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OPERATIONS AND INSPECTION COST MINIMIZATION FOR A REVERSE SUPPLY CHAIN

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Abstract: *Reverse supply chain is a process dealing with the backward flows of used/damaged products or materials. Reverse supply chain includes activities such as collection, inspection, reprocess, disposal and redistribution. A well-organized reverse supply chain can provide important advantages such as economic and environmental ones. In this study, we propose a configuration in which quality assurance is a substantial operation to be fulfilled in the reverse chain so that to minimize the total costs of the reverse supply chain. A mathematical model is formulated for product return in reverse supply chain considering quality assurance. We consider a multilayer, multi-product for the model. Control charts with exponentially weighted moving average (EWMA) statistics (mean and variance) are used to jointly monitor the mean and variance of a process. An EWMA cost minimization model is presented to design the joint control scheme based on performance criteria. The main objective of the paper is minimizing the total costs of reverse supply chain with respect to inspection.*

Key words: *Reverse supply chain; Quality inspection; Mathematical Model.*

1. Introduction and related works

With the increase in environmental consciousness, reverse supply chain and reverse supply chain management have received significant attention from both business and academic research during the past few years. According to the American Reverse Logistics Executive Council, Reverse Logistics is defined as Rogers and Tibben-Lembke (1998): "The process of planning, implementing, and controlling the efficient, cost effective flow of raw materials, in process inventory, finished goods and related information from the point of consumption to the point of origin for the purpose of recapturing value or proper disposal." A reverse logistics system comprises a series of activities, which form a continuous process to treat return products until they are properly recovered or disposed of. These activities include collection, cleaning, disassembly, test and sorting, storage, transport, and recovery operations. The latter can also be represented as one or a combination of several

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main recovery options, like reuse, repair, refurbishing, remanufacturing, cannibalization and recycling (Dekker and Van Der Laan, 1999; Beaulieu et al., 1999; Thierry et al., 1993). Also, these options are to be reclassified into three broad categories such as reuse, recycling, and remanufacturing. In reuse, the returned product can be used more than once in the same form after cleaning or reprocessing. On the other hand, recycling denotes material recovery without conserving any product structure. Finally, remanufacturing is an industrial process in which worn-out products are restored to like-new condition.

The design/redesign of the supply chain with return flows has become a challenge for many companies. This is an important area of research as it helps lowering costs, while improving coordination and customer service (Guide et al., 2003). For instance, Nike, the shoe manufacturer encourages consumers to bring their used shoes to the store where they had purchased them. These shoes are then shipped back to Nike's plants and made in to basketball courts and running tracks. By donating the material to the basketball courts and donating funds for building and maintaining these courts, Nike has enhanced the value of its brand Rogers and Tibben-Lembke (1998).Furthermore, according to other advocators' opinions, effective reverse supply chain activities can enhance relationships with consumers and supply chain partners, can be a source of significant cost savings, and can even function as a profit center (Stock et al., 2003).

For the last decade, increasing concerns over environmental degradation and increased opportunities for cost savings or revenues from returned products prompted some researchers to formulate more effective reverse logistics strategies. These researchers including Salema et al. (2007) have proposed a MILP model to analyze the problem of closed loop supply chains. They consider multi-product returns with uncertain behavior but limit their consideration of demand for returned products to factories and not to secondary markets or spare markets. Thus a supplier network which may be required to remanufacture a new product to meet the market demand is not considered. Also, this model is not suitable for modular products.

Del Castillo and Cochran (1996) presented a pair of linear programs and a simulation model to optimally configure the reverse logistics network involving the return of reusable containers in such a way that the number of reusable containers was maximized. However, they did not take into account transportation issues related to reverse logistics. Patti et al. (2008) have formulated a mixed integer goal programming model for analyzing paper recycling network. The model assumes five echelons and studies the inter-relationship between cost reduction, product quality improvement through increased segregation at the source, and environmental benefits through waste paper recovery. The model also assists in determining the facility location, and route and flow of different varieties of recyclable wastes. Aras et al. (2008) developed a non-linear model and tabu search solution approach for determining the locations of collection centers and the optimal purchase price of used products in a simple profit maximizing reverse logistics network.

