only when the materials arrive from its Upstream (Customer). Meanwhile, in PULL system, Collector works to replenish inventories at the downstream (Remanufacturer). This mechanism, accordingly, makes higher resource utilization, when the Collection Rate is at low level.

Table 1. Simulation results (Utilizations of each supply chain member)

Model	Collection Rate	Utilization@ Manufacturer	Utilization@ Collector	Utilization@ Re-manufacturer
push	0.6	0.92	0.32	0.30
push	0.2	0.92	0.12	0.10
pull	0.6	0.91	0.36	0.21
pull	0.2	0.90	0.24	0.15

In both PUSH system and PULL system, all of the reusable materials generated at Customer (market) are transferred to Collector. In PUSH system, the gathered materials in Collector are sent to Remanufacturer, which is a re-production process. After this regeneration process, materials accumulate on Manufacturer as its input materials. Meanwhile, in PULL system, the reusable materials staying at Collector would be transferred to Remanufacturer, only when the withdrawal signals from its downstream has been occurred. Therefore, reusable materials stocked in Collector demonstrates an upward trend. This reason suppresses increase of the materials in both Remanufacturer and Manufacturer.

3.2 Analysis of Variance (ANOVA)

Based on the above discussion, we configure a factorial design of simulation experiments. Three factors are defined;

- Factor A: "Logistics types", PUSH-type and PULL-type
- Factor B: "Range of demand distribution". Three distribution functions are defined U(4,12), U(6,10), and U(7,9), respectively.
- Factor C: "Collection Rate: Three rates are defined, high-level (0.7), middle-level (0.4), and low-level (0.1), respectively.

Therefore, 18 simulation runs are required. Factorial experiments are designed with respect to these three factors. Table 1, 2, and 3 represent inventory means. The factor A (Logistics type) and the factor C(Collection Rate) are significant in the case of Manufacturer (Table.4). The factor A (Logistics type) and the factor B (Demand variance) are significant in the case of Retailer (Table.5). And, the factor A (Logistics type) and the factor C (Collection rate) are significant in the case of Collector (Table.6). The F value of factor A (Logistics type) is large in every case. This result is as a corollary. The effect of Collection rate variance is large in Manufacturer and Collector. This result is considered reasonable and proper judging by chain structure.

In contrast, it is Retailer that the effect of demand variance (factor B) is large. Moreover, it should be noted that mutual factor with factor A (Logistics type) is large.

Manufacturer and Collector are sensitive with Factor A and Factor C (Collection Rate).

Table 2. Average of inventory volumes at "Manufacturer"

Factors		C (Collection Rate)		
A(Logistics types)	B(Demand)	0.1	0.4	0.7
PUSH	D(4,12)	27	30	36
	D(6,10)	25	32	37
	D(7,9)	25	30	35
PULL	D(4,12)	33	33	33
	D(6,10)	34	34	34
	D(7,9)	33	33	33

Table 3. Average of inventory volumes at "Retailer"

Factors		C (Collection Rate)		
A(Logistics types)	B(Demand)	0.1	0.4	0.7
PUSH	D(4,12)	8	8	8
	D(6,10)	13	13	13
	D(7,9)	10	10	10
PULL	D(4,12)	11	11	11
	D(6,10)	9	9	9
	D(7,9)	8	8	8

Table 4. Average of inventory volumes at "Collector"

Factors		C (Collection Rate)		
A(Logistics types)	B(Demand)	0.1	0.4	0.7
PUSH	D(4,12)	11	13	17
	D(6,10)	11	14	16
	D(7,9)	11	14	17
PULL	D(4,12)	2	3	9
	D(6,10)	2	3	8
	D(7,9)	2	3	7

Table 5. Analysis of Variance (ANOVA) of "Manufacturer")

Factor	Squared Sum	Freedom	Mean Square	F0
A(Logisics)	29	1	29	38.67**
B(Demand)	5	2	2.5	3.33
C(Collection)	81	2	40.5	54**
AxB	0	2	0	0
AxC	78	2	39	52**
BxC	3	4	0.78	1.04
Error	3	4	0.75	

Table 6. Analysis of Variance (ANOVA) of "Retailer"

Factor	Square Sum	Freedom	Mean Square	F0
A(Logisics)	5	1	5	40**
B(Demand)	14	2	6.8	54.4**
C(Collection)	0	2	0	0
AxB	39	2	19.5	156**
AxC	0	2	0	0
BxC	1	4	0.25	2
Error	1	4	0.125	

Table 7. Analysis of Variance (ANOVA) of "Collector"

Factor	Square Sum	freedom	Mean square	F0
A(Logisics)	401	1	401	1604**
B(Demand)	0	2	0	0
C(Collection)	108	2	54	216**
AxB	0	2	0	0
AxC	2	2	1	4
BxC	3	4	0.78	3.12
Error	1	4	0.25	

4 Conclusion and future research

Full factorial design of simulation experiments and analysis of variance (ANOVA) represent that difference of systems factor gives a large influence on system performance of reverse supply chain systems. Manufacturer and Retailer are, especially, affected by interactions of independent factors. In PUSH system, material inventory volume at Manufacturer increases according as time progress. Meanwhile, the inventories at both Collector and Remanufacturer do not fluctuate so much. In PULL system, the material consumption at Collector synchronizes with material inventory volume at Remanufacturer, and the material consumption at Remanufacturer synchronizes with material inventory volume at Manufacturer. When the Manufacturer possesses sufficient volume of input material, Remanufacturer does not need to provide Manufacturer with materials any more.

The next stage of this simulation analysis will need to consider processes cost factors at both reverse supplier (Collector and Remanufacturer). When the regeneration process at both Collector and Remanufacturer is expensive, the PULL system would be better choice.

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