Initiating product recovery network design efforts, Thierry (1997) introduced a linear program to design product distribution and product recovery networks involving the collection of used copying machines. However, his model did not address the location issue of where the product recovery (resale of products after remanufacturing and refurbishment) process should be installed and at what capacity. Krikke (1998) proposed a network graph and a mixed integer program to optimize the degree of disassembly and evaluate product recovery options in collecting used copying machines and redistributing them after refurbishment, while determining the location and capacity of remanufacturing, central stocking, and disposal facilities. Similarly, Krikke et al. (1999) developed a mixed integer program to determine the locations of shredding and melting facilities for the recovery and disposal of used automobiles, while determining the amount of product flows in the reverse logistics network. Jayaraman et al. (1999) presented a mixed integer program to determine the optimal number and locations of remanufacturing facilities for electronic equipment. Jayaraman et al. (2003) extended their prior work to solve the two-level hierarchical location problem involving the reverse logistics operations of hazardous products. They also developed heuristic concentration procedures combined with heuristic expansion components to handle relatively large problems with up to 40 collection sites and 30 refurbishment sites. Despite their success in solving large-sized problems, their model and solution procedures are still confined to a single period problem and are not designed to deal with the possibility of making trade-offs between freight rate discounts and inventory cost savings resulting from consolidation of returned products. Lee and Dong (2008) developed an MILP model for integrated logistics network design for end-of-lease computer products. They consider a simple network with a single production center and a given number of hybrid distribution-collection facilities to be opened which they solve using tabu search. However, all of researches are found for some cost in reverse logistics that contain and define some centers (Govindan, and Nicoleta Popiuc, 2014; Cardoso et al., 2013; Chuang et al., 2014; Huang et al., 2013; Soleimani, and Govindan, 2014).

Reformulation of supply chain network from nonlinear to a similar piecewise linear programming model was investigated by Diabat and Theodorou (2015), Diabat (2016), and Al-Salem et al. (2016). Also, optimization approaches employed in the literature for closed loop or green supply chains included both certain and uncertain namely, stochastic programming, robust optimization, genetic algorithm, hybrid particle swarm-genetic algorithm and other metaheuristics (Diabat and Al-Salem, 2015; Diabat and Deskoores, 2016; Alshamsi and Diabat, 2017; Hiassat et al. 2017; Zohal and Soleimani, 2016; Wang et al. 2016).

Our study focuses on a general framework and propose total cost minimization model in reverse supply chain considering quality assurance. According to the importance of reverse supply chain for saving cost and improvement of customer loyalty and futures sales we design a framework and a mathematical model for costs in a multilayer multi-product in reverse supply chain system. The main contributions of the paper are, including EWMA control chart for inspection process of returned products, making use of process capability index for quality assurance purpose, and cost optimization for integrated operations and inspections model for a multi-layer and multi-product reverse supply chain. The main advantage of the proposed model is to include quality control in the cost minimization decision, i.e., a tradeoff between cost minimization and quality maximization. Thus, managers can keep cost and quality at the same time. This decision is challenging in real production system. Another advantage is the proposed reverse supply chain in which inspection of return products are fulfilled in a comprehensive control mechanism.

This paper is organized as follows. In the next section, quality inspection and the proposed EWMA control chart for inspection process are explained. In Section 3, a general framework and problem definition for reverse supply chain integrated with the inspection cost monitoring are proposed. Section 4 proposes the mathematical model of the reverse supply chain. Section 5 gives the numerical results and the required analysis. Finally conclusions are addressed in the last section.

2. Quality inspection

Statistical process control (SPC) is an effective method of monitoring a process through the use of control charts. Control charts enable the use of objective criteria for distinguishing background variation from events of significance based on statistical techniques. Much of its power lies in the ability to monitor both process center and its variation about that center. By collecting data from samples at various points within the process, variations in the process that may affect the quality of the end product or service can be detected and corrected, thus reducing waste as well as the likelihood that problems will be passed on to the customer. With its emphasis on early detection and prevention of problems, SPC has a distinct advantage over quality methods, such as inspection, that apply resources to detecting and correcting problems in the end product or service.

2.1. EWMA control charts

We assume that the observations for the process variable *X* are independent and normally distributed. When the process is in control, the mean and variance of *X* is μ_0 and σ_0^2, respectively. At any sampling instant *t*, the sample mean and variance are computed from

$$\overline{X}_t = \sum_{i=1}^{n} x_{it} / n \tag{1}$$

and

$$s_t^2 = \sum_{i=1}^{n} (x_{it} - \overline{x}_t)^2 / (n-1) \tag{2}$$

where $\overline{x}_t$ and s_t^2 are the sample mean and variance at time *t*, and *n* is the fixed sample size, $n \geq 2$. Using $\overline{x}_t$ and s_t^2, the chart statistics are calculated as

$$z_t = \lambda_m \overline{x}_t + (1-\lambda_m) z_{t-1} \tag{3}$$

$$Y_t = \max\left\{\ln(\sigma_0^2), \lambda_v \ln(S_t^2) + (1-\lambda_v) Y_{t-1}\right\} \tag{4}$$

$$0 \leq \lambda_m, \lambda_v \leq 1 \tag{5}$$

$$Z_0 = \mu_0 \tag{6}$$

$$Y_0 = \ln(\sigma_0^2) \tag{7}$$

where λ_m and λ_v are the smoothing constants associated with the EWMA chart for mean (EWMA-m) and variance (EWMA-v), respectively. The statistic Z_t is used in the EWMA-m chart, and Y_t is associated with the EWMA-v chart.

2.2. Process monitoring by EWMA

When EWMA schemes are used for process monitoring, not only the current observations of *X* but also the observations from previous samples are taken into account. In the computation of the test statistic, more recent samples are given a larger weight than the ones taken earlier. The user can increase the weight given to the last sample by increasing the value of the smoothing constant.

Lucas and Saccucci (1990) described the properties of the EWMA-m chart in detail. We use the lower and upper control limits (LCL_m and UCL_m) computed based on the asymptotic in-control standard deviation of the EWMA chart statistic *Z* such that

$$LCL_m = \mu 0 - L_m \sigma_z \tag{8}$$

$$UCL_m = \mu 0 + L_m \sigma_z \tag{9}$$

whereis the control limit parameter. Thus, L_m, and $\sigma_z = \sigma_0(\lambda_m / (2-\lambda_m)n)^{0.5}$ whenever Z_t is outside the interval (LCL_m and UCL_m), the process is considered to be out of control and a search for assignable cause is conducted. Due to the natural variation of the process, out-of-control signals may also occur while the process is in control. However, when there is a shift in process mean and/or variance, the chart will generate an out-of-control signal much more quickly.

To monitor the process dispersion, a number of authors have previously studied the control charts based on EWMA of lnS^2 (Crowder and Hamilton, 1992; Gan, 1995; Acosta-Mejia et al., 1999). The particular dispersion chart we adopt in this study is referred to as EWMA-v which has the lower and upper control limits as follows:

$$\begin{aligned} LCL_v &= \ln(\sigma_0^2) \\ UCL_v &= \ln(\sigma_0^2) + L_v \sigma_y \end{aligned} \tag{10}$$

where $\sigma_y^2 = \lambda_v \psi' \left[(n-1)/2 \right] / (2-\lambda_v)$, ψ' (0) is the trigamma function, and L_v is the control limit parameter. The trigamma function is the second logarithmic derivative of the gamma function $\Gamma(0)$, i.e., $\psi'(u) = d^2 \ln\left[\Gamma(u)\right]/du^2$, u>0 . We consider an upper one-sided EWMA-v chart which is well-suited for detecting the increases in the process standard deviation. An increase in the process standard deviation would either reflect an undesirable special cause or the impact of an undesirable process change (either purposeful or unpurposeful); a decrease in process variation would indicate the effect of a process improvement. EWMA-v chart yields an out-of-control signal when Y_t exceeds *UCLv*. The statistical properties of the combined EWMA-m/EWMA-v control scheme have been explored in Morais and Pacheco (2000).

To illustrate the smoothing effect of exponential weighting, we plot the values of $\bar{X}_t$ and Z_t for 40 samples generated via simulation in Figure 1. The observations constituting the first 20 samples are generated from the in-control process distribution with mean=0, variance=1. The samples 21 through 40 are based on the out-of-control process distribution with mean=0.5, variance=1.5; we also set *n*=4, $\lambda_m = 0.2$ in this simulation experiment. The values of $\ln\left(S_t^2\right)$ and Y_t (with $\lambda_v = 0.2$) obtained from the same simulation run are displayed in Figure 2. The lower and upper control limits shown in these charts are based on $L_m = L_v = 2.5$. Figures 1 and 2 show that the time series of exponentially weighted sample statistics (Z_t and Y_t) exhibit less variability than the original series ($\bar{X}_t$ and $\ln\left(S_t^2\right)$) from which they are derived.

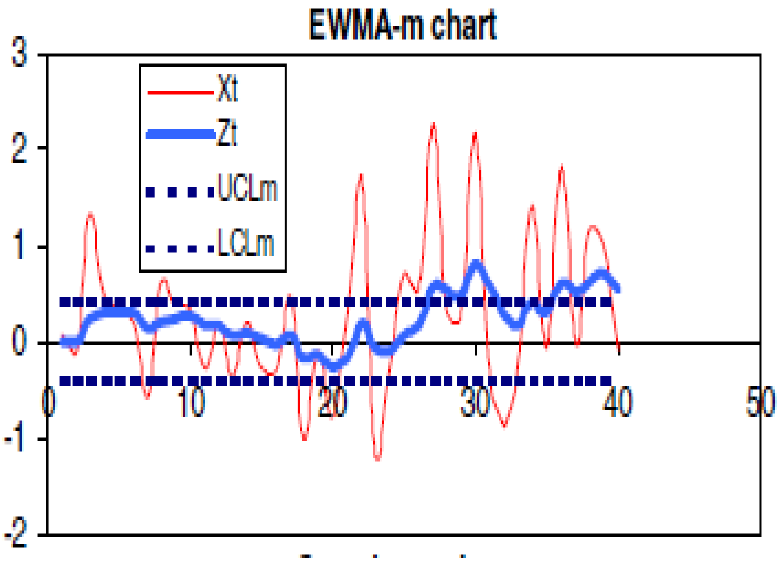

Figure 1. EWMA control chart for mean – Plot of $\bar{X}_t$ and test statistic Z_t

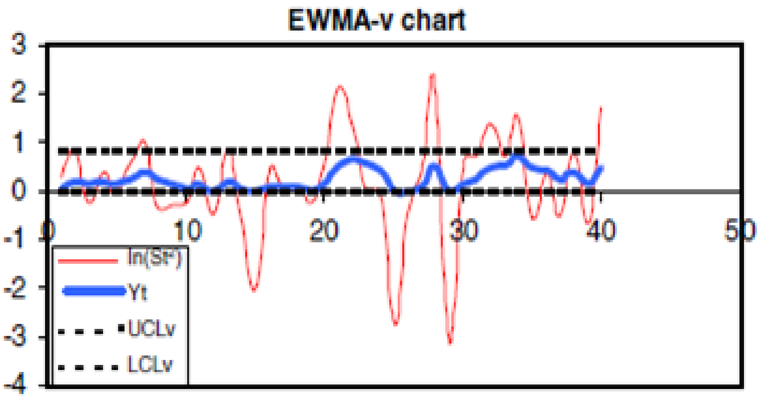

Figure 2. EWMA control chart for variance – Plot of $\ln\left(S_t^2\right)$ *and test statistic Yt*

3. Problem definition

The reverse supply chain under study is multi-layer and multi-product. In the designed model, the returned products after collecting and inspecting are divided into two groups of disassembling and not disassembling products. Some of the products that don't need to be disassembled will be transmitted to the inspecting center right after collecting centers. Then, considering to the variety of products and the request of manufacturing centers they will be sent directly to be remanufactured. In the remanufacturing process, according to the production center's demand, the parts which can be used again, after inspecting center will be sent to the remanufacturing center and after compounding with the other parts will be changed into new products and can return to the distribution chain to assure the quality of the product.. The quality assurance is based on the EWMA control chart for the product in inspection centers. The configuration of the problem is shown in Figure 3.

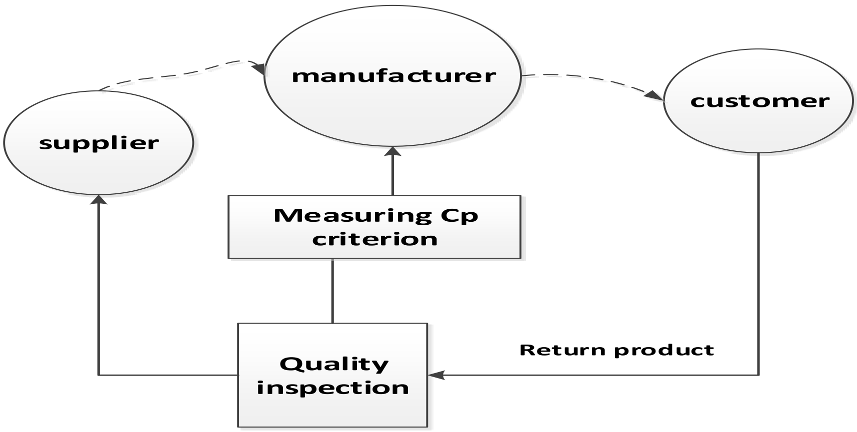

Figure 3. Framework for reverse supply chain

In this paper the reverse supply chain model has been considered for returned products with the purpose of minimizing the reverse supply chain costs considering the quality inspection process. The main assumptions included in the study are:

- ✓ The quantity of inspection and manufacturing are determined.
- ✓ Some products will transport straightly from customers to the inspection centers.

And the required indices are as follows:

k index of inspection centers
f index of manufacturing centers
m index of products

For the EWMA based inspection process, a comprehensive cost function is developed.

3.1. Cost of monitoring in EWMA

We denote the time between two consecutive samples (sampling interval) by h_{fm}. It is assumed that the in-control time for the process is distributed exponentially with mean $\frac{1}{\theta}$. We allow the possibility that both the process mean and variance may change when an assignable cause occurs. When the process is out of control, the mean of *X* becomes $\mu_1 = \mu_0 + \delta\sigma_0$ and the standard deviation of *X* shifts to σ_1. Using the Lorenzen and Vance (1986) framework, the expected cost per unit time (hour), *C*, associated with the control scheme consisting of EWMA-m and EWMA-v charts is in Lorenzen and Vance):

$$\begin{aligned}C = &\Big\{C_{0m}/\theta_{km} + C_{1m}\Big(-\tau_m + n_m E_m + h_{fm}(ARL_{1m}) + \gamma_{1mf}T_{1m} + \gamma_{2mf}T_{2m}\Big) \\ &+ S_m F_m / ARL_{0m} + RMC_{mf}\Big\} \\ &/\Big\{1/\theta_{km} + (1-\gamma_{1mf})S_m / ARL_{0m} - \tau_m + n_m E_m + h_{fm}(ARL_{1m}) + T_{1mf} + T_{2mf}\Big\} \\ &+ \Big\{\Big[(a_m + b_m n_m)/h_{mf}\Big]\Big[1/\theta_{km} - \tau_m + n_m E_m + h_{fm}(ARL_{1m}) + \gamma_{1mf}T_{1m} + \gamma_{2mf}T_{2m}\Big]\Big\} \\ &/\Big\{1/\theta_{km} + (1-\gamma_{1mf})S_m / ARL_{0m} - \tau_m + n_m E_m + h_{fm}(ARL_{1m}) + T_{1mf} + T_{2mf}\Big\}\end{aligned} \tag{11}$$

The effective parameters in the proposed inspection cost function are listed below:

C_0 cost per hour due to nonconformities produced while the process is in control
C_1 cost per hour due to nonconformities produced while the process is out of control
τ expected time between the occurrence of the assignable cause and the time of the last sample taken before the assignable cause $=[1-(1+\theta h)\exp(-\theta h)]/[\theta(1-\exp(-\theta h))]$
E time to sample and chart one item
ARL_0 average run length while in control
ARL_1 average run length while out of control
T_1 expected time to discover the assignable cause

T_2 expected time to repair the process
γ_1 =1 if production continues during inspection,
=0 if production ceases during inspection
γ_2 =1 if production continues during repair,
=0 if production ceases during repair
s expected number of samples taken while in control = $\exp(-\theta h)]/[1-\exp(-\theta h)]$

The traditional approach to the economic design of control charts involves calculation of the expected cost per hour by dividing the expected cost per cycle by the expected cycle length. Each cycle is made up of two parts: (a) an in-control interval, and (b) an out-of control interval following that. The cost function is derived by dividing the sum of costs incurred during the in-control and out-of-control segments by the expected cycle length. The expected lengths of the in-control and out-of-control intervals, $E(I_{in})$ and $E(I_{out})$, are

$$E(I_{in}) = (1/\theta) + (1-\gamma_1)sT_0 / ARL_0 \tag{12}$$

$$E(I_{out}) = -\tau + nE + h(ARL_1) + T_1 + T_2 \tag{13}$$

The in-control interval is composed of the expected time until failure and the expected time spent for investigating false alarms. The expected length of the in-control interval depends on whether the production continues during inspection or not.

The out-of-control interval includes the time from the occurrence of the assignable cause to the next sampling instant $(h_{fm} - \tau_m)$, the time until an out-of-control signal $h_{fm}(ARL_1 - 1)$, the time to collect and chart a sample (nE), the time to discover the assignable cause (T_1), and the time to repair the process (T_2). After an assignable cause is found and corrective action is taken, the process mean and variance are restored to their in-control values μ_0 and σ_0^2, and the cycle restarts.

The decision variables are $n, h_{fm}, L_m, L_v, \lambda_m, \lambda_v$. As defined previously, average run length is the expected number of samples taken before an out of control signal is observed. To minimize false alarms and react swiftly to out-of-control conditions, large values for ARL_0 and small values for ARL_1 are desirable. ARL_0 and ARL_1 depend on all decision variables except h.

4. Mathematical formulation

We want to demonstrate a model in reverse supply chain so that to minimize the chain costs. We aim to minimize total operations and inspection costs for the proposed reverse supply chain. The required parameters are reviewed as shown in Table 1:

Table 1. The parameters of the mathematical model

u_{km}	capacity of inspection center *k* for product *m*
h'_{fm}	capacity of manufacturing center *f* for product *m*
DM_{fm}	manufacturing center's demand *f* for product *m*
$CSPM_{kfm}$	unit cost of transportation from inspection center *k* into the manufacturing center *f* for product *m*
$FOCP_{km}$	fixed opening cost for inspection centers *k* and product *m*
RMC_{fm}	unit cost of remanufacturing in manufacturing center *f* for product *m*
C_{0m}	cost per hour due to nonconformities produced while the process is in control for product *m*
C_{1m}	cost per hour due to nonconformities produced while the process is out of control for product *m*
F_{mk}	cost per false alarm for inspection centers *k* and product *m*
a_{mk}	fixed cost per sample for inspection centers *k* and product *m*
b_{mk}	cost per unit sampled for inspection centers *k* and product *m*
S_m	expected number of samples taken while in control for product *m*
τ_m	expected time between the occurrence of the assignable cause and the time of the last sample taken before the assignable cause for product *m*
n_m	Number of sample for product *m*
E_m	time to sample and chart one item for product *m*
ARL_{0m}	average run length while in control for product *m*
ARL_{1m}	average run length while out of control for product *m*
T_{1mf}	expected time to discover the assignable cause for manufacturing center *f* and product *m*
T_{2mf}	expected time to repair the process for manufacturing center *f* and product *m*
γ_{1mf}	1 if production continues during inspection, and 0 if production ceases during inspection for manufacturing center *f* and product *m*
γ_{2mf}	1 if production continues during repair, and 0 if production ceases during repair for manufacturing center *f* and product *m*
λ_{me}	smoothing constants associated with the EWMA chart for mean
λ_v	smoothing constants associated with the EWMA chart for variance

And finally the decision variables are listed below:

Q_{kfm} amount shipped from inspection center into the manufacturing center *f* for product *m*

β_{km} 1, if inspection center *k* is open for product *m* and 0, otherwise

μ_{fm} the product *m* flow amount in manufacturing center *f*
θ_{km} the product *m* flow amount in inspection center *k*
CP_{kp} process capability for product *m* in inspection center *k*

The formulation of the mathematical model is given below:

$$Min\ \ Z = \sum_{k=1}^{K}\sum_{f=1}^{F}\sum_{m=1}^{M} CSRM_{kfm} Q_{kfm} + \sum_{k=1}^{K}\sum_{m=1}^{M} FOCP_{km}\beta_{km} + \sum_{f=1}^{F}\sum_{m=1}^{M} RMC_{fm}\mu_{fm} + C \tag{14}$$

By attention to the definition of indices, parameters and decision variables; the objective function is defined to be minimizing the costs of transportation and inspection of products, the fixed opening cost of centers and operations costs on products in reverse supply chain.

Constraints:

$$\sum_{f=1}^{F} Q_{kfm} \le u_{km}.\beta_{km}.CP_{km} \quad \forall k,m \tag{15}$$

This constraint is stating that the amount of shipping products from any inspection centers (if it is opened) into the manufacturing centers should be equal or smaller than the capacity of the same inspection centers for each product considering product process capability index.

$$\theta_{km} \le u_{km}.\beta_{km}.CP_{km} \quad \forall k,m \tag{16}$$

This constraint is stating that the amount of a product which is in the inspection center should be equal or smaller than the capacity of the same inspection center with respect to the quality assurance measure.

$$\mu_{fm} \le h'_{fm} \quad \forall f\ ,m \tag{17}$$

This constraint states that the amount of product in each manufacturing center should be equal or smaller than the capacity of the same manufacturing center.

$$\sum_{k=1}^{K} Q_{kfm} \ge DM_{fm} \quad \forall f,m \tag{18}$$

$$\mu_{fm} \ge DM_{fm} \quad \forall f,m \tag{19}$$

These two constraints guarantee the demand fulfillment in manufacturing and inspection centers for products.

(7) and (8) are the quality assurance inequalities to confine the model to satisfy the products' quality.

(9) and (10) enforce the binary and non- negativity restrictions on the corresponding decision variables.

$$CP_{km} = \frac{E(I_{in}) - E(I_{out})}{6\sigma_{km}} \quad \forall k\ ,m \tag{20}$$

If the upper and lower specification limits of the process are USL and LSL, the estimated variability of the process (expressed as a standard deviation) is $\hat{\sigma}$, then commonly accepted process capability index for product m in inspection center k is CP_{km}. Estimates what the process is capable of producing if the process mean were to be centered between the specification limits. Assumes process output is approximately normally distributed.

$$\begin{aligned} C = &\Big\{C_{0m}/\theta_{km} + C_{1m}\left(-\tau_m + n_m E_m + h_{fm}(ARL_{1m}) + \gamma_{1mf}T_{1m} + \gamma_{2mf}T_{2m}\right) \\ &+ S_m F_m / ARL_{0m} + RMC_{mf}\Big\} \\ &/\left\{1/\theta_{km} + (1-\gamma_{1mf})S_m / ARL_{0m} - \tau_m + n_m E_m + h_{fm}(ARL_{1m}) + T_{1mf} + T_{2mf}\right\} \\ &+ \left\{\left[(a_m + b_m n_m)/h_{mf}\right]\left[1/\theta_{km} - \tau_m + n_m E_m + h_{fm}(ARL_{1m}) + \gamma_{1mf}T_{1m} + \gamma_{2mf}T_{2m}\right]\right\} \\ &/\left\{1/\theta_{km} + (1-\gamma_{1mf})S_m / ARL_{0m} - \tau_m + n_m E_m + h_{fm}(ARL_{1m}) + T_{1mf} + T_{2mf}\right\} \end{aligned} \quad (21)$$

This function computes the inspection cost.

$$Q_{kfm}, \mu_{fm}, \theta_{km}, CP_{km} \geq 0 \quad \forall k, f, m \quad (22)$$

$$\beta_{km} \in \{0,1\} \quad \forall k, m \quad (23)$$

In these relations, the sign and type of decision variables are emphasized.

5. Numerical example

In this section, we solve an example to show the validity of the proposed mathematical model. The multi-layer and multi-product supply chain considered here has 3 inspection centers, 3 manufacturing centers, and 4 products. Here, the other inputs are:

$$U_{km} = \begin{bmatrix} 299 & 211 & 111 & 485 \\ 350 & 375 & 425 & 270 \\ 460 & 289 & 360 & 115 \end{bmatrix} \quad H_{fm} = \begin{bmatrix} 412 & 965 & 592 & 978 \\ 520 & 666 & 632 & 711 \\ 483 & 786 & 842 & 822 \end{bmatrix}$$

$$DM_{fm} = \begin{bmatrix} 125 & 235 & 482 & 116 \\ 455 & 142 & 471 & 192 \\ 260 & 368 & 269 & 453 \end{bmatrix} \quad CSPM_{kfm} = \begin{bmatrix} 11 & 44 & 27 \\ 18 & 38 & 25 \\ 22 & 32 & 49 \end{bmatrix} \quad FOCP_{km} = \begin{bmatrix} 45 & 85 & 44 & 96 \\ 46 & 75 & 61 & 93 \\ 58 & 89 & 69 & 81 \end{bmatrix}$$

$$RMC_{fm} = \begin{bmatrix} 12 & 44 & 28 & 42 \\ 18 & 48 & 33 & 15 \\ 29 & 50 & 39 & 27 \end{bmatrix} \quad OCP_{km} = \begin{bmatrix} 12 & 18 & 24 & 14 \\ 13 & 19 & 22 & 11 \\ 15 & 20 & 23 & 25 \end{bmatrix}$$

Implementing the model in Lingo optimization software package, the following outputs are obtained:

Q_{113}=592; Q_{223}=632; Q_{333}=842; Q_{234}=822
μ_{13}=592;632=$_{23}\mu$; μ_{33}=842; μ_{34}=822;

θ_{11}=299; θ_{13}=111;350=$_{21}\theta$; θ_{23}=425; θ_{31}=460;
β_{11}= β_{13}= β_{21}= β_{23}= β_{31}=1.

5.1. Analysis

In the following analysis we assume production continues during the search for an assignable cause, but it ceases during repair, $\gamma_1 = 1$, $\gamma_2 = 0$. We use the following values of parameters:

θϵ (0.01�0.05)

Parameter	F	W	a	b	E	T_0	T_1	T_2	P	σ_0^2	$\mu_0 = T$
Value	500	250	5	1	0.5	0	20	0	200	1	0

Let ρ be the ratio of the out-of-control standard deviation to in-control standard deviation, i.e. $\rho = \frac{\sigma_1}{\sigma_0}$. The optimal values of design parameters for given different shift values δ and ρ are listed in Table 1 for the joint EWMA scheme with K = 0.1. Note that, cost values from the proposed cost function is also computed in Table 2.

Regarding the decision variables, especially for large shifts, sample size and sampling interval have been found to be relatively more robust than other variables to changes in initial values. One of the reasons behind the observed sensitivity of control limits and smoothing constants to starting values may be the additional flexibility provided by using two charts rather than a single chart. The change in one variable, say L_m, is compensated by a change in another variable, say L_v, and hence, different combinations of variables essentially lead to the same impact on the total cost. If only a single chart was used, due to a smaller set of decision variables, the number of alternative combinations of variables resulting in approximately same value of the total cost would probably be less, and therefore, the search would be more likely to converge to the same values of decision variables at termination regardless of the initial values.

Table 2. Optimal economic design for the reverse supply chain

θ	δ	ρ	C	h	n	λ_{me}	λ_v	L_m	L_v
0.01	0.5	1	24.51	20.00	7	0.29	0.11	2.45	2.67
		1.5	32.26	10.65	11	0.80	0.77	2.80	1.83
		2	39.10	6.14	6	0.99	0.86	3.13	1.69
	1	1	28.54	15.63	10	0.83	0.15	2.53	3.12
		1.5	34.98	8.10	7	0.76	0.99	2.67	1.88
		2	41.92	5.19	5	0.81	0.84	3.09	1.69
	1.5	1	33.64	9.40	6	0.88	0.05	2.73	2.80
		1.5	39.43	5.53	5	0.85	0.81	2.75	2.04
		2	46.45	4.14	4	0.84	0.86	3.02	1.63

	2	1	40.21	5.27	4	0.85	0.11	2.96	2.27
		1.5	45.70	4.41	4	0.82	0.41	3.00	3.98
		2	52.68	3.43	3	0.83	0.89	2.94	1.53
0.05	0.5	1	25.36	20.00	2	0.68	0.11	3.90	1.38
		1.5	45.60	15.57	9	0.85	0.98	2.28	1.37
		2	65.77	4.87	5	0.94	0.74	2.90	1.52
	1	1	38.38	19.98	8	0.73	0.09	2.20	3.88
		1.5	54.33	7.64	6	0.80	0.94	2.34	1.65
		2	73.92	3.89	4	0.83	0.92	2.74	1.44
	1.5	1	53.15	7.41	5	0.82	0.86	2.44	3.19
		1.5	67.90	4.26	4	0.87	0.93	2.56	1.80
		2	87.20	3.03	3	0.93	0.88	2.77	1.41
	2	1	72.10	4.51	3	0.86	0.96	2.65	2.24
		1.5	86.35	3.37	3	0.78	0.66	2.63	1.78
		2	105.52	2.63	3	0.77	0.99	2.86	1.45

5.2. Managerial Implications

As we know, defects of a product, causes extra charges of substituting with a perfect one and etc. According to the obtained results and model analysis, managers can make important decisions in order to advance the goals. Quicker planning on more efficient products for timely delivery and recycling is important. In terms of timely delivery, it is also possible to plan, considering the return rate of the product with the highest return rate, that too many material and product other are Eco-friendly for precautionary reasons. Investing more on high-performance return products is another aspect for managers to decide. From the point of view of investing in return product with more efficiency, return product with reliability greater than other materials can be mentioned.

6.Conclusions

This paper concerned with inclusion of quality inspection in the process of reverse supply chain items' collection and re-manufacturing. We configured a reverse supply chain and modeled a minimization formulation to handle several cost operations within the return flow of the products. The major contribution of the work was to consider inspection operation as a quality assurance focal element. The presented model was an integer linear programming model for multi-layer, multi-product reverse supply chain that minimizes the products operation costs and inspection costs among different centers in layers for variety of products. We have studied the joint economic design of EWMA control charts for monitoring the mean and variance of a process. In our numerical examples we have observed that, in general, both the optimal sample size and sampling interval decrease as the size of shifts in mean and/or variance increases. The outputs implied that the proposed model is helpful in industrial system as it encompasses both cost and quality. The quality was monitored in EWMA control chart and then formulated as a cost model to be integrated with the operations cost minimization of the reverse supply chain.

As for future research directions, one can study the bullwhip effect of supply chain in the reverse model and analyze it as a new quality factor; also, the sensitivity analysis of the control parameters of EWMA control chart can be performed to have a more flexible interval for parameters.

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